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

Assessing management strategies to develop an Integrated Pest Management system for an invasive insect in aspen

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Abstract: As a vital broadleaved species in the mountain ecosystems of the US West, quaking aspen (*Populus tremuloides*) faces a significant threat from the invasive insect, oystershell scale (OSS, *Lepidosaphes ulmi*), particularly in its trailing-edge populations of the Southwest. Ongoing OSS outbreaks have not only caused mortality and dieback in quaking aspen but also led to a decline in the overall health of aspen ecosystems in Arizona. Previous research indicated that tall regeneration and saplings are the most affected size classes, posing a challenge to aspen recruitment and conservation efforts.

To mitigate negative impacts and slow OSS spread, we have implemented four management strategies: clear-felling, sanitation thinning, prescribed fire, and chemical insecticide application. Preliminary results one and three years after treatment indicate a short-term, large reduction in OSS infestation and severity in clear-felled stands. In Arizona, aspen stands with sanitation

thinning have shown reduction in OSS severity, however the removal of only dead OSS infested trees in Utah has yielded no significant changes in OSS severity. These results were obtained from one-year post-treatment, and further observations are necessary to draw definitive conclusions. Additionally, a preliminary survey revealed no OSS survival in heavily infested trees, 30 days following a dinotefuran insecticide treatment.

We will present updated findings, including data from the 2025 field season, for all four management strategies. This research will inform the development of an Integrated Pest Management strategy for OSS in aspen, providing crucial guidance for managers working to sustain aspen ecosystems in southwestern landscapes.

Do native microbial symbiont communities improve Fremont cottonwood (*Populus fremontii*) photosynthesis and thermal tolerance in hot environments?

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Abstract: Associations with soil microbes can play an important role in the success of native plants such as Fremont cottonwood (*Populus fremontii*). However, less is known about the importance of maintaining native microbial associations with Fremont cottonwood trees and how these relationships are related to photosynthetic capacity and thermal tolerance. We test the hypotheses that Fremont cottonwood grown with native microbial symbiont communities (NMSC) maintain 1) greater photosynthetic capacity and 2) a greater ability to regulate their temperature compared to trees grown with non-native communities. A common garden experiment was conducted in Phoenix, AZ using Fremont cottonwood trees and soil sourced from four field sites across an elevation gradient Arizona. Trees were grown with a dose of field soil that was either native or non-native to their respective field site. To compare the two groups, a suite of measurements reflecting photosynthetic potential and thermal response were taken in the Spring and Summer including leaf temperature, leaf thermal tolerance thresholds, leaf area to sapwood area ratio, stomatal conductance, maximum rate of Rubisco carboxylation and maximum rate of photosynthetic electron transport. The findings of this study have the potential to inform the conservation of a native foundation species, Fremont cottonwood. More broadly, the outcome of this work will help clarify the role of soil microbial communities in mediating plant responses to high temperatures which will be especially relevant for dryland species and species experiencing increasing temperatures and occurrence of episodic heatwaves.

Precursor to the Ancient Super Volcanoes of Southern Colorado: Assessing the Petrogenesis and Crustal Evolution of the Pre-Caldera Conejos Lavas at the Platoro Caldera Complex

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Abstract: Located on the edge of the Colorado Plateau and at the headwaters of the San Juan River, the Southern Rocky Mountain Volcanic Field (SRMVF) was an area of intense volcanic activity from approximately 35 to 23 million years ago. The SRMVF is host to extensive lava flows and explosive eruptions and is associated with one of the largest known eruptions of all time. My research is focused on refining the understanding of how this massive volcanic flare up event began and evolved in the early stages of magmatic activity. To do this, I focused on the earliest pre-caldera lava flows at the Platoro Caldera Complex. These lava flows, collectively known as the Conejos Formation, erupted over a period of five million years (between 35 and 30 mya), and key questions remain about the generation, storage, and evolution of the magma systems that fed them, including: Where in the crust (i.e., depth) was this magma stored, and at what temperature? Were all the early lava flows erupted from the same source magma chamber? How did parental magma evolve over time to produce volcanic deposits of different compositions?

To answer these questions, and to expand on work previously done in the area, I collected two types of compositional data: 1) Major and trace element composition of numerous lava flows and 2) targeted major element compositions of hundreds of individual mineral crystals. My work to date has revealed that the magmas were stored between 7 and 23 km depth in the crust, at a temperature ranging from 821 and 1027°C. Additionally, the presence of diverging concentrations of Ti and Mn between samples also suggest a difference in magmatic evolution. Given these differences on an individual and sample wide scale, I hypothesize that the lava flows erupted from different source magma chambers.

Keeper of the Fireplace: Fire in the Darkness

ANTHONY, L.¹

¹Chizh for Cheii

Abstract: K'e, which means "kinship" in Navajo, reflects the traditional teachings of the Diné people. An initiative that supports this philosophy is Chizh for Cheii, which has provided free firewood to thousands of elders and those in need. The dedication of volunteers plays a crucial role in supplying firewood to elders on the Navajo Nation. They locate supplies in both National and Tribal forests and are responsible for cutting, processing, loading, transporting, and distributing the firewood directly to the homes of the elders. Chizh for Cheii's mission is to foster love, compassion, and dignity by actively providing firewood to these elders. This dedication has led them to collaborate with the Wood for Life (WFL) partnership to achieve their mutual goals. Their efforts cultivate long-term sustainability through the hard work, commitment, and dedication of the volunteers while also building strong community relationships. Additionally, they secure funding through private donations and support from non-governmental organizations.

Climate adaptive restoration techniques using biocrust sods

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Abstract: Climate change and land use impacts on the Colorado Plateau affect ecosystem function and services. In this region, biocrusts are powerhouses in providing both: stabilizing soils and keeping dust out of the air, fixing carbon and nitrogen and promoting soil fertility, intercepting and slowing soil evaporation. To test methods to restore biocrusts to degraded landscapes using climate adaptive techniques we collected biocrust from Mojave, Sonoran and Colorado Plateau sources from areas slated for disturbance and cultivated in fields outside of Moab on substrates including various biodegradable and synthetic weed fabrics or jute, with and without shade (burlap or synthetic shade fabric). After two growing seasons, we harvested biocrusts on their substrates in 3m lengths, rolling onto a pvc pole and transporting to two restoration sites on the Colorado Plateau. We installed arrays of “biocrust sods” in blocks including untreated areas as controls. We quantified biocrust, weeds and disturbance on sods after one and five years. Weed barriers continued to abate weeds over time, and biocrust cover varied by substrate and source. Burlap shading had the strongest positive effect on biocrust cover. Mojave and Colorado Plateau had higher cover at both time points compared to Sonoran. Cattle disturbance damaged some sods but biocrust colonized in and around disturbances. Sods have potential in a variety of settings to bring back mature biocrust in islands, with weed abatement and soil stabilization. Further, sourcing biocrust materials from hotter/drier places has potential as a climate adaptive restoration strategy with more research.

Hybrid oaks are more sensitive to environmental stressors than their non-hybrid parents

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Abstract: Ecosystems globally are experiencing more intense and frequent heat and drought events. Plants in high elevation ecosystems are not an exception, with spatial and physiological limits impacting their productivity and survival. For plants with low plasticity, which cannot acclimate to extreme environmental conditions, hybridizing may be an alternative route for species range expansion. However, few studies have focused on the ecophysiological advantages of hybridization, especially in the context of environmental change. Here, we investigated the ecophysiological differences between a hybrid oak species (*Quercus gambelii* x *turbinella*, GTO) and its parent species (*Q. gambelii*, GO and *Q. turbinella*, TO) across a range of environmental conditions. We hypothesized that the hybrid species would inherit drought and heat-tolerant traits from TO and thus be more tolerant to aridity extremes than GO. This study was conducted in a mature common garden at the University of Utah in Salt Lake City, UT, within the historical native range of the 3 species. Four individuals of each species were subjected to leaf gas exchange measurements from late spring to mid-summer in 2024 and 2025. Leaf traits, such as predawn and midday leaf water potentials, critical temperatures (T_{crit}), and leaf mass per area (LMA), were determined for both years. Contrary to our hypothesis, we found that GTO had similarly high sensitivity to vapor pressure deficit and leaf temperatures, and lower T_{crit} as GO. Supporting these results, we observed a

significant decline in leaf gas exchange rates during peak summer for both species, but not for TO. The only commonalities between GTO and TO were lower water use efficiency and higher LMA values, which we attributed to higher transpiration rates used for leaf cooling often correlated to costlier leaves. Surprisingly, there was little to no difference in leaf water potentials across all species. Our findings suggest that GTO and GO are not physiologically well-equipped to sustain functioning during droughts and, especially, heatwaves. This climatic vulnerability, even in hybrid species, shows that more work must be conducted surrounding hybrids to understand their ability to assist in maintaining critical ecosystem services in the intermountain west and the Colorado Plateau.

Quantifying overlap in river drying and fish density to inform drought refuge management for an endangered minnow

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Abstract: Implementing environmental flows for sustaining freshwater aquatic life faces significant challenges. Beyond securing water, incorporating species' biology and distribution into the decisions on timing and location of water delivery needs consideration. The Middle Rio Grande in New Mexico offers a case-study where irrigation infrastructure may be used to deliver small environmental flows to create drought refuges for the endangered Rio Grande Silvery Minnow (*Hybognathus amarus*). During irrigation seasons, channel drying of up to ~90 km (42% of the occupied range) results in stranding and mortality of this imperiled minnow. First, during river drying, we identified areas with more minnows stranded in pools ("hotspots") through modeling of stranding data, modeled separately for young-of-year or adult. Next, we examined 11 potential locations to return water to the river channel and calculated the volume of water needed to maintain different lengths of refuges (2.5, 5, and 7.5 km) on an annual basis. We used Pareto fronts to optimize delivery locations, attempting to maximize the number of minnows benefitting while simultaneously minimizing the amount of water needed. Numbers of minnows that could benefit from small drought refuges varied by three orders of magnitude among years; additional volumes of augmented water ranged from < 800 to > 25,000 acre-feet annually. Pareto fronts suggested differing strategies for water delivery because annual population demographics and abundance varied widely. Optimal delivery locations were generally challenging for existing infrastructure, occurring in downstream areas. In some years, < 100 minnows would benefit from the creation of drought refuges, suggesting other flow management actions would be more effective than management for drought refuges. Future flow scenarios likely include strict tradeoffs among segments (e.g., purposely sacrificing one area to maintain another). Our accounting for population status and demography, climatic conditions, and water availability, can help inform these difficult decisions.

Spatial and temporal variation in pollinator habitat quality on northern Arizona rangelands

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Abstract: Western rangelands provide essential biodiversity habitat and ecosystem services, yet often exhibit degradation from legacies of overgrazing combined with modern climate change and decades of megadrought. Understanding how rangelands of varying vegetation types and disturbance histories have changed over time may guide future sustainable management. We evaluated current pollinator habitat components at northern Arizona rangeland sampling locations spanning an elevational gradient from sagebrush to mixed conifer. We documented pollinator forage plant diversity and cover and availability of pollinator nesting habitat, as well as occurrence of non-native plant species and evidence of disturbance. We also compared forage plant occurrence between our present-day dataset and a historic, baseline ecological assessment conducted in 2005. We found an overall decline in flowering plant richness and functional diversity over time within most vegetation types across our study region. Flowering plant cover and pollinator nesting resources varied extensively within each vegetation type, and both showed negative relationships with quantity of visible disturbance. Our results hold implications for pollinator-dependent plants and communities on Colorado Plateau rangelands. Understanding how pollinator habitat quality varies over space and time is essential for sustainable management of ecosystems across the US Southwest, which is a global hotspot of native bee diversity.

A Framework for Moving from Static Risk to Seasonal Strategy in 4FRI and CFR

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Abstract: Wildfire planning in the Southwest and southern Rockies often relies on static risk assessments based on extreme fire weather scenarios. While these approaches are valuable for identifying high-consequence hazards, they can obscure opportunities for beneficial fire use under more moderate, seasonally variable conditions. We present a seasonally informed wildfire risk framework designed to support more adaptive and context-specific planning. Developed in collaboration with fire managers and resource specialists, the framework integrates modeled fire behavior across a range of seasonal weather conditions with time-sensitive considerations of resource response and management objectives.

We apply this framework in two fire-prone landscapes—the Four Forest Restoration Initiative (4FRI) region of northern Arizona and the Colorado Front Range—each representing distinct ecological conditions and fire management challenges. By identifying seasonal “opportunity windows” when fire can be applied with acceptable risk, the framework shifts wildfire planning from a static, hazard-focused paradigm to one that accounts for timing, trade-offs, and restoration potential. This work underscores the value of embedding seasonal dynamics into fire planning to better align with the Southwest’s ecological complexity, operational realities, and changing climate.

Balancing Native Species Management, Downstream Water Delivery, and Energy Generation in a Changing Climate

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Abstract: Balancing water supply, energy generation, and ecosystem sustainability in regulated rivers is increasingly difficult under a changing climate. Rising hydrological variability changes the trade-offs between traditional resource use and ecosystem stability. In this work, we use limited state information to model optimal annual reservoir releases that support water supply, hydropower generation, and native species management under uncertain future conditions. Our approach identifies robust policies that perform well across a wide range of hydrological scenarios, demonstrating the effectiveness of simple optimization algorithms in nonstationary systems. Even under drier conditions, implementing flexible, proactive rules can increase the likelihood of sustaining ecosystems and meeting water delivery goals. By optimizing decisions before crises emerge, managers can better protect critical riverine resources and build resilience in the face of uncertainty.

Microclimate and Competition Effects on Seedling Establishment in Post-Fire Mixed-Conifer Forests of the Sierra Nevada

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Abstract: In mixed-conifer forests of the western U.S., climate change and over a century of fire exclusion have increased the frequency and severity of wildfires, limiting natural regeneration and threatening long-term forest persistence. High-severity fires often eliminate seed sources and create harsh microclimatic conditions that hinder seedling establishment. To accelerate forest recovery, land managers increasingly rely on reforestation strategies, including planting seedlings and applying herbicide to reduce competition from resprouting vegetation. While herbicide effectiveness has been broadly studied, species- and site-specific responses remain less understood, especially in the context of complex topography and variable post-fire conditions.

We established a reforestation experiment within the 2022 Mosquito Fire footprint in the central Sierra Nevada to evaluate how post-fire microsite conditions and shrub abundance influence seedling survival and growth across five conifer species. Seedlings were planted in paired plots with and without herbicide treatment, spanning a range of slope, aspect, and elevation. We monitored early seedling performance as well as soil moisture, temperature, and post-fire vegetation dynamics.

Preliminary results suggest that species-specific responses are strongly mediated by microenvironmental conditions. Shade-intolerant species, such as ponderosa pine, performed better in treated plots, while other species exhibited more variable responses. This research provides early insight into how species traits interact with post-fire environments and management interventions. Our findings highlight the importance of microsite variability in shaping reforestation outcomes and the need for site-specific strategies that account for both biotic and abiotic drivers. As high-severity fire becomes more frequent across the western U.S., understanding the nuanced drivers of seedling success is critical for informing adaptive, climate-resilient reforestation efforts.

Piloting laser scanning for estimating understory biomass and areal cover in pinyon-juniper woodlands of northern Arizona

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Abstract: While Light Detection and Ranging (LiDAR) technologies are commonly applied in forestry to better understand overstory dynamics, there remain unresolved challenges in using this technology to assess understory conditions, particularly vegetative biomass and cover. Accurate biomass and cover measurements are essential for understanding surface fuel loading, vegetation dynamics, wildlife habitat quality, and overall ecological health. Traditional methods of field sampling are not only resource-intensive but can also introduce errors and bias. While remote sensing technologies, including LiDAR, are often used to overcome these challenges, the methodologies for applying Terrestrial Laser Scanning (TLS) and Mobile Laser Scanning (MLS) to predict understory biomass are not yet fully developed or widely accepted in Colorado Plateau systems. This poster will share the methodology from recent work in pinyon-juniper woodlands of northern Arizona, which aims to provide land managers with a more efficient and accurate way to assess biomass and aerial cover in grasses, forbs, and shrubs using TLS and MLS data. This poster will also explore preliminary patterns in understory plant community response to overstory conditions such as canopy cover and drought dieback.

Collaborative Conservation in a Time of Uncertainty: Adapting for Change

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Abstract: A conservation collaborative is a coalition of organizations and agencies that works together to achieve shared goals for a watershed, landscape, or other ecologically-bounded

region. They bring together diverse stakeholders representing many interests, sometimes under difficult conditions, to work toward mutual goals that may include species or habitat conservation, natural resource preservation, wilderness stewardship, visitor use management, or municipal governance. The strength of collaboratives stems from their networks, which enable them to multiply resources in a way that makes them greater than the sum of their part(ner)s. Especially in socially and politically fractured times, they offer a literal common ground – tangible foundation for active democracy.

The Escalante River Watershed Partnership was formed in 2009 to involve local communities in addressing the spread of woody invasive species in south-central Utah. To date, project partners have leveraged over \$11M to treat over 8,000 riparian acres – the largest riparian restoration project ever conducted on BLM lands. But recent funding and staffing shortages have halted engagement of some partners and led to stalled project planning and implementation. Smaller, more rural collaboratives have been especially impacted. As these challenges continue to hamper environmental initiatives nationwide, the importance of collaborative partnerships to bolster those gaps has become that much greater.

This poster will examine ERWP as a model for how conservation collaboratives can and should adapt to the rapidly changing fiscal and political landscape while maintaining and perpetuating the crucial work they do. It will present results of a survey conducted by ERWP participants, and compare those results to changes occurring at other conservation collaboratives in rural areas of the Southwest.

Combined effects of climate change and insect damage on Fremont cottonwood leaves and their consumers

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Abstract: Higher temperatures are impacting the performance and traits of many species, with consequences for whole ecosystems. Predicting and responding to these effects requires a detailed assessment of climate tolerances in important species, such as habitat-forming trees. These assessments must account for genetic variation from across the species' range, as well as potential feedbacks between climate change and species interactions. We combined a set of three common gardens along a steep climate gradient in AZ and UT with a three-year simulated herbivory experiment to account for anticipated increases in insect activity at warmer temperatures. We found strong effects of both genetic variation and growing conditions on the physical and chemical characteristics of cottonwood leaves, which were remarkably consistent across years. We also found that chemical defense traits were much more strongly affected by both genetics and current climate than induction by simulated insect

attacks. After measuring these traits, we assessed consequences for both terrestrial and aquatic consumers of cottonwood leaves. Both tree genotype and chemical induction had detectable feedbacks on further visitation from foliar insects. Once leaves reached aquatic detritivores the effects of induction disappeared, but the effects of genetics and growing conditions clearly persisted. These results show the importance of understanding both genetic and environmental effects for forecasting higher level ecological consequences. Conserving or actively restoring hot-adapted genotypes of riparian trees may increase chances of tree persistence, but will also impact associated consumers.

Towards forest management prescriptions to improve wildfire resilience and snowmelt water availability for forest health, fuels moisture, and water resources

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Abstract: Land managers thin forests to reduce wildfire risk across millions of acres of snow-dominated conifer forests by reducing fuel loads and breaking fuel continuity. Given forests' strong influence on snowpack and snowmelt, fire-risk reduction projects offer an opportunity to enhance water balance for future forests and downstream resources. While forest cover reduction is guided by fire risk criteria, managers may have flexibility in configuring remaining forest patches, which can impact hydrologic outcomes.

Here, we present a practical approach to integrating snow hydrology research into forest management. First, we collaborate with forest and water managers to define key objectives, such as increasing snowmelt volume or delaying snowmelt to enhance soil and fuel moisture. Second, we analyze relationships among weather, topography, and forest structure using SNOTEL, airborne lidar, remote sensing, and Snowtopography stations, which track soil moisture and daily snow depth across diverse forest microclimates. Third, these data inform SnowPALM, a mechanistic forest hydrology model that resolves tree-snowpack interactions at a 1-m scale. Since SnowPALM is practical for smaller areas, the fourth step is to develop random forest machine learning models to scale predictions of snowpack and snowmelt across large forest thinning projects (>1000s of ha).

We illustrate results from a collaboration among university, agency, nonprofit, and water management partners using six years of field data, SnowPALM simulations, and machine

learning models at three sites within the 2.1M-acre Four Forests Restoration Initiative (4FRI) in Arizona. We identify up to nine machine learning input variables that practitioners could apply, based on available resources, to estimate the impact of forest thinning on snowpack, and we use them to quantify how completed thinning treatments have affected snowmelt dynamics across ~200 treatment units totaling ~12,000 ha (30,000 ac). Finally, we discuss near-term applications for designing forest thinning prescriptions that simultaneously reduce wildfire risk and improve water balance for locally defined management goals.

Can Community Science help foster Human Wildlife Coexistence?

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Abstract: Since January 2025 the conservation sector in the US and globally has been subject to unprecedented changes in institutions and funding streams. This situation calls for bold new approaches that aim to fill immediate funding and capacity gaps as well as trial new approaches for effective and sustainable conservation action in our radically changed world. Human Wildlife Conflict and attempts to achieve a situation of healthier co-existence - long hampered by the inequities in the costs and benefits associated with the conservation of especially iconic and damage-causing wildlife such as lions, elephants, and wolves. Direct financial and other benefits to the individuals and communities that bear the costs of living alongside such species is key to changing the distribution of costs and benefits and strengthening co-existence. The traditional mechanisms for such transfers, which include wildlife tourism, hunting tourism and wildlife trade have limits and constraints. Wildlife tourism is highly volatile, and hunting and wildlife trade are strongly opposed by many vocal groups in conservation. Community Science, whereby individuals and community members receive financial and non-financial benefits for contributing to monitoring wildlife and their habitats represents a novel approach to strengthening co-existence. Such individuals can also contribute to early warning and deterrent systems for damage causing wildlife. Based on a scoping review and on-ground pilots in communities will discuss examples of such Community Science systems already in place, as well as the potential to expand them. The presentation will conclude with thoughts on frameworks and necessary institutional support to expand these mechanisms.

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State-and-Transition models and Ecological Site Groups for PJ fire and fuel management

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Abstract: Pinyon Juniper (PJ) woodlands and savannahs are a dominant landscape across much of the Colorado Plateau, providing important wildlife habitat, and encompass large areas of mature and old growth. However, PJ on the Plateau is increasingly threatened by warming and drying conditions, due to drought-induced die-back and mortality as well as catastrophic wildfire. Like many areas across the west, Plateau PJ have been targeted for removal and thinning.

We used information from NRCS Ecological Site State-And-Transition Models, Federal inventory and monitoring data, remote sensing, fire history, and other data to describe Plateau PJ woodlands and savannahs ecological dynamics at the landscape scale. We characterize long-term trends using recently created spatio-temporal PJ woodland and savannah state maps and summarize PJ management practices prescribed in Ecological Site Descriptions.

We find reference state PJ woodlands in shallow, deep rocky, or sloping/break-type ecological sites, in both arid and semi-arid climates, and reference state PJ savannahs in deeper soils with

semi-arid settings, broadly matching where we see high PJ cover in Plateau parks. Fuels analysis revealed that reference state PJ woodlands in shallow, deep rocky type ecological sites accumulate nearly three times more surface fuels than those in deeper soils, with large woody debris comprising the fuel load majority. PJ woodlands in a shallow or deep rocky ecological site have the highest aboveground biomass but only moderate fuel loads (compared to aboveground biomass) suggesting processes that favor surface over crown fires. However, increased risk of tree mortality from aridification may alter fuel accumulation dynamics, creating management challenges including: changed decomposition rates (and fuel availability), increased ladder fuel continuity, and elevated insect outbreaks risk leading to rapid state transitions in response to changing fire regimes. These findings highlight the importance of including fuel dynamics within State-and-Transition models considering global change drivers, such as aridification.

Hoofprints in Time: Seasonal Grazing Timing and Biocrust Cover in Drought-Stressed Rangelands

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Abstract: Soil surface degradation due to drought threatens rangeland sustainability across the Southwest. Understanding temporal dynamics of seasonal grazing timing during drought and seasonal grazing during drought recovery is critical for adaptive livestock management. We analyzed soil surface cover at two sites in the Indian Creek area of Southeastern Utah from 2021-2024, examining precipitation (ambient vs. experimental drought) and simulated grazing treatments (no grazing, spring-only, winter-only, and winter+spring) across five replicated blocks per site. Drought structures were installed Fall 2021 and removed Fall 2023 to simulate drought cessation and opportunity for recovery.

Analysis focused on loose erodible soil versus protective surface crusts (physical crust and biological soil crusts including cyanobacteria, mosses, and lichens) as erosion risk indicators. Results revealed catastrophic soil surface degradation at both sites regardless of drought treatments (observed in drought and ambient plots), though ambient plots maintained somewhat higher protective cover than droughted plots. Loose erodible soil increased dramatically from 42% in 2021 to 83% by 2024, while protective surfaces declined from 56% to 14%.

Spring-only and Spring+Winter simulated grazing consistently showed highest erosion risk across all years and precipitation treatments. Winter-only grazing showed the highest initial protection during drought years. Treatment effectiveness collapsed dramatically in Fall 2024 measurements (76.7% loose soil, 1.5 years into drought treatments), with even the best treatment combinations having loose soil amounts exceeding the worst 2021 measurements (0.5 years droughted, 49.2% loose soil). Erosion risk increased from protective crust dominance in 2021 to loose-soil dominance in 2024, with all plots showing minimal evidence of recovery with grazing rest.

These findings demonstrate that adaptive seasonal grazing during drought may provide some buffer to detrimental drought effects on protective soil cover. Additionally, 2 years of recovery is unlikely to be sufficient in grazing rest to increase protective crust cover to pre-drought conditions, suggesting proactive restoration interventions may be necessary to prevent irreversible soil loss in semi-arid rangelands facing climate change pressures.

Assessing early effectiveness of silvicultural treatments in quaking aspen exclosures affected by oystershell scale

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Abstract: Quaking aspen (*Populus tremuloides*) is a disproportionately significant species in the US Southwest, having a high cultural, aesthetic, and economic value, yet minimal populations often lack resilience and sustainability. Aspen's ongoing decline is caused by many factors, including climate, ungulate browsing, and biotic damaging agents, all of which contribute to high mortality and low regeneration and recruitment. Oystershell scale (OSS; *Lepidosaphes ulmi*) is a small, invasive sapsucking insect recently found causing severe dieback and mortality of aspen in Arizona and Utah. Management strategies for OSS in aspen stands are lacking, with no proven strategies for properly managing OSS outbreaks. Additionally, little is known about how effective silvicultural treatments are in meeting prescription objectives in aspen stands. Beginning in 2019, silvicultural treatments were implemented in aspen exclosures to assess treatment effectiveness for reducing OSS-caused mortality and improving aspen regeneration as part of a collaborative project between researchers and managers. Experimental treatments included clearfelling, sanitation thinning, and no action units. We installed permanent plots before treatment and re-measured plots 1 year following treatment, recording overstory, understory, and damaging agent data. The purpose of this study is to compare differences in OSS severity and aspen regeneration response across all treatment units before and after intervention to assess early treatment response and effectiveness. We will present preliminary treatment outcomes, compare these quantitatively, and assess results in the context of meeting prescription objectives. We expect these results to support management decision-making in aspen stands impacted by multiple threats.

Fungal colonization modulates trait plasticity in cottonwood cross types during drought

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Abstract: Cottonwoods (*Populus* spp.) serve as foundation species in riparian ecosystems and are notable for hosting both arbuscular (AMF) and ectomycorrhizal fungi (EMF). However, their physiological plasticity under environmental stress, particularly drought, remains incompletely understood, especially in the context of variable fungal colonization. We investigated how fungal colonization influences trait plasticity during drought across a gradient of cottonwood cross types, including Fremont (*P. fremontii*), narrowleaf (*P. angustifolia*), and their hybrids.

Using cuttings grown under factorial drought (D/W) treatments in a greenhouse, we measured a suite of root, shoot, and leaf traits and quantified fungal colonization (AMF, EMF, DSE). Cross types exhibited strong baseline trait differences, necessitating their inclusion as a covariate. While fungal colonization had few consistent direct effects on absolute trait values, it significantly influenced trait plasticity during drought, particularly in hybrids. In these individuals, increasing AMF and DSE colonization was associated with reduced plasticity in growth metrics and leaf area traits, potentially signaling a stabilizing or constrained response to stress. In contrast, narrowleaf individuals showed a positive relationship between root trait plasticity and fungal colonization, and Fremonts exhibited minimal plasticity-fungal coupling.

Stomatal density traits revealed additional complexity: Fremonts, characterized by higher top-leaf stomatal densities, became less plastic with increasing EMF colonization, suggesting a potentially maladaptive interaction. Conversely, hybrids showed increased plasticity in stomatal ratio traits, which may reflect adaptive flexibility. These patterns suggest that the functional role of mycorrhizal symbioses under drought is cross type-specific and may either buffer or constrain plastic responses depending on host lineage and fungal guild.

Our results highlight the nuanced roles that root symbionts play in mediating plant phenotypic plasticity, underscoring the importance of hybrid genotypes and fungal community composition in shaping drought resilience in foundation tree species.

The Perils of Precedent: Pinyon Jay Conservation in Pinyon-Juniper Woodlands **BOONE, J.D.¹**

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Abstract: After years of conservation obscurity, the Pinyon Jay's sustained and substantial population declines have recently elicited a rapidly growing concern. This new awareness of the plight of the Pinyon Jay led to a petition for ESA listing and helped jump start an ongoing reconsideration of how pinyon-juniper (PJ) woodlands are managed. It is widely assumed that traditional criteria for PJ management – which are largely driven by rangeland values and goals – are inadequate for Pinyon Jays, and perhaps harmful in some cases. Finding a better woodland management paradigm, however, is complicated by lack of consensus about the root causes of Pinyon Jay decline. In the absence of a definitive answer, managers and conservation planners tend to fall back on “tried and true” bird conservation formulas. Among these are prioritizations for the conservation of breeding habitat and old growth woodland. In this talk, a case will be made that both of these well-established precedents are likely to be ineffective for Pinyon Jay conservation. Worse yet, pursuing these familiar pathways may create the

impression that “something is being done” while in fact diverting attention from the more likely causes of Pinyon Jay decline. Pinyon Jays are an unusual and unique species, with a novel and complicated natural history. Effective conservation measures will require a recognition of their particular biology and ecology rather than resorting to more generalized bird conservation formulas.

CrustNet: Global determinants of biodiversity in biocrusts, and outcomes for ecosystem function, resistance and resilience

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Abstract: Around the world, and for the past ~2 billion years, surfaces of many soils have a “living skin” made by tiny plants and microbes called a biological soil crust (biocrust). Biocrusts are crucially important for helping to support the ecosystems they inhabit, for example making soil fertile, storing or redirecting water and stopping erosion. Biocrusts also boost the variety of living things present in an area (biodiversity). The CrustNet project will determine what controls the biodiversity of biocrusts globally for the first time, and its outcomes. CrustNet is a networked, distributed study of biocrust ecology, with participants around the world. Participants will conduct the same set of studies and collect the same types of data to be pooled together to create an unprecedented global database about biocrusts. CrustNet addresses: (1) The determinants of the global scale functional biodiversity of biocrusts (2) determinants of the variability and shape of the relationship between biodiversity and ecosystem function across ecosystems, and (3) effects of biocrust functional biodiversity on ecosystem resistance and resilience to physical disturbance and climate change. CrustNet uses a tiered research protocol, including low-cost observational studies and manipulative experiments. Tier 1 includes mandatory detailed surveys of the composition of biocrusts, measurement of ecosystem functions along a biocrust development gradient, and contribution of samples to a trait database. Tier 2 includes low-cost experimentally-applied physical disturbance of the soil and subsequent tracking of the response of biocrusts. Tier 3 includes experimental climate manipulations using reciprocal transplantations and rainfall reduction using passive shelters. These studies will be foundational to our understanding of determinants of biocrust diversity, function and response to disturbance. In the process of conducting this research, a world-wide collaboration will be established, leading to greater participation of researchers from diverse backgrounds, and unparalleled training opportunities.

Informing climate adaptation decisions in western drylands

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Abstract: As climate change progresses, natural resource management decisions increasingly require information about anticipated climate impacts and potential climate adaptation strategies. This need is particularly pronounced in dryland, water-limited ecosystems which represent a large majority of public and tribal land in the U.S. West, and where plant communities and wildlife populations are especially vulnerable to enhanced drought and temperatures. We are pursuing research to inform four types of decisions: 1) prioritizing conservation and restoration in areas most likely to sustain benefits in coming decades; 2) modifying livestock grazing intensity to minimize wildfire risk while also sustaining wildlife habitat; 3) treating woodland vegetation to enhance resilience to future droughts; and 4) timing seeding of native plants in postfire restoration seedings to minimize drought-induced seedling mortality. Within sagebrush shrublands, we found that sustaining high-quality wildlife habitats may be most efficiently advanced by focusing on the eastern portion of the region, particularly SW Wyoming. In the more vulnerable western sagebrush region, grazing could be a useful tool for reducing wildfire risk, and utilizing drought forecasts may enhance restoration success. Results suggest that vegetation treatments can achieve multiple objectives in PJ woodlands, both reducing fuel loads and increasing drought resilience. However, treatment benefits for drought resilience are unlikely to compensate for long-term declines in climatic suitability in the southern extent of most species' range, including for many tree species that are currently abundant in PJ woodlands of the Colorado Plateau. Looking forward, we are exploring approaches to assess the systemic uncertainty of climate adaptation benefits and to evaluate the long-term economic return on climate adaptation investments.

Exploring gaps in resident mitigation education programs across Arizona

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Abstract: Wildfire risk mitigation on private property is central to effective, cohesive adaptation at the landscape level. However, consistent and sustained homeowner engagement in mitigation activities such as fuels reduction and structure retrofitting remain elusive, spurring the development of a diverse suite of tools and programs to motivate action. Education-centered programs such as Firewise USA and FireSmart Canada rely on home ignition zone (HIZ) graphics to communicate mitigation best practices to homeowners, yet studies that explicitly examine their relevance and utility across diverse ecosystems remain unexplored. These materials often stereotype wildland-urban interface properties as ones situated in forested ecosystems on large lots, leaving ecosystems like shrublands, grasslands, and deserts, and urban or suburban properties underrepresented. This study sought to understand current use and applicability of HIZ illustrations across four Arizona, USA

ecosystems with the intent to identify place-based recommendations that can improve mitigation engagement on properties in underrepresented ecosystems. Data collection with fire professionals, prevention experts, and community leaders occurred in two phases: (1) initial workshops with 64 participants at a statewide meeting, followed by (2) focus groups with 42 participants in four communities across Arizona. Workshop participants evaluated existing HIZ materials and provided input on what did and did not work for their local social and ecological contexts. We then created new graphics tailored to four Arizona locations in collaboration with a graphic designer. These were then presented to focus group participants. The focus groups emphasized challenges related to scale, capacity, and the need for varied communication approaches within communities that transcended current HIZ education materials. Findings indicate that local fire prevention and communication staff strongly support place-based HIZ graphics, but current education resources do not reflect community-specific needs or conditions. We conclude with recommendations for increasing homeowner participation in mitigation by incorporating place throughout homeowner education.

The Colorado River Basin's Millennium Drought: A few dry decades or the new normal?

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Abstract: The Colorado River Basin (CRB) is no stranger to drought, though the recent “millennium drought” (2,000-present) is unsurpassed since 800 AD. Rising air temperatures and shifts in form, timing and amount of precipitation have the potential, if they continue, to substantially alter ecosystems, hydrology and human infrastructure. This has prompted managers and decision-makers in the CRB to ask if the basin should be managed as if it is experiencing a prolonged drought or the first stages of aridification. Identifying whether the CRB is in drought or aridifying is complicated by the basin's size, the broad range in normal conditions for the basin, and complex landscapes which make detecting persistent change difficult. Managing the basin under aridification would require novel planning and management strategies. During the 2023 USGS Actionable Strategic Integrated Science and Technology (ASIST) Co-Development Workshop, CRB partners and managers emphasized the importance of understanding the likelihood that recent drought might be early signs of aridification to their planning. In response, the ASIST group supported the development of an information product as a StoryMap for the non-scientist that collects, synthesizes and presents the state of the science on drought and aridification in the CRB. This new product explores historical drought, future climate, aridification detection, drought management, and presents a curated selection of other drought-related information sources and products.

Seasonal dynamics of groundwater, vegetation, and moisture supply and demand in the Upper San Pedro watershed

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Abstract: Groundwater-dependent ecosystems (GDEs) across the Southwest are under threat due to aridification, water extraction, and land use change, among other stressors. When paired with groundwater monitoring, remote sensing provides an opportunity to examine long-term responses to changes in groundwater availability at the landscape scale and the corresponding sensitivities of these ecosystems to climate variability. We utilized in situ groundwater data from a spatially dense network of wells in the Upper San Pedro River in southeastern Arizona, distributed across the riparian and upland areas, to compare how indicators of vegetation function differently to groundwater variability between the two hydrologic settings. Riparian vegetation was significantly less greenness and had less ability to transpire when water tables were deeper than average during the summer monsoons, indicating sustained groundwater dependency even during wetter seasons. Additionally, riparian vegetation was overall more responsive to vapor pressure deficit, confirming that ET and productivity from this system are seasonally energy-limited and demand-driven. This portends that future increases in aridity could decrease groundwater storage via riparian transpiration. Interestingly, we did *not* find that riparian vegetation was relatively less affected by precipitation compared to upland vegetation at monthly timescales, suggesting that riparian plants use a variety of moisture sources and “seasons” of precipitation which recharge the near-stream aquifer. Consequently, both upland and riparian ecosystems are similarly sensitive to climate variability, contradicting the assumed role of groundwater as a buffer against unpredictable moisture supplies. These results showcase the complexity of the Upper San Pedro’s plant communities and their responses to hydroclimate, informing our ability to predict how future environmental change will affect the function and extent of GDEs.

Mapping stinknet (*Oncosiphon pilulifer*) using harmonized Landsat and Sentinel data in southern Arizona’s Sonoran Desert

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Abstract: Pima, Pinal, and Maricopa Counties in southern Arizona are managing large-scale, rapid infestations of the invasive plant stinknet (*Oncosiphon pilulifer*). The noxious weed forms highly flammable, dense patches that generate acrid smoke when burned and trigger contact dermatitis and respiratory distress in individuals allergic to this plant. In Arizona, stinknet has been found in Saguaro National Park and Cabeza Prieta National Wildlife Refuge but has not yet been identified in Tumacácori National Historical Park. To protect ecosystems and boundary areas vulnerable to stinknet encroachment, natural resource managers at the National Park Service and US Fish & Wildlife Service have been manually monitoring and removing the invasive species in the park. The NASA DEVELOP team used Harmonized Landsat and Sentinel (HLS) imagery to derive vegetation indices including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI), Soil Adjusted Vegetation Index (SAVI) and Normalized Difference Yellow Index (NDYI) to examine phenology and identify stinknet from surrounding native vegetation. Additional data products from the Global Precipitation Measurement Mission (GPM), Shuttle Radar Topography Mission (STRM), and Landscape Fire and Resource Management Planning Tools

(LANDFIRE) were incorporated to identify areas within and around the park susceptible to infestation. The team computed stinknet distribution maps using an unsupervised classification method to create an inventory of stinknet presence in Pima, Pinal, and Maricopa counties. This also included a supervised modeling component of habitat suitability to characterize the spatial distribution of stinknet, helping partners at the National Park Service and US Fish & Wildlife Service proactively manage stinknet throughout the park and refuge boundaries.

Implications of delayed Monsoon onset on carbon cycle dynamics in Southwestern grasslands

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Abstract: Dryland ecosystems are highly sensitive to shifts in precipitation timing, which are expected to intensify with climate change and have significant consequences for carbon cycling processes. In the southwestern U.S., most annual precipitation occurs during a distinct summer rainy season driven by the North American Monsoon. However, regional climate models predict a delayed onset of the Monsoon. To investigate ecosystem responses to shifts in Monsoon seasonality, we conducted a 12-year experiment (2013-2024) in two semi-arid grasslands along a regional transition zone: Chihuahuan Desert grassland dominated by *Bouteloua eriopoda* and Great Plains grassland dominated by *Bouteloua gracilis*. Using rainout shelters, we excluded and stored July-August rainfall and reapplied it in September-October as multiple events, altering precipitation seasonality without changing total amount. We measured aboveground net primary production (ANPP) and species composition in 20 permanently located treatment and control plots, alongside continuous soil CO₂ efflux in six plots using in situ sensors. Contrary to expectations that Great Plains grassland would be more sensitive to delayed Monsoon onset due to its less arid evolutionary history, Chihuahuan Desert grassland exhibited stronger responses. Reductions in both ANPP and soil respiration occurred in both grasslands, with the largest declines in Chihuahuan Desert grassland. These differences were driven primarily by the dominant grasses: *B. eriopoda* disappeared completely from delayed Monsoon treatments in Chihuahuan Desert grassland after eight years, while *B. gracilis* exhibited more moderate declines. These results suggest rainfall timing, independent of total amount, can have substantial and lasting effects on carbon cycling processes in Southwestern grasslands. As regional aridification intensifies and *B. eriopoda* continues to encroach into and replace Great Plains grasslands, these ecosystems may become increasingly vulnerable to changes in Monsoon seasonality. Consequently, these findings underscore the need for adaptive management strategies that account for shifts in Monsoon timing under future climate scenarios.

Forecasting non-native smallmouth bass responses to future hydrologic conditions in the upper Colorado River basin

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Abstract: Increased abundance and range expansions of non-native smallmouth bass (*Micropterus dolomieu*) in the upper Colorado River basin have coincided with declines in native fishes, therefore controlling smallmouth bass is a priority management strategy for native fish conservation. Abundance of smallmouth bass is known to vary in response to environmental conditions, with long growing seasons and hydrologic and thermal stability during the post-hatching period producing large cohorts of smallmouth bass. We used a recently developed population model for smallmouth bass in the Yampa and Green Rivers in the upper Colorado River basin to forecast smallmouth bass population responses to a range of potential future hydrologic conditions. The model combines daily river discharge and water temperature data to predict annual recruitment and incorporates impacts of density dependence, age specific natural mortality, and exploitation due to mechanical removal efforts. We simulated smallmouth bass responses across 400 hydrologic traces produced by ensembles of five different hydrologic models and assumed current policies driving reservoir storage and water release operations were maintained. Future hydrologic conditions will likely promote high population densities of smallmouth bass. Assessing responses of non-native species to future environmental conditions is a first step in identifying potential changes to current control methods, including increasing efforts or trying new control strategies.

The Canyonlands Research Center: Seeking evidence-based solutions for the Colorado Plateau in a changing climate

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Abstract: The Colorado Plateau includes both protected areas and “working landscapes” where livestock producers and other private landowners earn livelihoods from the land. Sustaining the region’s ecosystems requires finding solutions to management challenges experienced in both types of land. To that end, The Nature Conservancy (TNC) established the Canyonlands Research Center, located on TNC’s Dugout Ranch, surrounded by Bears Ears National Monument. In partnership with university scientists and state and federal agencies, the Center’s mission is to facilitate research that informs land management solutions in a changing climate, with attention to both ecological and socio-cultural sustainability. The Dugout is a working cattle ranch operating on over 5,000 acres of deeded land plus 350,000 acres of Bureau of Land Management and U.S. Forest Service grazing allotments. We use the ranch operation to study benefits and tradeoffs of raising a heritage cattle breed, Rarámuri criollo, that may be better adapted to Plateau ecosystems, and to evaluate the efficacy of precision ranching tools such as virtual fencing and ground-based sensors for improving water efficiency and protecting sensitive areas. We provide facilities for university and government scientists to test innovative ecological restoration techniques and concepts, and to explore more basic questions about the functioning of Colorado Plateau ecosystems that may be useful for predicting and directing responses to climate change. Outreach and education is an important component of the Center’s mission, with programs that include workshops for ranchers and land managers, an 8-week internship for undergraduate students who are tribal members, and an artist-in-residence program.

Community adaptation to wildfire and post-fire flood risk: lessons from Northern Arizona

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Abstract: Wildfires in the Southwestern U.S. are often followed by heavy monsoonal rainfall that can drastically alter local hydrology and result in post-fire flooding. While wildfire and post-fire flood events require different hazard planning approaches, it is not clear whether communities understand, prepare for, and act on these differences. Previous cycles of wildfires and subsequent post-fire flood events may also influence if and how communities prepare and respond to threats, with some research indicating that response can become more predictable and defined over time. This study examines two Arizona communities: Oak Creek Canyon and Doney Park, both of which are ranked as the top two communities most at risk for wildfire in Coconino County. These locations were selected due to their repeated cycles of wildfires, mandatory evacuations, and post-fire flooding events that followed, with markedly different community outcomes. The communities also differ in their social dynamics and topographical characteristics, which contribute to how they prepare and respond to these hazards. These differences provide valuable insight to better understand how these events influence current preparedness and risk perceptions. This presentation shares findings from semi-structured interviews with residents and local professionals within each community to better understand the evolution of hazard planning, risk perceptions, and safety measures at the local level over time. We conclude with recommendations to aid communities and practitioners to address longer-term anticipation of social responses to wildfire and post-fire flood cycles in ways that enhance preparedness while embracing local social contexts.

Daily fluctuating flows affect riparian plant species distributions from local to regional scales

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Abstract: The number of hydropower dams has grown globally over recent decades, with significant impacts on downstream riparian plant communities. Many of these dams generate daily fluctuating flows known as hydropeaking to meet sub-daily variation in energy demands. Hydropeaking can significantly impact riparian plant communities, with obligate riparian species tending to experience the greatest negative effects on habitat suitability. Whether this pattern holds in arid biomes where daily soil moisture enhancements could benefit some plants is an open question. We used occurrence records to model species responses to variation in daily flow fluctuations across 32, 689 river segments in the Western USA. We then applied estimates of hydropeaking responses derived from those models to understanding the abundance and fine scale hydrologic niches of riparian plant species in the Colorado River ecosystem downstream of Glen Canyon Dam, which has experienced vegetation expansion

attributed to river regulation, including hydropeaking that began in 1964. At the regional scale, species with greater wetland dependence exhibited increasingly negative responses to hydropeaking across 1,496 species, consistent with previous studies at smaller scales. At the local scale of the Colorado River, we found that species inhabiting near-channel habitat characterized by daily inundation and exposure had positive modeled responses to hydropeaking, consistent with a long history of selection for species tolerant of hydropeaking. In contrast, species inhabiting the zone immediately above peak daily river stage had negative modeled responses to hydropeaking, suggesting that they are being excluded from otherwise suitable habitat nearer the channel. These results demonstrate that hydropeaking can impact species distributions from local to regional scales by excluding obligate wetland species and reducing habitat suitability for some facultative wetland species. These results from an arid river system are consistent with those reported from other biomes.

Drivers of juniper dieback and resprouting in Northern Arizona following a global change-type drought

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Abstract: Pinyon-juniper woodlands are widespread across the Southwest and are often characterized as drought tolerant. Yet in 2021, a severe global change-type drought triggered extensive crown dieback in oneseed juniper (*Juniperus monosperma*) across Northern Arizona. This dieback event was followed by an above-average monsoon season, during which many junipers began to resprout. We investigated variation in dieback and resprouting in juniper following the dieback event. Across 26 plots (n=405 trees), we found that smaller trees and those growing at hotter, drier sites with higher grass cover and tree density, were more likely to exhibit severe crown dieback. We also surveyed 700 juniper trees using line transects and found that, despite being considered a non-resprouter, 22% of all juniper trees and 37% of those with $\geq 50\%$ dieback resprouted by 2022. Resprouting probability was highest in trees with very severe (90%) dieback and at higher elevations. Larger trees with severe dieback were most likely to resprout, but when dieback was low, smaller trees had higher resprouting probability. The effect of tree size on resprouting was more pronounced in open-grown trees. These findings challenge long-standing assumptions about the drought tolerance and recovery strategies of juniper in semi-arid systems. Understanding which trees die and which recover is key to producing accurate forecasts of vegetation change in drylands under future climate conditions. As global change-type droughts become more frequent and intense, identifying the

demographic and environmental factors that influence tree vulnerability and resilience will be critical for projecting woodland dynamics and informing adaptive management in this culturally and ecologically important forest type.

Analyzing White Pine Growth in the Southwest

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Abstract: Due to rising temperatures and increased drought severity, many species are now threatened; intrinsically increasing biotic threats such as white pine blister rust disease. Tree cores from white pine across three regions in Arizona (Northern, Central, and Southern) were collected and visually cross-dated. Once the trees were dated, they were verified using dendrochronology software programs. Growth data from the cores were also collected to analyze trends in Basal Area Increment (BAI) in relation to climate variables. Preliminary results suggest that while temperatures increased across all regions, growth responses varied. The Southern site exhibited the greatest variability, with decreasing BAI and increase in temperature and Climate Moisture Index (CMI). The Central region showed a notable increase in CMI and a relatively stable BAI, similar to the Northern region. These patterns point to regional differences in resilience; however, biotic factors have not yet been accounted for. Building on previous work, this internship contributed to the ongoing effort to further understand the relationships between environmental stressors and white pine, to improve management and protect the species. The continuation of interdisciplinary collaboration will be beneficial in advancing this research and aid in the development of future management strategies.

Radial growth and water use during the spring growing season (April -June) in restored vs. control ponderosa pine forests, Arizona

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Abstract: The semiarid U.S. southwest is experiencing fast temperature rises, leading to recurring heat waves, earlier snowmelt, and worsening drought conditions. Specifically, ponderosa pine (*Pinus ponderosa*) forests in northern Arizona depend primarily on winter precipitation stored in deep soil layers as their main water source, particularly during the summer dry season. Land -use changes in the 1870's –driven by fire suppression, removal of Indigenous stewardship, grazing, and logging – transformed landscapes from open stands into dense thickets, exacerbating competition for below-ground resources. This project uses two treatments (full restoration and control) at the G.A. Pearson Natural Area (GPNA) in the Fort Valley Experimental Forest near Flagstaff, Arizona, where thinning and low intensity burning were implemented as restoration techniques.

In the fall of 2024, we installed high-resolution temporal sensors in both treatments to measure stem growth and water dynamics (automated point dendrometers), and nearby soil moisture (shallow and deep) of young and old trees. For the 2025 spring growing season (April to

June), we found that the start of soil moisture drawdown was the same across the tree age classes and treatments, but young trees in the full restoration had significantly earlier start dates (~18-30 days) for radial growth. We also found that the onset of radial growth in young trees was related to temperature and light, whereas the onset of growth in older trees was more moisture driven. The collection of data is ongoing through October 2025 allowing us to quantify radial growth and soil moisture dynamics during the remainder of the growth period, including the monsoon season (July-September). Our overall goal is to better understand the environmental and biological controls on tree growth and how that may be impacted by restoration and future climate.

Connecting wildfire recovery and resilience: insights from six fires in the Southwestern United States

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Abstract: Wildfires across the Southwest are occurring more frequently and are causing more damage to communities worsening each year, influencing how communities recover from and become resilient to wildfires. This shift necessitates research that examines interpretations of recovery across diverse local contexts, how social and ecological recovery differ by location, and understandings of resilience and fire, including interviewee perceptions of their area's ability to prepare for future fire events. We conducted semi-structured interviews (n=57) were conducted with key informants affected by six recent wildfires across Arizona and New Mexico to better understand how residents and professionals affected by six fires across Arizona and New Mexico from 2014-2021 over different vegetation vary in their experiences with and approaches to wildfire recovery and resilience. From these interviews four major themes emerged: uncertainties about place-based resilience; how resilience is used to describe adaptive capacity; social apprehension towards reintroducing fire to the landscape; and uncertainties about how impacts from future fire events impact resilience. Understanding how stakeholders perceive their resilience towards future fire events is an important step towards shifting perceptions about fire on these Southwestern landscapes. This presentation will explore findings from the semi-structured interviews about varying perceptions of resilience between land managers and residents and stakeholders' interpretations of recovery trajectories for each fire. We conclude with the next steps for this research.

Documenting perceptions of resilience after wildfires across social and ecological contexts: Lessons learned from four workshops in the Southwest

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Abstract: Social and ecological recovery efforts and progress after wildfire interact with one another to influence adaptation to future fire events. Combinations of different recovery efforts vary across fires, communities, and landscapes depending on local capacity, ecological outcomes, funding, and collaboration among other factors, and lead to varied perceptions and practices related to resilience. Few efforts have sought to document the variations in these conditions over time and space, underscoring the need for methodologies that examine understandings of resilience at larger scales after wildfire. This presentation summarizes the process of conducting half-day workshops after four wildfires in Arizona and New Mexico: the 2018 Ute Park, 2020 Bighorn, 2021 Telegraph, and 2021 Backbone Fires. Workshops involved both semi-structured discussion and interactive mapping activities to determine areas with different resilience and the factors driving those variations. Fire history, fuel treatments, fire behavior, and willingness to implement regulations and codes surfaced as common resilience drivers across locations. Participants gravitated towards mapping ecological resilience, while the lack of spatial clarity associated with social resilience indicated limited utility and accuracy for broader systems-based mapping efforts. We conclude with overarching lessons learned from our workshops, including reflections on factors driving variations in resilience across study locations, insights on gathering resilience-related data, and methodological considerations for workshops with mapping activities.

Wood For Life: A Forest Service Perspective

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Abstract: Beginning as a surplus of non-saw grade quality timber, Wood For Life evolved to fulfill a need of the Forest Service and the surrounding community. The excess wood created from silvicultural efforts to thin the forest poses a dilemma for fire managers. By partnering with local organizations and embracing policy that benefits the public, Wood For Life is able to accomplish multiple objectives. Removal of large firewood boles from slash piles reduces resonance time and prevents soil sterilization. After the closure of the Kayenta coal mine, an uptick in demand for firewood was seen as many had to transition to a new fuel source to heat homes. This energy demand was able to be met by offering fuelwood for free that was being created in excess from forest restoration projects happening on the Coconino. As demand continued to grow, relationships began to form in response to the need for more firewood and wood hauling. Indigenous fuel crews saw an increase in activity as they rose to support their communities by performing hand thinning operations across the Coconino. Forest restoration projects obtained greater support and a more streamlined implementation process as these projects benefited the community by reducing fire risk and supplied the much-needed energy source.

Management willing and the creek don't rise: Assessing uncertain futures in Colorado River reservoirs on inundated cultural and paleontological resources

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Abstract: Reservoir impoundments by dams provide needed water resources to populations worldwide, but they also directly impact the condition and preservation of cultural and paleontological resources. Initial submergence by water and burial by sedimentation during reservoir filling can cause physical and chemical alterations that are detrimental to resource condition, although some of the greatest impacts are observed during periodic reservoir fluctuations caused by changes in the volume of stored water. Specifically, the near-shore environment within a reservoir is subject to high energy wave action that can erode and remove resource components, and fluctuations in water levels influence soil dynamics, sediment stability, and gully adjustments that further degrade resources. We apply commonly available spatial datasets, such as geologic maps, remote sensing imagery, and digital topobathy data, as well as known resource locations to identify 1) where resources are at the greatest risk from changing reservoir levels, and 2) how future conditions within the reservoirs might impact resource preservation. We focus on Lake Powell and Lake Mead, the two largest Department of Interior managed reservoirs in the USA. For both reservoirs, we developed spatially explicit estimations of near-surface erosion potential, termed a hazard rank, that we evaluated using published topographic datasets and identification of significant visual changes within aerial imagery collected before inundation and in 2022 when reservoirs were low owing to drought and water management policy decisions. We combined the validated hazard rank with probabilities for resource distributions to create a categorical estimate of resource impact for shoreline contours from full pool to the reservoir bed. We use historic observations of reservoir water surface elevations to evaluate the range of potential resource impacts within each reservoir. The models will next be applied to assess how future Colorado River management decisions might impact resource preservation.

Capacity and limitations of drone-based monitoring for plant population dynamics in sagebrush steppe

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Abstract: High-resolution aerial imagery has revolutionized the ability to map and monitor plant populations at spatial scales that match the scope of ecological disturbance and management in dryland systems. However, remotely sensed data are fundamentally different from field observations, and subject to distinct sources of error, including misclassification, missed detections, and double-counting of individuals. These observation errors can bias ecological inference and must be explicitly modeled to extract meaningful population parameters such as abundance, growth, and recruitment.

State-space modeling frameworks offer a powerful solution by disentangling ecological processes from observation processes. These hierarchical models account for both measurement error in data and biological variation in plant demography, enabling robust estimation of population dynamics. We demonstrate how integrating ground-based validation

with remote sensing from Uncrewed Aerial Systems (UAS) platforms can calibrate detection probabilities and correct for false positives and negatives in shrub counts. In sagebrush steppe ecosystems—where recruitment after fire is highly variable in space and time—this approach yields spatially continuous estimates of population abundance that outperform raw image-based counts.

By addressing the unique challenges of UAS data, state-space models unlock the full potential of remote sensing for ecological inference. This is especially critical in imperiled drylands, where management decisions often occur across thousands of hectares and where plant populations respond nonlinearly to disturbance and climate drivers. Our work highlights the need for statistical models that explicitly incorporate observation uncertainty to scale up population ecology, bridging the gap between field ecology and the spatial extent of land management.

Dye tracing below the North Rim of Grand Canyon National Park reveals continued evidence of spatiotemporal heterogeneity of the groundwater system

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Abstract: It is imperative to understand the groundwater system below the North Rim of Grand Canyon National Park to inform park water infrastructure projects and protect sensitive spring ecosystems. Dye tracing addresses this objective by delineating flow paths, rates, and source areas from sinkholes on the North Rim to springs in the canyon and by assessing any annual changes in these characteristics. Food-grade, fluorescent dyes were injected into three sinkholes on the North Rim prior to snowmelt in April 2024 and into two sinkholes in March 2025. Three of these five sinkholes were repeated injection sites from those in 2015-2017. Charcoal receptor packets were placed at 43 spring and stream sites in the canyon prior to the 2024 injection and are exchanged every 4-8 weeks to determine if, when, and where dyes emerge. Results support previous evidence for snowmelt entering long-term storage but also suggest annual heterogeneity of flow paths. Positive detections of three of the five dyes have occurred at springs in the park's new drinking water source, Bright Angel Creek, first during the 2024 snowmelt pulse and now continuously through baseflow. Two of these dyes injected into repeated sinkholes have been detected at different springs, suggesting changes in flow paths from year to year. NASA satellite and game camera imagery of snowpack on the North Rim, NOAA snow depth data, and the earliest detections of dye at springs indicate a travel time from infiltration to discharge of 2-26 days. The timing, location, and duration of dye detections will be used with snowpack and groundwater flow data to compare flow paths across different snowpack conditions, to delineate source areas, and to calculate annual water budgets at springs. Dye receptors will continue to be exchanged and analyzed for all five dyes through 2025 and possibly into 2026 depending on continued detections.

How innovative Regulations, Policy, and Plans can support a more Fire Adapted Community

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Abstract: Regulations, Policy, and Plans are a primary component of the Fire Adapted Communities Learning Network framework. Turning this framework into action, the Wildland Fire Mitigation and Management Commission developed 148 federal policy recommendations for mitigating wildfire risk across both built and natural environments. While the US Congress is currently drafting legislation that includes nearly a half of the Commission recommendations, local governments can be effective leaders by developing and implementing innovative wildfire risk reduction actions. This discussion will focus on how the Flagstaff Fire Department is working towards a more Fire Adapted Community by supporting the Commission recommendations and developing new Regulations, Policy, and Plans and at the local government level.

Wildfire risk reduction across the natural and built environments: Local solutions and long-term strategies

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Abstract: Since its formal integration in 1997, the City of Flagstaff's Wildland Fire Management Program has become a regional model for proactive wildfire risk reduction. Grounded in the National Cohesive Wildfire Management Strategy, the program leverages forest stewardship, code enforcement, community outreach, and ecological restoration to protect lives, property, and ecosystems.

This presentation explores the city's holistic approach, structured around the "5E's +1 of Wildfire Community Risk Reduction": Enforcement, Engineering, Emergency Response, Education, Economic incentives, and Enabling peer communities. By combining scientific forest management with civic planning, community education, and operational preparedness, Flagstaff is advancing a fire-adapted future.

The presentation will share lessons from Flagstaff's experience in navigating inter-agency coordination, planning in mixed-ownership landscapes, and leveraging local policy and mapping tools to advance fire-adapted communities.

Partnerships and community engagement in and around Santa Fe communities

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Abstract: Community wildfire adaptation is a highly local and place-based endeavor that almost always requires ingenuity, perseverance, and flexibility. Across two decades in city government with the City of Santa Fe, successful wildfire adaptation requires navigating politics, bureaucracy, and opportunity to create landowner pathways and solutions. Additionally, it requires a vision to see and work beyond silos, jurisdictional barriers, and

funding restrictions. A recipe for successful adaptation is resilient partnerships, continuous learning and teaching, and program innovation.

Exploring climate and competition impacts on Emory oak growth

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Abstract: Emory oak (*Quercus emoryi*) is a culturally significant species to the western Apache tribes as a nutritious food source and for ceremonial practices. In recent decades, some western Apache elders have reported a decline in Emory oak populations. In this study, we use dendrochronological techniques to evaluate the climate response and growth variability of Emory oak growing at sites in northern Arizona, near the northern limit of the species range. Our results showed that Emory oak growth is strongly positively influenced by precipitation, with winter moisture playing a critical role in sustaining growth. Temperature and vapor pressure deficit (VPD) are negatively correlated with tree growth, suggesting that continued climate warming could stress Emory oak populations. We found that oaks growing with fewer competitors had consistently greater basal area growth by approximately 60% when compared to oaks with more competitors. Given that competition for water resources reduces growth, particularly in high-density stands, thinning treatments in dense stands could help increase oak growth. These findings suggest that targeted management strategies, including selective thinning, could improve Emory oak status.

From River to Rim: Nutrient Selection in Diets of Reproductive Female Bats Within Grand Canyon National Park

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Abstract: Grand Canyon National Park is a refuge for twenty-two bat species, making it the most species-rich national park for bats in the United States. The park's extreme elevational gradient creates distinct ecosystems that support this exceptional diversity. Despite the ecological significance of this community, bat phenology, particularly in reproductive females, remains poorly understood. Long-term acoustic monitoring in the park demonstrates a distinct increase in bat activity along both the Colorado River and canyon rim during the reproductive season. While bioacoustic surveys provide valuable insights into species presence, spatial distribution, and temporal activity, they cannot resolve sex-specific habitat use or the nutritional drivers of resource selection. This limitation highlights the need for complementary approaches, such as dietary analysis, to better understand the ecological and physiological factors shaping reproductive female behavior.

We propose a novel dietary analysis to investigate the nutritional ecology of reproductive female bats. Specifically, this study will assess whether insectivorous females consume significant proportions of omega-3 highly unsaturated fatty acid (HUFA)-rich aquatic insects during the maternity period across contrasting elevations. Using DNA metabarcoding with high-throughput sequencing (HTS), we will identify insect taxa from guano collected from reproductive females. Dietary profiles will be used to quantify the relative contribution of aquatic versus terrestrial insects, the latter of which are typically deficient in HUFAs. By comparing aquatic-to-terrestrial prey proportions across elevations, we aim to determine whether reproductive females preferentially exploit HUFA-rich aquatic insects, an essential nutritional resource for reproductive success.

Applied Social Science for Decision-Making: Examples and Lessons Learned from the Southwest

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Abstract: In recent decades, there has been an ongoing shift in the way research is developed in relation to decision-makers or other potential end users of scientific information. The academic community has examined and defined the development and application of research along a spectrum from the linear delivery of research to society to deeply engaged co-production of knowledge with researchers and decision-makers participating in every step of the research process. The attention to this topic represents a broader need for scientific information to be relevant and actionable to societal needs. There are numerous ways for this to be accomplished, and the success of different approaches to this task is often context dependent. This presentation will provide examples from different approaches to developing and applying social science information for decision-making in the Southwest. Examples from the presentations in this session will be highlighted, as well as a handful of other relevant examples, with the overall purpose of providing lessons learned for the scientific and decision-making communities about developing research that can be effectively applied in decision-making.

Indigenous Ways of Doing: Knowledge Systems Rooted in Community and Culture

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Abstract: Indigenous People have long been leading efforts to work in tandem with the environment to care for their communities and non-human relatives, and address threats such as flooding, fires, coastal erosion, drought, and much more. The arrival of settlers brought the implementation of new ways of managing the land and people including the displacement of people leading to the disruption or elimination of established ways of caring for the environment. The focus on implementing Western land management practices often left out or ignored Indigenous practices (i.e. cultural burning), people and knowledge. Although Indigenous people have been doing the work of adapting to environmental threats caused by

humans and nature, they have not always been acknowledged in mainstream media including scientific journals, national and global reports, and academic papers and research. The Institute for Tribal Environmental Professionals (ITEP) and their Tribal Wellbeing for Seven Generations Program has been facilitating projects, workshops, and resources that would benefit Tribes and Indigenous communities as they address climatic and non-climatic threats. ITEP will highlight projects including the Status of Tribes and Climate Change (STACC) Reports.

Innovate, excite, connect: Creating outreach solutions to expand research audiences

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Abstract: Science communication can often be the kryptonite of many researchers and scientists. Identifying and communicating the importance and scope of science projects can be a driving force of engagement and advocacy from stakeholders and the general public. Most laypeople may not understand the results and findings listed in technical reports and require a level of translation to connect the science to their lives. In this talk, I would like to discuss examples of alternative outreach products to further inspire curiosity around the data we collect. It is my hope that researchers and scientists are encouraged to incorporate some kind of outreach product in accompaniment with their peer reviewed papers and analyses whenever possible.

- 1) Utilizing social media or local publications to advertise new online tools, interesting photos, or publication summaries. The Boatman's Quarterly Review is a Grand Canyon publication including poetry, photographs, drawings, interviews, book reviews, and science stories.
- 2) Creating and updating online webpages to make them more user friendly and interactive. New examples include USGS Science Collaboration Portal for the Colorado River Basin, Uranium and Arsenic Groundwater in Grand Canyon Mapper, Arizona Groundwater Explorer.
- 3) Creating approachable outreach materials and events that have multiple uses and values. Use art to visualize science. Create postcards with historic or captivating images. Utilize QR codes. Make things that won't just get thrown away after the event is over.

Climate means drive trait plasticity more than climate variation or predictability in Fremont cottonwood

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Abstract: The ability to predict trait responses under altered environments is becoming increasingly important for the management of critical ecosystems, especially in the American Southwest where hot, prolonged droughts have led to widespread forest dieback. Fremont cottonwood is a foundation species structuring Southwestern riparian forests and the climate resilience of these forests may largely depend on how well cottonwoods track changing environments through genetic adaptation and/or phenotypic plasticity. Given the rapid pace of climate change in the Southwest and long generation time of forest trees, phenotypic plasticity likely plays a crucial role in the species' climate response and population persistence. Across heterogeneous landscapes, different plant species and populations exhibit varying levels of phenotypic plasticity, both because of underlying genetic variation determining the capacity to evolve plasticity and because their environments may select for or against trait plasticity. Using 16 populations of Fremont cottonwood planted in three common gardens across a broad environmental gradient, we tested the theory that greater plasticity evolves under more variable, predictable environments. Climate data was extracted from each population source to test phytochemical trait plasticity against source population climate mean, variance, and predictability. We found when all plasticity-climate models were summarized, climate means explained most of the variation in phenotypic plasticity, followed by climate variability, and finally climate predictability. We also found precipitation variables were more important in explaining plasticity compared to temperature variables. Our results challenge the theory that environmental variability and predictability are most important to the evolution of plasticity. Taken together, these insights into the climatic drivers that promote greater population plasticity may improve the ability to predict where riparian forests will have the plastic capacity to survive extreme climate change events.

Leaf hyperspectral reflectance predicts morphological traits, hybrid status, and sex of foundation trees

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Abstract: Hybrid zones between tree species generate novel traits that affect ecosystem processes and the structure of dependent communities. However, monitoring the distributions and success of hybrids across changing environmental gradients on the landscape is challenging. We evaluated the efficacy of leaf hyperspectral reflectance data to discriminate among two parental species and their naturally occurring F1 and backcross hybrids (i.e., cross types) in a large hybrid zone in the American Southwest. We surveyed a common garden of two species of cottonwood (*Populus fremontii* and *P. angustifolia*) and their hybrids collecting leaf reflectance across visible, near infrared and shortwave infrared wavelengths (500 nm – 2400 nm) as well as morphological traits known to distinguish these species (leaf shape and

thickness). We found that cross types had distinct leaf reflectance, particularly at some wavelengths and consequently, could predict both cross type and tree sex with an equivalent accuracy to leaf morphology (87% accuracy). High resolution monitoring of traits via leaf reflectance is much more efficient to collect than processing many leaf samples in a laboratory with traditional methods. This is particularly important as the geographic ranges of hybrids and their parental species are expected to shift in response to climate change. We show that leaf spectra are a robust tool for both monitoring survival of tree types and sexes with distinct environmental sensitivities and predicting ecological consequences via traits and spectral indices tied to tree stress responses under changing conditions.

Mycorrhizal soil inoculum along a grazing disturbance gradient in dryland systems

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Abstract: Advances in soil ecology have improved our understanding of the influence the soil community exerts on the establishment and survival of plants. Arbuscular mycorrhizal fungi (AMF) are soil microbes that provide plant hosts with benefits such as drought tolerance, disease resistance, and access to nutrients. We wanted to investigate if the abundance of AMF in dryland systems differed depending on grazing disturbance history, and if the translocation of soil inoculum from less disturbed to more disturbed areas in the same area can improve plant growth and survivorship. To do this, we conducted a greenhouse bioassay using plots established for RestoreNet 2.0, a WSARE-funded collaboration utilizing field sites across the Great Basin and Colorado Plateau.

We grew the native grass *Bouteloua gracilis* in soil collected from grazed (“disturbed”) and grazing-excluded (“reference”) paired plots at six locations and measured the abundance of AMF in their roots, as well as their above- and below-ground biomass. We predicted that AMF would be more abundant and that *B. gracilis* would grow larger in reference than disturbed plots regardless of site. We found that the abundance of AMF was greater in reference than disturbed plots at 4 of the 6 sites in partial support of our prediction. Across all sites and disturbance levels, plant biomass was positively correlated with AMF abundance. These results suggest that *B. gracilis* benefits from increased AMF but that AMF abundance is not always predicted by grazing disturbance. Using these preliminary data, we implemented a field installation of soil inoculum from reference sites to test its effect on seeded plant success on disturbed sites in Summer 2024. This year, we will collect and analyze plant and soil data 1-year post-treatment to explore its use as a technique to boost restoration success.

The effect of encapsulating fire mosses in dissolvable capsules on fire moss establishment success

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Abstract: Forest management practices and climate change have resulted in more frequent, higher intensity fires in southwestern North America. High severity burns produce stark alterations to soil physical properties and microbial communities, often resulting in low vascular plant establishment success. Conversely, some moss species, often referred to as ‘fire mosses’, are identified as high abundance early colonizers of severely burned soils. Naturally occurring fire mosses have been shown to improve topsoil stability and microbial community composition of soils affected by high intensity wildfire. We aim to supplement post-fire vascular plant restoration efforts by developing low-cost technologies that reestablish native fire mosses post fire using greenhouse cultivated inoculum. Prior research has isolated the moss species *Bryum argenteum*, *Funaria hygrometrica*, and *Ceratodon purpureus* as the primary fire moss species in ecosystems near Flagstaff, Arizona. As such, we are utilizing these three moss species as our focal organisms for our restoration treatments. Here, we present data describing the effect of encapsulating cultivated moss inoculum in dissolvable pill capsules on establishment success. Currently, we are analyzing the results of a four-factor controlled field experiment designed to identify the effect of capsule material, abscisic acid, diatomaceous earth, and hydrogel additives on clonal moss inoculum establishment rates. Preliminary results suggest that variance in establishment success of cultivated moss is best described by microclimatic factors influenced by pellet material. Additionally, we are monitoring an experiment designed to quantify establishment of the focal fire moss in two nearby but climatically distinct sites within the Preacher Fire burn scar in the Tonto National Forest near Payson, Arizona. With this experiment, we will identify the effects of topography and climate on encapsulated inoculum establishment and, in turn, the effect of moss establishment on characteristics of soil health, microbial community, and erosion.

Assessing quaking aspen (*Populus tremuloides*) extent, health, and mortality in northern Arizona using earth observations

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Abstract: Quaking aspen (*Populus tremuloides*) populations in northern Arizona face mounting environmental stressors, including changing temperature and precipitation patterns, oystershell scale infestations, and ungulate browsing. As an iconic and ecologically beneficial tree species, land managers prescribe various treatments to conserve and support healthy stands of aspen. In partnership with the US Forest Service, National Park Service, Arizona Department of Forestry and Fire Management, and Northern Arizona University School of Forestry, the NASA DEVELOP team investigated the feasibility of using Earth observations to assess aspen extent, health, and mortality across northern Arizona. To classify aspen extent and health, the team used field data and Earth observations from Landsat 8 Operational Land

Imager (OLI) & Thermal Infrared Sensor (TIRS), Landsat 9 Operational Land Imager 2 (OLI-2) & Thermal Infrared Sensor 2 (TIRS-2), Sentinel-2 Multi-Spectral Instrument (MSI), Global Precipitation Measurement (GPM) Integrated Multi-satellite Retrievals for GPM (IMERG), ISS ECOSystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), and ISS Global Ecosystem Dynamics Investigation (GEDI). Two case studies of recent wildfires—the 2019 Museum Fire and the 2022 Pipeline Fire—were also analyzed to evaluate the influence of pre-fire forest conditions on burn severity and post-fire aspen regrowth. The results of this project provide actionable insights for land management and aspen conservation planning, revealing trends in aspen coverage and health over time, while supporting the adoption of satellite-based workflows into operational landscape monitoring.

Effects of changes in fuel structure on potential fire behavior in pinyon-juniper woodlands

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Abstract: Pinyon pine (*Pinus edulis*) has experienced large-scale mortality in recent decades due to extreme drought, insect outbreaks, and a changing climate, reshaping surface, ladder, and canopy fuels in pinyon-juniper woodlands that provide carbon storage, nesting habitat for migratory birds, and culturally essential pinyon nuts. Because many persistent pinyon-juniper systems historically burned infrequently, with return intervals of up to 400 years or more, even modest changes in fuel can influence potential fire behavior relevant to management. This project assesses the impact of recent mortality on simulated potential fire behavior by modeling structural changes using the Fire Dynamics Simulator (FDS). Plot data, along with mobile and terrestrial LiDAR from 10 sites across a pinyon-juniper mortality gradient in northern Arizona, are used to parameterize three-dimensional fuels and simulate fire under varying structural conditions. This poster outlines our methodological framework and current project status, emphasizing that the results reflect physics-based simulations of potential fire behavior rather than inferences about long-term fire regimes.

Identifying areas of high restoration potential following Utah juniper (*Juniperus osteosperma*) encroachment

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Abstract: Utah's diverse landscapes support a complex and dynamic ecosystem. The encroachment of woody invasives, such as Utah juniper (*Juniperus osteosperma*), disrupts this ecosystem, increasing wildfire risk and threatening ecosystem processes, biodiversity, and watershed health. To address the concern of juniper encroachment, the Utah Department of Natural Resources' Division of Wildlife Resources funds strategic tree removal efforts to restore habitat and improve ecological resilience. In support of habitat restoration efforts, the

NASA DEVELOP team leveraged optical imagery Landsat 5 Thematic Mapper (TM), Landsat 8 Operational Land Imager (OLI), Landsat 9 OLI-2 to derive vegetation indices including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI), and Soil Adjusted Vegetation Index (SAVI) to map the invasive tree. These data, along with topographic information from the Shuttle Radar Topography Mission (STRM) were incorporated into distribution maps of Utah juniper and areas of high fuel loads that may lead to increased fire risk. The team overlaid Utah juniper distribution maps and high-risk fuel maps to produce a restoration potential map of Utah to inform the prioritization of invasive species management activities and funding allocation for future habitat restoration through the Utah Department of Natural Resources' Watershed Restoration Initiative.

Hydrogeologic perspective on uranium mining near Grand Canyon informed by regional hydrotectonic studies

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Abstract: The Grand Canyon provides a dissected view of the aquifers of the Colorado Plateau. Stacked sandstone and karst aquifers are vertically connected by a framework of faults, fractures and breccia pipes (structural conduits) creating a complex groundwater network. Our recent review (open access: <https://doi.org/10.1146/annurev-earth-080723-083513>) synthesizes datasets from UNM, USGS, NPS, and other academic workers. Hydrochemical variations serve as natural tracers. North Rim (N-Rim), South Rim (S-Rim), and far-west springs have different stable isotope fingerprints, reflecting different mean recharge elevations. Variation within each region reflects proportions of fast/slow aquifer pathways. The upper aquifer (C-aquifer comprising the Kaibab, Toroweap, Coconino, and Supai formations) does not have a well-defined regional lower confining unit and geochemical evidence indicates hydrological connection to the lower R-M aquifer (Redwall-Muav) by structural conduits and locally by mining activities. Stable isotope and other tracers show that both aquifers contain a similar range of hydrochemistry and model ages indicating that a component of very young (decades old) water mixes into both aquifers and that they are connected by structural conduits. Natural and anthropogenic tracers show that recharge can travel two km vertically and tens of kilometers laterally in weeks to months via such conduits to mix with older karst baseflow. Six decades of Transcanyon Pipeline activity and infiltration of leakage and effluent along the Bright Angel fault can be traced widely in S-Rim groundwaters. The Pinyon Plain (formerly Canyon) mining disturbances have created miles of water pathways that allow oxygenated waters to penetrate and mobilize uranium and arsenic from ore bodies that are distributed vertically from the Coconino to the Supai formations. The underlying R-M aquifer is at present poorly monitored. Given the risk of irretrievable harm, uranium mining threats demand better monitoring and application of hydrotectonic concepts.

Impacts of Powerline Rights-of-Way in Three Arizona Plant communities

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Abstract: With the decline of pollinators worldwide, powerline rights-of-way (ROWs) have the potential to provide additional habitat to support pollinator populations. Powerline ROWs are established through clearing of tree canopy cover and woody fuels, providing open strips that contain flowering plants that provide important resources for pollinators. We sampled plants and pollinators on Salt River Project powerline ROWs across three vegetation types in Arizona: ponderosa pine forest, pinyon-juniper woodlands (PJ), and Sonoran Desert. Our aim was to determine how pollinator habitat varied on and off the ROW as well as between vegetation types. We collected data at 27 sites in spring to early fall over three years from 2021 to 2023. Each site contained two 50 m transects, one located beneath and perpendicular to the powerline (on-ROW) and another beginning 25 meters into the adjacent natural area (off-ROW). We found that plant richness and abundance were higher on powerline ROWs than in adjacent natural areas within the ponderosa pine forest vegetation type but not within PJ woodlands or Sonoran Desert. Pollinator richness and abundance followed the same pattern, with higher richness and abundance on-ROW than off-ROW in the ponderosa pine forest but not the PJ woodlands or Sonoran Desert. Richness and abundance of both plants and pollinators also varied by sampling season and year. The results of this study will be able to assist ROW managers in maximizing pollinator resources on powerline ROWs even as they meet their other management objectives.

The desert pallid bee and its nectar plants predicted to respond positively to a warming climate in the southwest desert

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Abstract: Wild bees are vital for the pollination of native plants and crops, providing essential ecosystem services. Climate change is known to impact biodiversity and species distributions, but insects adapted to desert ecosystems may exhibit unique physiological, behavioral, and evolutionary responses. The desert pallid bee (Apidae: *Centris pallida*) is a solitary bee that nests in soil and is native to the arid southwestern United States and northern Mexico. During adulthood, it primarily forages on yellow palo verde (*Parkinsonia microphylla*), blue palo verde (*Parkinsonia florida*), and desert ironwood (*Olneya tesota*). Here, we used MaxEnt to estimate the current and forecasted overlapping geographically suitable habitat between *C. pallida* and all three nectar plants essential for adult and larva survival. MaxEnt is a species distribution model based on machine learning that is frequently used in ecological and conservation studies. We predicted potentially suitable areas for each species for the years 2000-2021 and 2021-2040 using the current distribution model and climate projections with moderate CO₂ levels. We estimated a continued spatial alignment in the suitable area of *C. pallida* and its host plants, with a 70% increase in the range overlap area, although shifted to higher average altitudes and a slight northern latitude expansion. We also discuss how future research may confirm the findings using more rigorous model selection criteria or an ensemble

with other models such as the GAM or Random Forest. These findings may provide insight to stakeholders on the conservation needs of desert-adapted pollinators.

Understanding climate impacts on cone production and the need for comprehensive pinyon jay population monitoring in the Dinétah (Navajo Nation)

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Abstract: The pinyon pine (*Pinus edulis*) ecosystem on Dinétah (Navajo Nation) is facing growing pressures from climate change. We focus on highlighting how changing climate patterns drive annual cone yield, which affects the availability of food resources for the pinyon jay (*Gymnorhinus cyanocephalus*), a key seed-dispersing bird species. Cone scar records show decreases in production in dry years and immediately after a fire. We discuss the pressing need for more rigorous monitoring of pinyon jay populations as the current lack of data limits conservation and wildlife management planning. We summarize recent data collection efforts on Dinétah using the Great Basin Bird Observatory's community science program. Additionally, the Diné people have multiple cultural uses of these two interwoven species that can inform their changing distribution patterns across the landscape. By combining cultural and ecological knowledge, this research is essential for developing comprehensive management practices that honor Indigenous Knowledge while informing climate-resilient strategies.

Identifying *Phragmites australis* subspecies using genetic markers

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Abstract: *Phragmites australis* (common reed) is a wetland and riparian perennial grass with native and nonnative subspecies found throughout the United States. Native *Phragmites* (*P. a. ssp. americanus*) is ecologically and culturally important. It has practical and ceremonial functions for many southwestern U.S. Indigenous people and appears in the emergence stories of some. Invasive common reed (*P. a. ssp. australis*) is one of the most influential invasive species in wetlands and has resulted in loss of the native subspecies in some areas. Recent invasions have occurred in the western U.S. risking unique wetland habitats. The nonnative *Phragmites* has been documented upstream and downstream of the Glen and Grand Canyon region, but the level of invasion in that region is unknown. We identified subspecies using DNA extracted from plant tissue from locations (n=84) across the Colorado River corridor and in tributaries. Real-time quantitative polymerase chain reaction (q-PCR), which uses target

DNA sequences for rapid identification, was used to determine each sample's subspecies. Two stands of nonnative *Phragmites* were identified near the confluence of the Paria and Colorado Rivers and two in Arches National Park. All other stands were native *Phragmites*. Identification of nonnative *Phragmites* is essential in management of both native and nonnative stands. Potential management actions include mechanical removal and herbicide, which are expected to be developed and coordinated with Indigenous partners. This project seeks to further investigate genetic similarity between native *Phragmites* populations through microsatellite markers, which can determine genetic similarities based on small replicates of DNA.

Using moisture sensor data to improve understanding of water availability in dryland restoration contexts

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Abstract: Restoration in drylands is difficult, and often shows poor outcomes, but as more data become available from sensor networks, trait databases, and other sources, opportunities are emerging for developing predictive frameworks that can improve outcomes for target species and ecosystem states. In drylands, water is of paramount importance and thus it is crucial to gain an understanding of both required water availability for particular organisms, and the nuances of water availability at a site. However, understanding water availability beyond basics like total precipitation can be difficult due to the technical challenges of going from raw sensor data to relevant metrics such as soil water potentials over time and depth of water acquisition. Here we present an analysis of moisture sensor data from a bajada shrubland site at the Jornada Experimental Range in which we use soil water release curves to create a “water sufficiency curve” for quantification of how often moisture at particular depths is sufficient to support active physiology in plants and biocrusts. These curves show that surface moisture levels often drop well below water potentials that can support any organism, suggesting that plants that are active during dry periods have access to deeper water. We also show how such analyses can contribute to quantifying features such as the length of time during which photosynthesis can occur. In the case of biocrusts at the site, we estimate that conditions are adequate for photosynthetic activity ~18% of the time, a value of relevance to biocrust restoration as well as for goals such as scaling C flux contributions. These results suggest some useful strategies for working with sensor data in restoration contexts and highlight the potential of melding soil moisture data with physiological parameters to improve restoration outcomes.

Understanding mechanisms of big sagebrush (*Artemisia tridentata*) survival and growth to promote its management under current and future climate conditions in the Colorado Plateau

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Abstract: Big sagebrush (*Artemisia tridentata*) populations are at risk of decline in the Colorado Plateau due to climate change. Increased temperatures and altered precipitation regimes may create unfavorable conditions for sagebrush, which are already on the southern end of their historic range. Increasing temperatures are predicted to have negative impacts on sagebrush at hotter, drier sites, but positive impacts at cooler, wetter sites. Thus, elevation may be an important predictor of sagebrush survival and growth in this region. A significant proportion of the annual precipitation on the Colorado Plateau comes during the summer monsoon, and little is understood about how monsoonal moisture impacts sagebrush survival and growth. Our study aims to understand 1) how big sagebrush densities differ across an elevational gradient, and 2) how predicted changes in monsoonal patterns interact with winter drought conditions to impact sagebrush survival and growth. To accomplish the first goal, we sampled shrub density, vegetation cover, and leaf tissue in 66 plots spread out along an elevational gradient around San Juan Co., UT, in May/June 2024. To accomplish the second goal, we established big sagebrush plants in a common garden experiment at the Canyonlands Research Center in San Juan Co., UT, in May 2023. Rain-out shelters were placed over the plots for 12 weeks during the summer and then again during winter to simulate two different monsoonal precipitation patterns, winter drought, and winter herbivory in a full factorial design. Sagebrush densities showed a positive linear relationship with elevation, this effect was stronger with sagebrush < 50 cm tall than for sagebrush > 50 cm tall, but was significant for both size classes. In the common garden, winter drought had a negative effect on midday stem-water potential compared with non-droughted plots. Summer and winter precipitation treatments showed no significant effects on sagebrush height or volume.

Assessing environmental drivers of C3/C4 grass species occurrence in national parks across the western United States

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Abstract: The western United States hosts diverse landscapes and iconic national parks that attract millions of visitors each year, spanning picturesque deserts, open grasslands, and snow-covered mountaintops. The community composition of each park is key to its ecological health. To protect and conserve these ecosystems, the National Park Service has gathered long-term data through their Inventory and Monitoring (I&M) program on “vital signs” of each park’s wildlife, water resources, soils, and vegetation. In this study, we synthesize long-term data from I&M networks in the western United States via flexible Bayesian models, with a goal of informing management of national parks. Using 20+ years of vegetation and climate data from five networks, 29 parks, and ~1375 plots, we hierarchically model the probability of presence of focal C3 and C4 native perennial grasses to evaluate factors governing changes in their occurrence across time and space. We integrate data from multiple monitoring protocols, including ocular (quadrat) and line-point intercept estimates of occurrence and cover. Our models include a stochastic antecedent design, allowing us to quantify legacy (lagged) effects of environmental conditions. We account for uncertainty in the imperfect detection of species based on key plant traits that impact detection probability. Results indicate that the presence of key grass species is highly dependent on antecedent conditions including temperature, precipitation, and vapor pressure deficit, and that these effects significantly differ between photosynthetic pathways. We identify similar decreases in C3 grasses across national parks with varied terrain and climate. Our synthesis of data from different I&M networks provides insights into the drivers of biodiversity across large spatial and ecological gradients. This research further demonstrates the value of I&M data for identifying trends and changes in plant community composition over time.

Seasonal Drivers of Carbon Flux Variability in Southwestern Ecosystems

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Abstract: Understanding how carbon dynamics of dryland ecosystems shift with climate is critical for anticipating future carbon balance in the southwest U.S. We analyzed eddy covariance data from 2007–2024 across six major biomes along the New Mexico Elevation Gradient (C4 desert grassland, creosote shrubland, juniper savanna, piñon-juniper woodland, ponderosa pine, and subalpine mixed conifer forest) to assess trends in gross primary production (GPP), ecosystem respiration (RE), and net ecosystem exchange (NEE).

Flux trajectories varied by biome. GPP declined at piñon-juniper and mixed conifer sites, while RE increased in creosote shrubland and declined in forests. Most sites remained carbon neutral, but three showed increasing NEE, indicating weakening sinks: creosote shrubland, piñon-juniper woodland, and subalpine mixed conifer forest.

Drivers of change differed seasonally and by site. Piñon-juniper woodlands showed full-year declines in GPP and RE, especially in spring and monsoon. The conifer forest saw declining

spring GPP and rising winter RE. Creosote shrubland had no growing-season trends, but winter RE increased, suggesting subtle seasonal shifts.

Importantly, even ecosystems with stable NEE exhibited strong climate sensitivity. Several sites with no long-term trend in NEE showed high seasonal correlations with SPEI. Monsoon responses were widespread and often linear at low elevations, while nonlinear responses emerged in forests and shrublands. In spring, only high-elevation forests showed nonlinear behavior.

These results show that carbon balance is shaped not only by long-term trends but also by seasonal timing and climate sensitivity. Even seemingly stable systems may respond strongly to drought, particularly during the Monsoon. Subtle changes, such as increased winter respiration or spring drought, may tip the balance.

Forecasting carbon dynamics in the Southwest will require models that capture seasonal drought responses, nonlinear behavior, and functional diversity across elevation gradients.

Resident perceptions of smoke from prescribed fire: A case study of two Flagstaff, Arizona neighborhoods

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Abstract: Smoke from forest management activities remains a prevalent concern amongst both land managers and residents. Existing research on resident smoke perceptions of prescribed fire focuses on general experiences and opinions, rather than those specific to particular prescribed fire events. To address this gap in smoke related literature, we conducted a mail-in survey of residents in two Flagstaff area neighborhoods adjacent to two separate prescribed burn events immediately following firing operations. This allowed us to capitalize on heightened memory recall of participants while exploring questions related to their expectations, experiences, and attitudes towards the recent prescribed fire activity. We present preliminary findings from these two neighborhoods, with a focus on exploring (1) perceptions of ideal conditions for prescribed burns and smoke management, (2) communication preferences, including trustworthiness of various sources and the types of information desired, (3) mitigation actions, including health protective behaviors to reduce smoke impacts, and (4) key differences between study areas. We provide recommendations regarding how these findings may be used to develop effective smoke and prescribed fire related communication strategies, promote risk mitigation behaviors to reduce health impacts, and engage residents in opportunities to better understand decision making surrounding smoke and fire management.

Adapting avian monitoring for large-scale native restoration on the Lower Colorado River using Motus and Autonomous Recording Units Technology

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Abstract: The Lower Colorado River Multi Species Conservation Program (LCR MSCP) supports the conservation of covered native mammal, bird, fish, amphibian, reptile, invertebrate and plant species through habitat creation and management, population monitoring, and species research. Due to changes in budget the program has recently changed the methods it uses to monitor avian use of conservation areas. For many years the program employed field crews to conduct intensive on-the-ground monitoring of birds, and other wildlife. This intensive monitoring is no longer possible at the same level of effort and the program has transitioned to a mix of on-the-ground monitoring and automated monitoring. Over the last several years the LCR MSCP has begun using Motus Technology and Autonomous Recording Units (ARU) to monitor for avian use at conservation areas. Motus towers have been established along the river by partner agencies, and these can detect any animal with a nano tag attached to them. This allows for passive detection of animals that are within range of station without needing an observer on the ground to detect them. The program is also deploying ARU, units that record natural soundscapes, and then analyzing those recordings using neural network software to identify species of interest. The use of these automated monitoring methods allows for data to be collected over a large area and at numerous conservation areas, that otherwise would not be possible. This presentation will show how these technologies have been used over the past 3 years. It will also show how the program could use this data, in conjunction with remotely sensed data, to evaluate avian use of conservation areas based on vegetation metrics.

Colorado Plateau Native Plant Materials Production and Use: Challenges and Opportunities

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Abstract: Rim to Rim Restoration, located in SE Utah, has been involved in the planning, implementation and monitoring of habitat and plant regeneration projects for over 2 decades. Only recently have revegetation projects in the upper Colorado Plateau been designed with native plants selected over cheaper and sometimes easier to establish exotic plant materials. This shift is evidenced in the seed and plant selections in Utah Watershed Restoration Initiative projects over the past 15 years.

In 2009 Rim to Rim acquired a 30 acre parcel with water rights along the Colorado River from The Nature Conservancy. Rim to Rim has worked over the past 16 years to remove Russian knapweed and install the infrastructure needed to propagate native plants and biocrusts in an effort to fill some gaps in research and testing facilities in the area, as well as provide a location to explore seed increase with an eye to scaling up production for species currently unavailable commercially. In addition, RRR monitors plants at project sites to explore methods for encouraging both passive and active plant establishment processes.

Challenges for native plant use in plant restoration projects sometimes stem from a lack of understanding of the timelines necessary for plant production, coupled with challenges in procuring or growing out appropriate seed. In addition to collecting and increasing seed RRR uses containerized plants to establish some species. Most recently RRR has been exploring the idea of creating native grass coirs or small bales for restoration purposes – especially to assist

with establishing plant species that are hard to handle (such as *Artistida purpurea*, among others).

A river in need of irrigating: Optimal spatiotemporal allocation of environmental water

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Abstract: Natural river flows are a key element of ecological resilience for riparian ecosystems, but extensive contemporary river regulation via dams, existing water right allocations, and changing climatic conditions all imply a high opportunity cost to prioritizing natural flow mimicry. The general scarcity of river flows necessitates new rules governing the spatial and temporal extent of restoration, yet there has been little development when it comes to systematic environmental water allocation. This is primarily because regulated river systems rarely allocate water to this purpose, and additionally because accurate spatial modeling of river flows and biological populations cannot be captured so parsimoniously as to facilitate common dynamic optimization algorithms. In this paper, we demonstrate a computational solution to this new class of problem using forward dynamic programming and address an illustrative adaptive management objective in the Rio Grande where agricultural water leasing is required to maintain river continuity.

Advancing fuels assessments in pinyon-juniper woodlands using terrestrial laser scanning (TLS)

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Abstract: Pinyon-juniper (PJ) woodlands across the Colorado Plateau are experiencing increased stand-replacing fire behavior, posing new challenges for monitoring and management. While terrestrial laser scanning (TLS) offers high-resolution, three-dimensional data critical for assessing fuels and vegetation structure, most TLS protocols were developed for forests dominated by trees with an arboral growth forms—conditions not representative of all PJ woodlands. These systems are defined by sparse, often multi-stemmed trees, with discontinuous canopies and heterogeneous surface fuel beds, limiting the direct applicability of existing methods. To address these limitations, we established the Southwestern TLS Community of Practice—a collaborative network of scientists, managers, and practitioners working to refine and adapt TLS applications for dryland woodlands. We present results from a case study in PJ woodlands of the Mogollon Highlands, where single-scan TLS acquisitions were used to estimate canopy and surface fuel metrics. These metrics informed the development of predictive models of fuel structure to support monitoring and fuel assessments. Our work underscores the importance of regionally appropriate protocols and highlights how collaboration across institutions and agencies can drive innovation and improve the utility of TLS in complex, fire-affected landscapes.

Land snails and slugs in the context of management and protection of natural areas

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Abstract: The United States Southwest supports hundreds of land snail species, including a diverse array of sizes and shell morphologies. The majority of species, and the highest numbers and biomass, are generally from smaller species with adult sizes less than 5 mm in their largest dimension. In the Southwest, the terrestrial mollusk fauna occurs in habitats ranging from subtropical and desert areas to high mountains. However, the taxonomy of most forms is very poorly known, with little study of most groups over the past 70 to 80 years or more. The distribution, abundance, habitat relationships, and ecological requirements of most members of this diverse group is even less well-known. Because of the combination of great variations in elevation, rainfall, and long-term climate and habitat changes, local populations of species may be strongly disjunct. Given their limited vagility coupled with an ability to maintain small local populations, land snails and slugs have a high tendency toward local endemism. Because of the dependence of many species on microhabitats such as well-developed tree and shrub litter layers, together with their low dispersal abilities, recovery from habitat degradation may require many decades. This presentation will review the southwestern land mollusk fauna in light of these aspects of their biology and ecology, and discuss implications for conservation and management.

Drought and historic overgrazing limit biocrust and perennial grass recovery in a temperate grassland

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Abstract: Improper grazing management, invasive plants, and interactions with drought are commonly cited drivers of rangeland degradation. Previous research suggests that these drivers have altered rangeland structure and function in the southwestern US, leaving large, degraded areas in alternative states, and long-term grazing rest is often suggested as an option for passive restoration. We test these hypothesized degradation and restoration pathways using a long-term study in Canyonlands National Park in southeastern Utah, USA. In this temperate dryland, we compare grassland conditions during an unprecedented ‘megadrought’ starting in 2000 and across a historic grazing gradient: never grazed by domestic livestock, infrequently grazed through mid-1960s, and frequently grazed through 1975. In our twice annual monitoring from 1996 to present, we find total cover to be similar among pastures, likely due to invasive annual cover in the grazed pastures offsetting reduced cover of perennial grasses. The dominant invasive annual grass *Bromus tectorum* was generally constrained by aridity and to the initial patches invaded in the study onset, with evidence of a shift in invasive species composition from *Bromus tectorum* to *Salsola tragus* during the study. Cover of biocrusts (mosses and lichens) dropped in response to the megadrought, were greater in pastures that were never grazed or infrequently grazed, and showed only slight evidence of some biocrust recovery after more than 50 years of livestock removal. Results suggest that the impact of

historic management decisions related to grazing domestic livestock continues to shape these landscapes, with ongoing drought conditions causing some convergence in perennial grass cover and loss of biocrusts, even in the never-grazed pastures. Taken together, this work suggests even protected rangelands are vulnerable to climate change and drought, and active restoration may be needed to repair the most severe degradation caused by historic overgrazing.

Forecasting impacts of invasive smallmouth bass on native fishes of the Colorado River basin

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Abstract: Smallmouth bass (*Micropterus dolomieu*) are a potential source of predation mortality for the native fishes of the Colorado River Basin, and their range continues to expand in response to changing environmental conditions. There is a need to determine the degree to which the continued range expansion of smallmouth bass populations poses a threat to native fishes to inform conservation and management actions. The potential impacts of smallmouth bass on native species are likely to be driven by a combination of availability of different native and nonnative prey species, smallmouth dietary preferences, and environmental stochasticity. Our objective was to use a length-specific population simulation to quantify how river temperature driven by reservoir levels and population expansion of smallmouth bass might impact the native humpback chub (*Gila cypha*) downstream of Glen Canyon Dam. We first conducted a formal meta-analysis on the dietary preferences of smallmouth bass to parameterize this model. This, alongside relative abundance of alternative prey items, was then used to quantify potential size- and species-specific trophic impacts of smallmouth bass on humpback chub. We used this model to forecast population growth and length-specific population dynamics of humpback chub in the Little Colorado River and the mainstem of the Colorado River. We hypothesized higher temperatures lead to accelerated population growth of smallmouth bass and a greater risk of smallmouth bass predation of humpback chub. This approach represents a robust set of methods by which to forecast potential trophic impacts of nonnative species expansion on native fishes and assess potential impacts of smallmouth bass on humpback chub under different scenarios of reservoir storage and release, environmental conditions, and management actions.

Cultural revitalization through restoration of traditional plants and gathering areas

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Abstract: Traditional plants, both wild and domesticated, historically played an important role in Native American Tribes' sustenance but also in their songs, traditions, and stories. While there have been dramatic changes in food sources in the modern era, many Tribes still collect

wild plants and plant traditional crops in the old ways. The Western Apache still collect acorns and a plethora of other wild plants for food and crafts, while the Hopi Tribe still grows traditional landraces and collect wild teas and other plants. These gathering activities also provide opportunities for Native youth to learn about their history, how their ancestors sustained on the landscape, and provide a venue for the telling of traditions and stories. In this way, and like many other places in the world, traditional plants for foods and crafts provide a direct link to Native history and traditions. In this session, WestLand tribal cultural consultants will share their experience on environmental projects and how their contributions have changed the narrative personally and professionally.

Combining physical captures and antenna detections to estimate endangered Klamath sucker abundance

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Abstract: The Upper Klamath basin is home to two federally-endangered endemic lake sucker species, Shortnose Sucker (SNS; *Chasmistes brevirostris*) and Lost River Sucker (LRS; *Deltistes luxatus*), the latter of which has two alternate life history forms (resident lake-spawning and migratory river-spawning). Monitoring of these fishes in the Upper Klamath Lake system includes two different encounter types: 1) physical captures and 2) detections from remote antennas that detect fishes marked with passive integrated transponder (PIT) tags as they swim by. Physical captures of migratory LRS and SNS are from trammel nets in Upper Klamath Lake (as fish aggregate in the lake pre-spawning), whereas antenna detections are from antenna arrays located along their migration route in the Williamson River. For resident LRS, physical captures are from trammel nets and antenna detections are from submersible antennas, both of which occur in spawning habitats (springs) along the eastern shore of Upper Klamath Lake. For all three fish populations, antenna detection probabilities are much higher than physical capture probabilities; however, unmarked fish cannot be detected on antennas thus presenting a challenge for abundance estimation. By using a robust design model that accounts for different antenna detection probabilities for marked and unmarked fish, we were able to obtain abundance estimates for all three fish populations over the last two decades. The time series of abundance estimates of all three fishes suggest dramatic declines (i.e., between 76-92%) over the last two decades. Additionally, results support the findings of previous work that find adult survival is high, recruitment is low, and that populations are aging during this period.

Soil surface modifications can improve dryland reclamation following energy development

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Abstract: The Colorado Plateau, a high elevation dryland in the southwestern U.S., has a long history of energy and mineral exploration and development. After extraction is complete, reclamation practitioners are charged with restoring desirable plant communities and preventing soil erosion. However, practitioners face challenges including low and variable precipitation, low soil fertility, and potentially extreme impacts from development. We aimed to identify novel reclamation methods that could address these challenges, testing different combinations of seed mixes, surface modifications, and soil amendments. Eight study sites with a common study design were established from 2018-2023 on abandoned oil or gas well pads. Treatments comprised combinations of seed mixes with surface modifications, including soil pits, cedar mulch, connectivity modifiers (artificial nurse plants), fertilizer, local mycorrhizae, and over 30 additional site-specific methods of interest to reclamation practitioners. We monitored plant community and soil metrics for two years after establishment. Precipitation had large effects on establishment of seeded species, with very dry seasons resulting in lower seeded species cover and density across all treatments. Soil pits and cedar mulch generally improved seeded and native species establishment. Other methods increased total plant establishment and lowered bare soil exposure, though this was primarily through increased cover of unseeded invasive species. Overall, this study provides guidance to restoration practitioners and demonstrates several novel restoration methods that show promise in establishing desirable plant communities and decreasing potential soil erosion under a variety of climatic conditions.

Understanding household adaptation to smoke from wildfires and forest management above and below the Mogollon Rim

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Abstract: Northern Arizona land management agencies increasingly leverage prescribed fire, managed fire, and other techniques that produce smoke to reduce wildfire risk, underscoring the importance of smoke adaptation in nearby communities. Smoke from wildfires and forest management can produce social impacts such as economic disruptions and health consequences while simultaneously improving forest health and associated ecosystem services. Health practitioners advocate for household-level social and structural adaptations that can reduce smoke exposure while creating “clean air spaces” within homes using approaches such as installing air filters. However, it is unclear what motivates households to engage in smoke adaptation actions, and the extent to which uptake varies between households and communities. This presentation shares findings from over 2000 responses to a household mail survey administered in Parks, Kachina Village, Mountainaire, Sedona, and Camp Verde to

understand household smoke adaptation. Analysis examines differences between communities that directly benefit from fuels reduction activities that produce smoke on the rim versus communities below the rim that experience indirect ecosystem benefits but low air quality can linger for longer periods. The presentation will conclude with recommendations for engaging northern Arizona households in smoke adaptation activities, including message framing and opportunities for program development.

Enforcement as a wildfire prevention tool: public and professional perceptions of stage restrictions in the U.S. Southwest

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The size and frequency of human-caused large wildfires continue to increase across the U.S. Southwest due to an array of shifting social and ecological conditions, resulting in increased infrastructural and ecological damage. Federal, state, and local agencies tasked with mitigating wildfire risk increasingly turn to regulation as a key tool for preventing ignitions; this commonly includes forest closures, stage restrictions, and campfire bans among other approaches. However, little is known about public and manager support and use of these enforcement mechanisms, raising questions about their feasibility and effectiveness across diverse public lands and visitorships. This presentation draws on insights in three communities with close connections to adjacent public lands. We conducted focus groups with residents and professionals in Flagstaff, AZ (n = 45), Los Alamos, NM (n = 33), and Payson, AZ (n = 30) to understand perceptions of and experiences with forest restrictions to reduce human-caused wildfire ignitions, with an emergent focus on stage restrictions. We highlight variations in support for different enforcement strategies and the factors that influence them across national forests, finding that recreational preferences and public land characteristics are important drivers. We also examine disconnects between public and manager interpretations of forest restrictions with the intent to provide insights on current information needs and messaging strategies. We conclude with recommendations regarding communication and implementation of regulatory tools to reduce wildfire risk on public lands.

Southwestern Willow Flycatcher status and habitat restoration efforts along the Virgin River in Utah

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Abstract: Riparian habitats have been in decline throughout the southwestern U.S. since ca. 1900, as water management practices (i.e., river damming, channelization, and water diversion) have reduced the frequency and intensity of flooding events and thus the potential for establishment and regeneration of most native woody riparian species. As native willows (*Salix* spp.) and cottonwoods (*Populus* spp.) have declined, non-native tamarisk (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*) have invaded, resulting in a widespread shift from riparian habitats dominated by native tree species to those dominated by exotic species. The

endangered Southwestern Willow Flycatcher (*Empidonax traillii extimus*) breeds in several off-channel wetlands in the Virgin River floodplain in the vicinity of St. George, Utah and are precariously balanced between rapid human development and severely altered riparian habitat. The Utah Division of Wildlife Resources has been conducting monitoring efforts and conservation actions for the flycatcher since 2008. These actions include protecting suitable nesting sites, mitigating losses of suitable habitat, managing and restoring lowland riparian for suitable habitat, and implementing tamarisk (*Tamarix ramosissima*) control programs that do not negatively impact nesting flycatchers. Efforts to restore, enhance, and re-create native riparian habitat will be necessary to recover both the habitat itself and those priority species dependent upon it (e.g., Southwestern Willow Flycatcher).

Hydrologic variability influences steelhead outmigration patterns in California's Central Valley

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Abstract: The species *Oncorhynchus mykiss* (*O. mykiss*) exhibits remarkable life history diversity, allowing populations to persist across a range of environmental conditions, contributing to the species' broad geographic distribution around the world. In the Central Valley of California, towards the southern extent of *O. mykiss* natural range, a distinct population of anadromous *O. mykiss*, the Central Valley steelhead (CCV steelhead), have been impacted by human development resulting in listing under the Endangered Species Act in 1998. To complete their anadromous life cycle, CCV steelhead must outmigrate through the heavily modified Sacramento-San Joaquin Delta (Delta) where considerable amount of freshwater is exported south at large pumping facilities. Mortality of fish associated with these export facilities has been implicated as a driver of decline of multiple native fish species including the CCV steelhead. However, no quantitative estimates exist to assess population-level effects of these operations on CCV steelhead, and doing so requires understanding environmental drivers of steelhead loss at the export facilities. CCV steelhead typically spend 1–3 years in freshwater before outmigrating, with the expression of anadromy versus residency strongly shaped by environmental conditions, like flow and temperature, in early freshwater years. We developed a negative binomial model to evaluate steelhead entrainment in the context of these environmental conditions and found that tributary conditions from previous years are as important as, or more important than, contemporary Delta hydrodynamics shaped by water exports. These findings suggest that management strategies focused solely on same-year operational changes to reduce mortality of CCV steelhead may not adequately reflect interannual variability in steelhead entrainment risk and highlights the importance of incorporating multi-year environmental data into decision-making frameworks specific to the species.

Forecasting decadal scale Smallmouth Bass invasion dynamics to identify critical uncertainties and inform management and water policy

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Abstract: In many regions, long-term drought is altering patterns of water use and reservoir storage, which in turn can facilitate the spread of non-native fishes. Decreasing supply and increasing demand in the USA's Colorado River basin has reduced water storage in the country's two largest reservoirs. In 2022, historically low water levels in Lake Powell and associated fish entrainment and warming of release temperatures led to the first observations of non-native Smallmouth Bass (*Micropterus dolomieu*) reproduction in the Grand Canyon segment of the Colorado River downstream from Lake Powell. These piscivorous fish have the potential to threaten federally-listed fish species. In response to this invasion, several management strategies have been implemented including mechanical removal of Smallmouth Bass and water storage/dam operations designed to decrease release temperatures to reduce the risk of reproduction, growth, and establishment. To assist managers confronting this Smallmouth Bass range expansion, we developed a matrix-based stage-structured population model to forecast the effects of different suppression scenarios, while accounting for different sources of uncertainty in demographic rates including dispersal dynamics and recruitment, sensitivity to environmental conditions, operational uncertainties associated with control options, and uncertainty related to future climate and basin-wide hydrology and water management strategies. The objectives of our study were 1) to simulate and compare the effectiveness of different prevention and suppression actions, and 2) assess the importance of sources of uncertainty related to the rate and drivers of the invasion to inform future research. Our simulations predict high risk of Smallmouth Bass establishment throughout Grand Canyon under low reservoir levels despite varying levels of suppression; however, higher reservoir water levels or cold-water releases are predicted to stop population growth under most hydrological scenarios. Understanding the sources of uncertainty in invasion dynamics can assist managers in developing response strategies, future monitoring, and research to inform resource management.

The National Forest Foundation's Support of Wood For Life

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¹National Forest Foundation

Abstract: Wood For Life (WFL) shares a sustainable source of firewood with local Tribes and Indigenous communities from forest restoration and wildfire mitigation projects. This is a mutually beneficial partnership that includes the National Forest Foundation (NFF), U.S. Forest Service, NAU's Ecological Restoration Institute (ERI), Tribal governments, Indigenous nonprofits, youth conservation corps, and other Partners who want to be involved. The NFF and the U.S. Forest Service work together to process small diameter material from restoration and wildfire mitigation projects and provide the wood to Tribal partners through tools like Stewardship Agreements and Free Use Permits. Once the wood arrives on Tribal lands, youth crews and Tribal fire crews from the community work to distribute the wood directly to the elders or families most in need. The NFF's support of Wood For Life is founded in a desire to build equitable and sustainable relationships throughout the network of involved parties, while keeping a strong focus on restoring, sustaining, and building on the meaningful connections

individuals and future generations have with Our Forests. Through genuine engagement, knowledge sharing, and exploration of what could be possible, WFL continues to grow organically, with change being one of the few constants. And because of the focus on relationship building and identifying the strengths of our partners—along with the shared love for the land—WFL continues to provide a safe space for different worlds, communities, and personalities to come together to invest in the ability for all future generations to have a connection with the Forests that take care of us.

Models, Monsoons and Tree Rings: Assessing the Reliability of the CMIP6 at the Regional Scale

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Abstract: The North American Monsoon (NAM) supplies semi-regular occurrences of late-summer precipitation to the southwestern United States. Many models project the future of NAM to weaken where it is strongest over Mexico but there is much uncertainty about how it will behave over the United States. Better understanding the mechanisms that will influence future shifts in landscape structure and composition associated with NAM climate shifts can improve management decisions. We can strengthen predictions with the addition of supplementary data to understand which models are most competent at capturing essential NAM dynamics and variability. We hypothesized that a longer environmental proxy record can be used to 1) estimate if directly observed NAM variability is representative of the full breadth of NAM variability and (2) use this information to down-select models by their skill. We sampled 58 lodgepole pine trees (*Pinus contorta* var. *latifolia*) from three sites in the Gunnison National Forest, Colorado. These trees are located on the northern edge of NAM, reliably capture the recent past through tree rings, contain monthly-to-seasonal hydroclimate information, and temporally overlap with model outputs. We calculated past growth-climate interactions; notably we found a significantly positive correlation between tree growth and July/August monsoonal precipitation ($p > 0.05$) using historical instrumental data (1900-2018). The tree-ring chronologies were then used as a constraint on three models from the Coupled Model Intercomparison Project Phase Six (CMIP6), each with different levels of skill in reproducing historical southwestern United States hydroclimate (“unreliable”, “moderately reliable”, and “reliable”). We compared model outputs to ring width indices resolved annually and seasonally. This study’s findings show that tree rings can be novel observational constraints beyond their traditional use for annual-to-decadal timescales by constraining seasonal-to-sub-seasonal hydroclimate phenomena and can eventually be used to improve forecasts of ecosystem change in the Rocky Mountain landscape.

Droughting Megadroughts: Lessons Learned from almost Two Decades of Climate Change Experiments on the Colorado Plateau

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Abstract: The Colorado Plateau has experienced prolonged megadrought conditions for much of the twentieth century, driven by reduced precipitation and periods of extreme heat. These trends, projected to continue with ongoing climate change, underscore the need for studies that anticipate ecosystem responses and inform adaptive land management. Therefore, understanding how these landscapes respond to warming and drying is of critical public interest.

We present key findings of two decades of research from four long-term climate change experiments. Experiments include: (1) active warming using infrared heaters (since 2005), (2) a 30% precipitation reduction via drought shelters (since 2010), (3) seasonal 66% drought with a four-year recovery phase (initiated in 2015), and (4) combined simulated 66% drought and grazing treatments (begun in 2021). Across these experiments, we examined ecological responses, including vegetation cover, plant phenology, biological soil crusts (biocrusts), and biogeochemical cycling.

Both warming and drought treatments resulted in decreased vegetation cover, with notable declines in perennial grasses. Interestingly, in the warming experiment, surviving grasses exhibited increased growth, possibly compensating for stress-induced photosynthetic limitations. Plant phenology responded to both stressors: warming advanced the onset of the growing season thereby lengthening the period of activity, while drought delayed emergence, growth, and reproduction and shortening the growing season.

Biocrust communities were also sensitive to climate manipulation. Mosses, lichens, and dark cyanobacterial crusts declined across experiments, correlating with reduced soil aggregate stability thereby increasing vulnerability to erosion. Additionally, the warming experiment showed potential declines in soil organic carbon and microbial biomass, whereas drought impacts on soil carbon and nitrogen stocks were less pronounced.

Together, these results highlight both shared and divergent ecosystem responses to warming and drying. The consistent decline in vegetation and biocrust communities suggests that without proactive and thoughtful management, the Colorado Plateau's ecosystems may face increased risk of degradation under ongoing climate change.

Modeling the Influence of Changing Reservoir Levels on Mineral Dust Emissions at Lake Powell and Lake Mead

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Abstract: Lake Powell and Lake Mead are the two largest reservoirs in the USA. The reservoirs play a vital role in management of the Colorado River, which supports water supply, agriculture, and energy production for the nation. When reservoir levels decline due to prolonged drought or increasing water demand, vast areas of formerly submerged lakebed sediment become exposed to the atmosphere. These subaerially exposed reservoir sediment surfaces are potential sources of dust emissions. It is important to understand the mineralogy of the reservoir sediments, as the specific composition of carbonates or clays for example, can influence both the chemistry and health impacts of dust particles. To evaluate mineralogical composition across these dynamic shorelines, we used imaging spectroscopy data from NASA's Earth Surface Mineral Dust Source Investigation (EMIT) mission, combined with the USGS' Processing Routines in Interactive Data Language (IDL) for Spectroscopic Measurements (PRISM). This hyperspectral remote sensing approach enables high-resolution, spatially explicit mapping of calcite, other carbonate-bearing, and clay mineral assemblages across both terrestrial and reservoir-exposed surfaces. Our results show that reservoir-derived sediments contain significantly higher proportions of calcite than adjacent terrestrial units, reflecting processes such as lacustrine carbonate precipitation, reservoir sediment deposition, and post-depositional weathering. These spatial patterns vary across geologic units and between hydrologic zones, underscoring the role of reservoir processes in reshaping surface mineralogy. We pair these mineral maps with in-situ measurements and dust emission modeling to quantify the dust emission potential of these surfaces. These integrated observations will be applied to improve predictions of sediment exposure and dust emissions under various potential reservoir storage scenarios. Together, these methods demonstrate a scalable, non-invasive approach for assessing the environmental and health risks associated with sediment exposure and dust generation in large reservoir systems in the western USA.

The Mogollon Highlands Ecoregion: A Previously Neglected Center of Ecological Diversity and High Conservation Value

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Abstract: A previously neglected center of ecological diversity, the Mogollon Highlands Ecoregion (MHE), is a broad, biogeographically rich ecotonal region, connecting the Colorado

Plateau with the hot deserts to the south and the Southern Rocky Mountains. The MHE spans 11.3M ha, and includes 11 biotic communities, 63 land cover types, and 7 ecoregions. Recently, two studies were published on the ecological uniqueness and conservation importance of the MHE. High levels of beta-diversity across topo-edaphic gradients include deserts to mountain tops. The MHE has notably high diversity of snakes (39 species, on par with the Madrean Archipelago), birds, and butterflies, as well as high richness in perennial shrubs and conifers, e.g. in Cembroid (piñon) pines. The MHE also harbors populations of mammalian focal species such as grey wolf and grizzly bear. Main stressors are climate change, livestock grazing, and fire mitigation outside the Wildlands-Urban Interface (WUI), especially in forests lacking historic surface-fire regimes. An ecoregional GAP analysis of vegetation communities and focal species (gray wolf, grizzly bear) that addressed fire concerns and climate projections showed low levels of overall protection (~9%), including for mature forests (18%). Wolf and bear models suggest that while connectivity options are limited, some suitable habitat occurs within the Gila subregion. To maintain the exceptional biodiversity of the MHE, we recommend: (1) strengthening roadless protections, that if implemented would reach a 23% protection level, still falling short of the worldwide 30 x 30 (30% protected lands by 2030) goal, necessitating additional protections; (2) maintaining and restoring connectivity for focal species especially via road obliteration; and (3) strategic targeting of fuels reduction closest to homes in WUI to prepare communities for increased climate-driven wildfires. Moreover, we strongly encourage further study of biodiversity and fire patterns in this region of continentally significant ecological importance.

Piñon pines and climate stress: comparing responses of Border piñon and Mogollon Highlands piñon to recent hot dry decades

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Abstract: Piñon pines are fire-intolerant, iconic conifers distributed across the southwestern U.S. and northern Mexico. While widespread mortality in relatively sensitive *Pinus edulis* (Colorado piñon) has been well-documented since 2003, the response of other piñon species to rising temperatures and mega-droughts is unknown. Here we examine *Pinus discolor* (Border piñon) and compare its drought and fire responses with *Pinus x fallax* (Mogollon Highlands piñon). We hypothesize that tolerance will be reflected in population dynamics, specifically in continued recruitment and low mortality values in large trees. Border piñon populations at the species' leading-edge experienced greater drought magnitude than lower-latitude populations in the central range in Chihuahua, Mexico (Climate Water Deficit; 1958-2022). Frequent, widespread fire events occurred at the leading-edge sites and across the Sky Islands (1990-2022), but sites in Mexico were less affected by fire. In pre-fire timeframes, young tree density was higher at the leading edge and maximum tree size was recorded at Norogachic in the

central range. Mogollon Highlands piñon sites in central Arizona had similar drought magnitude to the Sky Islands but were more like the Mexico sites in experiencing less fire. We observed variation in piñon population dynamics corresponding to elevation; drier, lower elevation sites have had active recruitment and <3% mortality of adults. Higher elevation sites that interface Ponderosa pine forests had up to 17% adult mortality and continual stress from scale insects, *Matsococcus* sp. Population trends support the hypothesis that this hybrid (*P. edulis* x *P. californiarum*) maintains drought adapted traits that allows success in hotter and drier habitats. Drought adaptations allow persistence under extreme conditions in both species, however, fire potentially limits the abundance and distribution of large trees. Conserving piñon may depend on identifying habitat refugia that support persistence despite intensifying climate pressures and wildfire activity.

Crop Water Productivity utilizing field measurements and satellite remote sensing: A Case study of Irrigated Cotton in the Central Valley of California

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Abstract: Water availability in the southwest represents a major concern with a growing demand and decreasing supply of this finite resource. Irrigation from surface and ground water has allowed for great food and fiber production in the southwest. A major source of the nation's agriculture is produced in the Central Valley of California (CVC). With agriculture using approximately 80% of overall human freshwater use, how crops use water is of key interest to growers and water resource managers. To better understand this, Crop Water Productivity (CWP) provides a valuable measurement of crop output divided by water input. This ratio of agricultural product produced per unit of water consumed has been lacking over regional scales in the greater southwest. As an important measurement with limited study, satellite remote sensing can aid in filling this knowledge gap in critical water use areas. Therefore, objectives were to analyze CWP utilizing satellite remote sensing combined with field observations.

Many crops highly dependent on irrigation are competing for limited water resources in the CVC. A methodology for a novel conjunction of remotely sensed data and 2023-24 onsite field measurements of cotton calibrated with farmer provided information was established. Methods explored correlating Normalized Difference Vegetation Index across satellite sensors including PlanetScope, Sentinel-2, and Landsat-9 at varying resolutions with select field measured plant biomass. Then, utilizing OpenET actual evapotranspiration, CWP was calculated. This allowed for insight into the quantum of water used and how much water can potentially be saved by increasing CWP. This benchmark CWP value can lead to developing better models to map where CWP is high and low shedding light on productive growing regions and identifying where CWP can be improved. The methodology used can be extrapolated to greater regions spanning continued growing seasons to help improve food and water security in the 21st Century.

Quantifying the effects of key climate variables on the probability of extreme growth in trees

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Abstract: Due to climate change, rare events such as droughts and floods are becoming increasingly common, with long-lasting effects on tree growth. Numerous studies exploring the link between tree growth and climate tend to underestimate high growth and overestimate low growth, suggesting that models do not sufficiently capture growth extremes. Understanding these extremes is essential for predicting the broader impacts of climate on forest ecosystems. Hence, this study uses multinomial logistic regression models to investigate how specific seasonal hydroclimate variables (i.e., maximum vapor pressure deficit [VPD] and total precipitation) influence the occurrence of extreme high and low growth years. Using site-level, tree-ring width data for blue oak (*Quercus douglasii*) and pinyon (*Pinus edulis*) across the western USA, we defined high and low growth as ring width indices above the 90th or below the 10th percentile, respectively. Average model accuracy across sites for predicting growth classes (i.e., extremely low, nominal, extremely high) using seasonal climate was 77% for blue oak and 79% for pinyon. The odds of an extreme high growth year relative to a nominal growth year increase by 2.18 and 2.28 times for each millimeter of additional summer precipitation for blue oak and pinyon, respectively. The odds of an extremely low growth year relative to a nominal growth year decrease by 59% for blue oak and 41% for pinyon for each millimeter of additional summer precipitation, respectively. For both species, summer and winter VPD affect the odds of extremely low growth relative to nominal growth but are irrelevant to high growth. Preliminary results suggest “asymmetric” growth responses to climate: important hydroclimate variables responsible for low growth years differ from the climate variables leading to high growth years. This has implications for forecasting the impacts of future climate on extreme tree growth and forest productivity states.

Identifying and quantifying effects of extreme climate on tree growth at multiple scales

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Abstract: Tree-ring datasets, such as the International Tree-Ring Data Bank (ITRDB) and the U.S. Forest Service’s Forest Inventory and Analysis (FIA) program, provide extensive

information on tree growth and climate relationships across various species, regions, and time periods. We analyzed these tree-ring datasets using advanced statistical modeling, yielding three distinct studies. The first study identified growth patterns that distinguish drought-killed from drought-surviving trees for seven species across the U.S. and Europe. We found that mortality was preceded by either (1) highly climate-sensitive growth, (2) a weakening climate-growth relationship, or (3) a gradual loss of climate sensitivity over time, with each growth pattern pointing to essential mechanisms behind forest resilience. The second study focused on analyzing the influence of climate over various temporal scales, ranging from long-term averages to year-to-year changes, and slow multi-year trends. Our results reveal discrepancies between short-term and long-term climate drivers that have important implications for dynamically changing climates. The final study builds on these insights by predicting extremely high and low growth patterns from climate data for several species across the Western U.S. The goal of this study is to improve our ability to predict when and where extreme growth will occur across the Western U.S. Together, these findings illustrate how integrating large ecological datasets with advanced modeling techniques can improve our understanding of climate sensitivity and forest resilience. By identifying the mechanisms driving tree response to both gradual and extreme climate changes, this research strengthens our ability to anticipate the impacts of climate change on forest productivity and carbon storage. These insights are essential for designing adaptive, climate-informed forest management in an increasingly uncertain future.

Bucking the suppression status quo: incentives to shift the management paradigm on natural ignitions

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Abstract: Wildfire policy has evolved rapidly over the past three decades, necessitating repeated shifts in management and communication strategies for US land management agencies. One growing focus considers the use of “other than full suppression” (OTFS) strategies, where managers use natural ignitions to achieve management objectives. While policy and guidance give managers operational flexibility, various factors contribute to risk aversion that inhibits OTFS use. This research investigates (1) if wildfire management professionals can reach consensus on incentives used to promote OTFS management, and (2) if Delphi techniques, whereby individual participants complete anonymous iterative surveys and provide feedback on group responses, can serve as a suitable method in wildfire policy exploration. Results suggest that consistent public support from agency leadership, rewards for successful use of OTFS strategies, and allowing acres affected by OTFS wildfires to count towards regional targets were among the most impactful in the eyes of participants. Furthermore, Delphi techniques showed promise in policy exploration and gave insight into not only what incentives could be impactful, but how such changes might be prioritized and coordinated. These results suggest that incentivizing OTFS management requires a combination of policy adjustment and agency alignment to better leverage wildfire for ecosystem restoration.

The United States Drought Monitor: Then, Now, and the Future. Encapsulating the Gold Standard of Drought Monitoring

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Abstract: From a joint effort, combining of ideas from both Svoboda and LeComte in the late 1990's, to what we currently are doing 25 years later, the United States Drought Monitor (USDM) has stood the test of time and has developed into the "Gold Standard" of drought monitoring not only in the United States but around the world. The USDM has always utilized the best available technology and data and the continual development of the process of making the map has been quite evident all while maintaining the initial methodology of utilizing percentile ranking of drought indicators and indices. This methodology allows the USDM to not only change with the times, being able to adapt to new inputs and technologies, but also continues to allow that the best attributes of dozens of inputs along with expert input are utilized to have the best weekly assessment of drought possible for the United States. The flexibility of the USDM process is what will maintain it into the future where AI/ML techniques are already being developed creating composite drought indicators (CDI's) that will feed into the USDM but will also help identify and characterize the various types of drought that are all incorporated into the single USDM product. The flexibility of the USDM process will also allow it to continue incorporating climate non-stationarity into the weekly analysis. 25 years in, the USDM is still relatively young in the climate world, but the next 25 years should be a period where more continuous changes and adaptations take place. As we do not know all the future advancements in data and technology, the book is far from being written as to the possibilities of what the future may bring. If one had to guess, advances in data resolution and clarity, more CDI's and gridded data will continue to push the current thresholds of what is possible with current inputs.

Natural tracers differentiate how baseflow and snowmelt conditions affect the Grand Canyon's water supply

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High-elevation karstic aquifers fed by snowmelt are integral to supplying water for arid regions. The Grand Canyon's regional deep R aquifer has been under-studied regarding understanding the dynamics and differences between base-flow and snow-melt flow conditions. It is hypothesized that natural tracers collected from the water of Roaring Springs, the main water source of Grand Canyon National Park's Transcanyon Waterline, will differentiate snow-melt and base-flow conditions. An automatic water sampler stationed at the bottom of the Grand Canyon near Roaring Springs collected daily stable isotopes of ¹⁸O and deuterium samples before, during, and after snowmelt. These samples were collected for the 2024 and 2025 snowmelt seasons. A data logger inside Roaring Springs has collected a continuous record of temperature, conductivity, and pressure since 2013. Natural tracers describe shifts in the flow regimes of water through the regional aquifer and identify differences between base-flow and snow-melt conditions. The peaks in discharge resulting

from snowmelt reaching the logger at Roaring Springs correlate with the timing of more negative isotopic values from samples collected at the automatic water sampler. The peaks in discharge at a large, perched C aquifer spring on the North Rim called Robber's Roost are one day prior to snow-melt peaks at Roaring Springs. Snowmelt flows laterally from the North Rim to Roaring Springs where water is discharged from the Redwall-Muav aquifer thousands of meters below. These data delineate the time of recharge of snowmelt to the C and R aquifers. They can also enable Grand Canyon National Park to better understand a major part of its water supply as they plan for a future where there will be less water available to provide to residents, visitors, and ecosystems.

Mycorrhizal fungal responses to drought in pinyon-juniper woodlands over time: implications for host plant survival and fungal diversity

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Abstract: Mycorrhizal fungi associate with most plant species where they can improve the ability of their hosts to tolerate stresses like drought by improving access to soil resources and providing protection from disease. However, there are thousands of species of mycorrhizal fungi that differ from one another in the environments they tolerate and the benefits they provide to plants. Studies over the past 25 years on the mycorrhizal fungal associations of pinyon pine indicate that fungal diversity has dropped consistently and substantially due to drought, leaving a community dominated by a single genus of fungi in some areas. Greenhouse, field and common garden studies show that pinyons are strongly dependent on mycorrhizal fungi for growth and survival during drought, but these benefits depend on pinyon genotype. Tree mortality due to drought also alters mycorrhizal fungal abundance, distribution and diversity, but some fungal species remain for a decade or more, likely as dormant propagules, providing the opportunity for seedling re-establishment if drought eases. Restoration of key mycorrhizal fungal taxa may be key to re-establishing pinyons in high mortality sites.

Using biochar as a soil amendment in wildland forests and agricultural settings in northern Arizona

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Abstract: Forested landscapes across the American West, particularly in fire-prone regions, present both a challenge and an opportunity. Restoration thinning of forests is essential for reducing wildfire risk, and converting this excess biomass into biochar offers a promising, economically viable solution. Biochar production not only supports forest management but also contributes to long-term carbon sequestration and constitutes an improved in-soil reservoir

for water and nutrients. Extensive literature underscores the role of biochar in enhancing soil health, boosting water retention, nutrient availability, and microbial activity; yet much of this research remains geographically limited. In particular, there is a lack of field-tested evidence for biochar's performance in the unique conditions of the American Southwest, including its arid climate, variable soil types, and post-disturbance restoration needs. We share early findings from applied research in Northern Arizona, examining the efficacy of biochar as a soil amendment in two distinct settings: (1) replanting efforts in post-fire ponderosa pine (*Pinus ponderosa*) forests, and (2) small-scale vegetable farming operations. The study will review what is known about the impact of biochar on soils and crops, provide an update about our research work, and examine the potential for expanded use and the social, economic, and logistical hurdles to reaching such goals. The session aims to spark discussion on research gaps, stakeholder engagement, and strategies for integrating biochar into regional sustainability and restoration efforts.

Magic carpets, bedraggled area rugs, and crust capsules: Biocrust restoration materials development

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Abstract: Restoring biological soil crusts (biocrusts) in degraded ecosystems can enhance soil stability, hydrologic function, fertility, and carbon storage, and may combat invasion of exotic vascular plants. While direct application of crumbled biocrust (either salvaged or cultivated) can sometimes be effective, techniques which ameliorate biotic and abiotic limitations to propagule establishment may improve restoration outcomes. Some of these techniques have the added benefit of directly suppressing invasive vascular plants or may be used to simultaneously apply biocrust inoculum and native vascular plant seeds. We will detail trials of two recently developed techniques for aiding biocrust establishment which represent opposite ends of the intensity/application area continuum: biocrust sods (ideal for high intensity, low area applications such as in fuel breaks, solar farms, and trailheads) and biocrust capsules (ideal for low intensity, high area applications). Sods were deployed at three test sites with differing restoration objectives: Stateline Solar, a photovoltaic solar farm where dust and weed suppression were desired; Mojave National Preserve, where reduction of fire-prone invasive annual grasses was the primary restoration goal; and Chicago Valley, where plant-permeable sods were designed to promote native plant establishment and cover unauthorized off-highway vehicle tracks. Locally salvaged biocrust was cultivated on various combinations of biodegradable substrates designed to meet specific restoration objectives for each site. At Chicago Valley and Mojave National Preserve, we also tested capsules of two types (tapioca or vegetarian) containing biocrust, pectin, and native seeds, with or without diatomaceous earth. Preliminary monitoring indicates that sods are a promising restoration tool at Chicago Valley and Stateline Solar, but their utility may be limited at Mojave National Preserve and other sites with large populations of burrowing rodents. Our observations also suggest that the

effectiveness of capsules may vary by biocrust organism type and with site soil surface characteristics.

Multi-scale vegetation response to Minute 323 in-channel flows: Insights from Sentinel-2 and Landsat imagery

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Abstract: The Minute 323 Binational Agreement between the United States and Mexico enabled restoration of 558 ha of riparian habitat in Mexico's Colorado River Delta through targeted planting and irrigation. As part of this agreement, in-channel flows were designed to provide ecological and social benefits to both restored and unrestored areas. These flows were delivered during spring to early fall of 2021, 2022, and 2024, with annual volumes ranging from 28 to 36 hm³, released from Morelos Dam (river km 0) and conveyed to Reach 4 (km 64), Reach 5 (km 90), and Reach 7 (km 106).

To assess vegetation response at multiple spatial scales, we used Sentinel-2 Normalized Difference Vegetation Index (NDVI) to estimate mean growing-season greenness in zones adjacent to the river channel, and Landsat-derived Enhanced Vegetation Index (EVI2) to evaluate reach-scale vegetation dynamics. We compared flow years to non-flow reference years (2020, 2023) and included upstream Reach 3 (km 31), which did not receive flows, as a control.

Results from Sentinel-2 NDVI indicate increasing greenness after 2020 in Reach 4 and Reach 5, primarily within the first 30 meters on either side of the river's centerline. However, greenness increases were not always aligned with flow delivery, as the non-flow year 2023 showed notable gains. Landsat EVI2 reflected similar trends in Reach 4, but no significant response was detected in Reach 5. In the control Reach 3 there were not increases in greenness at any scale.

These findings suggest that vegetation dynamics in response to environmental flows vary by spatial scale and reach characteristics, with implications for future restoration strategies that could balance the benefits from targeted irrigation vs. in-channel flows.

Evaluating Beaver-Mediated Riparian Vegetation Dynamics in an Arid Southwestern Stream

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Abstract: Wetlands in the arid landscapes of the Southwestern U.S. are critical for biodiversity, aquifer recharge, and habitat connectivity. However, these ecosystems are increasingly threatened by anthropogenic pressures and climate change. North American

beavers (*Castor canadensis*) create and sustain wetlands through dam-building, yet their populations remain depleted due to historical fur trade and continued removal. Process-based restoration efforts, such as beaver reintroduction, offer a potential strategy to mitigate climate-related challenges. In 2020, Bandelier National Monument reintroduced beavers to a first-order, seasonally ephemeral creek with low base flow (~2 cfs). Using field surveys from 2020, the summer of reintroduction, and field surveys four years post introduction, I evaluate the effects of beaver on Southwestern riparian vegetation. I achieve this with two natural experimental designs: (1) before-after-control-impact (BACI), with plots resurveyed in 2020 and 2024, four of which experienced beaver damming and 2) within-creek differences of vegetation composition, comparing exclusively 2024 cover and richness of beaver dammed and undammed reaches. I empirically assessed vegetation community composition in response to beaver activity, revealing that both biotic and abiotic drivers, such as elevation and fire history, exert influence on community composition. Beavers contribute within this broader ecological framework, stimulating the response of early ruderal species, such as introduced species, and facultative shrub species in drylands. They decrease facultative tree species richness and cover, but overall increase vegetation cover with increased vegetation providing surface roughness that slows floods and minimizes soil loss, ultimately aiding in the riparian succession cycle. These findings inform land managers of the current state of vegetation communities, with long term studies needed to understand the evolution of beaver wetlands on Frijoles creek.

Informing sustainable tourism in Utah's national parks

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Abstract: National Park Service (NPS) units are major tourist destinations and economic contributors to state and local communities. Utah is home to thirteen NPS units, including five national parks: Capitol Reef, Arches, Canyonlands, Bryce Canyon, and Zion National Parks. In 2023, these sites welcomed 15.7 million visitors, generating \$1.9 billion in visitor spending (NPS, 2024; Kem C. Gardner Policy Institute, 2024). This visitation coincides with Utah Office of Tourism (UOT) and stakeholder efforts to promote responsible travel. In May 2024, visitors to the five Utah national parks were invited to participate in a survey about their park experience. Sampling occurred over two weekends during the early summer season—the first weekend of May (May 3-5) and Memorial Day Weekend (May 24-27). Potential respondents provided an email address and were sent a link to an online survey that included questions about demographics, trip characteristics, national park experience, and behaviors while visiting. Data were analyzed and summarized individually for each park to identify park-specific findings and recommendations. Patterns and key findings that emerged from the study include differences in travel group and age demographic between the early-season weekend and holiday weekend; primary trip purpose and motivations for visiting national parks were consistent among parks and between weekends; driving was the dominant mode of transportation; respondents overall rated park facilities and services favorably; perceived

crowding and crowding-related factors were more severe during the holiday weekend; and overall visitors are knowledgeable of responsible travel practices, though there is an opportunity to improve preparedness and engagement in park protection efforts. Findings from this study offer valuable insights for tourism and park management stakeholders aiming to support sustainable tourism strategies that support high-quality visitor experiences while preserving Utah's treasured national parks and communities.

Expanding Conservation Knowledge: Lessons from the Endangered Species Act

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Abstract: The increasing complexities in wildlife management present significant challenges to effective conservation. Political considerations, power dynamics, and the absence of interdisciplinary approaches often limit the integration of diverse knowledge systems into conservation practice. Conservation science has historically excluded social sciences, practitioner expertise, and Indigenous knowledge, shaping what is considered "best available science" and influencing conservation decision-making under policies such as the U.S. Endangered Species Act (ESA). This research examines how knowledge is produced, applied, and valued in species recovery efforts under the ESA. Using recovery plans, delisting determinations, and interviews with conservation practitioners, we assess what knowledge is deemed necessary for species recovery versus what knowledge is actually used in practice. By identifying gaps between these two, we highlight pathways for expanding conservation science to be more inclusive and responsive to complex conservation challenges. Our findings contribute to interdisciplinary approaches for fostering resilient human-wildlife coexistence by addressing two key themes: (1) the application of social science in conservation by revealing how decision-making incorporates (or excludes) diverse knowledge systems, and (2) the complexity of wildlife management by demonstrating how the negotiation of knowledge boundaries influences conservation outcomes. This work aligns with the broader session focus on integrating societal considerations into wildlife management, strengthening participation, and fostering community-driven conservation solutions. By understanding the politics of knowledge in conservation, we can move toward more effective, just, and inclusive conservation strategies that enhance biodiversity protection and human well-being.

Alpine bumble bee (*Bombus* spp.) communities of the La Sal Mountains, Utah

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Abstract: In the fall of 2013, the Utah Division of Wildlife Resources (UDWR) released 20 non-native *Oreamnos americanus* (mountain goats) into the isolated laccolithic La Sal Mountain Range in southeastern Utah. As of August 2024, UDWR estimated the population at 109. As part of an effort to monitor the effects of *O. americanus* on the small, isolated alpine environments in the La Sal Range, alpine arthropod communities were sampled to provide baseline conditions as the goats were introduced. As part of this inventory, we netted pollinators encountered during random, unstructured wandering surveys through the major

habitats present at each study area. Beaver Basin and Manns Peak each had two primary habitat types, and the Mt. Peale site had all three: herbaceous alpine vegetation, rocky cushion plants and lichens, and krummholz islands of stunted conifers among patches of flowering herbaceous plants.

Here I report on some aspects of the ecology of the bumble bee community in the La Sal Mountains based on net captures. Fourteen species of *Bombus* were recorded during at least one survey period on at least one study plot, between 2016 and 2019. Community composition varied among the three study areas, as well as temporal differences at each site over the four years. Bumble bee community structure was evaluated using Non-metric Multidimensional Scaling (NMS) using PC-ORD. Patterns in the ordination data indicated preferences among different bumble bee species for different flower hosts, habitats and study sites. Ordination patterns were structured by floral preferences that correlate with bee morphology (tongue length, cheek structure, and mid leg structure) and flower structure. Seven bumble bee species were observed all four years, others were less common. *Bombus balteatus* was recorded farther south than previously known in Utah, and *B. occidentalis* was documented for the first time since the 1960's.

Data Visualization for Nonprofits and Public Lands

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Abstract: Many nonprofits and public land management agencies collect huge amounts of data that often live out their lives in tables and reports. However, tables of data rarely engage donors, board members, legislators, and other stakeholders in the same way that visualizations can. I obtained publicly available data sets from the National Park Service, Bureau of Land Management, and the nonprofit for which I work, Grand Staircase Escalante Partners, then converted them into visualizations in Tableau Public. Data ranged from qualitative narrative reports to quantitative measures and calculations, and covered topics that included native plant surveys, visitation rates, the value of ecosystem services, and petition data. Qualitative data were transformed to create data that could be fed into data visualization systems such as Tableau Public. The visualizations served purposes that ranged from providing resource managers with ways to access and relate data, to providing evidence for nonprofit campaign support. This work demonstrates the effectiveness of visualizations, and the presentation will briefly cover basic data practices that are needed to move from tables of data to compelling visualizations.

Introduction to Infrastructure and Innovation for Ecological Restoration with Biocrusts

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Abstract: This session brings together researchers and practitioners from plant and biocrust restoration, to share their latest experiences with land restoration on the Colorado Plateau.

From native plant materials production and understanding how water availability impacts restoration outcomes, to soil reclamation with biocrusts, together we will think about the ongoing challenges and opportunities for restoration with plants and biocrusts. Crucially, we will consider the infrastructure required for building capacity for restoration on the ground, and then we will consider how plant and biocrust restoration techniques might be used synergistically to improve restoration success. We leave time at the end of the session to discuss what we have heard, to innovate together, and to inspire collaboration.

Investigating Irrigation and Fertilizer Effects on Native Seed Production

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Abstract: Phenotypic plasticity influences the expression of adaptive traits over time, yet it can be difficult to disentangle from environmentally induced genetic and physiological responses, which may or may not be expressed or inherited. Another mechanism influencing trait expression is maternal effects, where offspring phenotypes are shaped by maternal environmental conditions during development. Over multiple generations, selection for specific traits, such as drought resistance or other local adaptations, can lead to persistent maternal effects within populations. However, studying these effects in multi-generational species like perennial forbs remains challenging in both field and greenhouse contexts. To explore the persistence and extent of adaptive traits relevant to restoration, a common garden experiment was conducted in the summers of 2021 and 2022. Maternal plants were grown under different combinations of fertilizer and irrigation treatments to simulate variable environmental conditions. In summer 2023, a follow-up greenhouse experiment evaluated the traits of offspring from these maternal lineages, assessing characteristics such as plant height, mortality, and reproductive effort. This study investigates the degree and potential heritability of maternal effects to better understand how provenance and adaptive trait expression influence seed sourcing for restoration. By integrating maternal effects into the evaluation of plant material, this research aims to improve restoration outcomes. Large-scale habitat restoration efforts depend on the successful propagation and establishment of native species, and considering maternal environmental legacies could enhance the performance and resilience of restored ecosystems.

***Phacelia alba*: A native plant and its pollinators' response post fire.**

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Abstract: As climatic warming continues, the Colorado Plateau faces increasing wildfire frequency and severity.³ Understanding fire impacts and natural successional processes is increasingly important for land managers. Additionally, understanding native pollinator populations post-fire is of increasing concern given their crucial role in the efficient

recolonization of native plants and in the face of global insect population declines. In the aftermath of the 2024 Deer Springs fire, land managers reported significant increases in the population of *Phacelia alba* (Rydberg). *Phacelia alba* is an annual species in section Glandulosae native to the Southwest which has gone largely unstudied since its original description in 1917. Based on the initial reports, we describe this population increase, and conducted pollinator surveys to understand *P. alba*'s role in the successional community post-fire. Pollinators, consisting primarily of Hymenoptera, were collected by net and jar as they were observed visiting *P. alba* flowers. Specimens were collected on three dates while *P. alba* was in flower and later identified to genus. Many of the identified specimens were found to belong to the families Megachilidae and Halictidae, including a notable presence of the genus *Anthidium*, a genus which includes known *Phacelia* specialists and generalists. Many of the identified genera also included many stem and ground nesting bees, some of which were observed nesting in the ground near the *P. alba* and one found in a stem. Additionally, parasitic mites, wasps, flower flies, and crab spiders were observed on the plant. Finally, we suggest that *P. alba* may play a significant role in the recovery of burned habitat and suggest potential for future research on its life history and land management applications.

Exploring links between biocrusts and dryland plant community composition

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Abstract: In drylands, biocrusts are patchily distributed and contribute to heterogeneity in soil characteristics that can affect plant establishment and growth. Yet, understanding of how biocrusts relate to patterns of plant diversity and community structure remains limited. Using remote sensing imagery collected from Unoccupied Aerial Systems (UAS), we examined relationships between biocrust-associated soil cover heterogeneity and plant diversity patterns on the Colorado Plateau. Separately, we used a global meta-analysis of published studies and plant functional trait information to explore how morphological seed traits relate to biocrust effects on plant emergence with the goal of inferring potential relationships among biocrusts, plant emergence, and community assembly. Field-based analyses revealed positive associations between soil cover heterogeneity and biocrust cover with plant diversity and community composition. Meta-analysis showed that morphological seed traits were important predictors of plant emergence responses to biocrusts. For example, seed mass and seed appendages controlled the effects of biocrusts on the emergence of native and non-native plant species. Together, these results increase understanding of co-occurrence patterns between biocrusts and dryland plant diversity and indicate functional traits that might be important in explaining plant species- and functional-group specificity in plant responses to biocrusts. This information improves fundamental understanding of biocrust-plant interactions and highlights the promise of high-resolution UAS data and trait-based approaches for extrapolating these

patterns over larger landscapes, which could improve conservation planning and predictions of dryland responses to soil degradation under global change.

The Pinyon-Juniper Project: Toward a Conservation Strategy for the Biome

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Abstract: Pinyon-juniper woodlands are gaining increased conservation attention due to localized pinyon pine die-offs and the decline of the pinyon jay. While pinyon-juniper woodlands have been studied for decades at local scales, relatively little is known about their status, trends, and threats at a biome-scale relative to the sagebrush biome. A biome-wide assessment and a spatial strategy for pinyon-juniper woodlands are needed to effectively manage both sagebrush and pinyon-juniper habitats. The Intermountain West Joint Venture (IWJV) is facilitating a collaborative effort to assess the status, trends, threats, and values associated with pinyon-juniper woodlands. The project has begun to collaboratively develop a spatial strategy for the biome that supports the targeting of conservation and management based on a variety of factors, including wildfire risk, wildlife habitat value, cultural resources and values, current woodland condition, predicted future condition, and adjacency to sagebrush habitat. A Science Team comes together to survey and synthesize existing spatial data and science, and develop new products. An Advisory Team consisting of land managers and decision-makers oversees the process, ensuring management relevance and providing opportunities for technical transfer of project deliverables. To support this effort and facilitate knowledge exchange, the IWJV is also developing a community of practice focused on the management of pinyon-juniper woodlands. This practitioner-focused network will provide a platform to share knowledge, approaches, successes, and lessons learned from the research and management communities.

Rapid structured decision making for delta smelt freshwater outflow management

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Abstract: Managers of the Central Valley Project (CVP) and State Water Projects (SWP) in the Central Valley of California, United States, are confronted with contentious and difficult tradeoffs between beneficial uses affected by water management decisions. These decisions involve altering the timing and magnitude of water releases from an extensive network of dams and reservoirs affecting habitat for commercially important salmonids, federally- and state-listed endangered fishes, water deliveries for agriculture or municipalities, and water quality. Declines in state and federally endangered fishes and mandates to maximize water deliveries for human uses triggered a structured decision-making (SDM) process to assist management agencies in confronting these tradeoffs while gathering input from cooperating agencies and

interested parties (hereafter participants) through workshops in spring of 2025. Within a multi-criteria decision analysis context, we used a water planning simulation model (CalSim3) and species-specific life cycle models to predict consequences and analyze tradeoffs between water management alternatives, which were ranked based on four individual participating organizations' objective weights. The three highest ranking water management alternatives performed poorly for Delta Smelt but performed best for CVP and SWP water exports and objectives related to coldwater pool operations for salmonids. While an optimal strategy that staved off extinction of Delta Smelt was elusive, insights gained from the rapid prototype decision analysis suggested non-flow actions and other conservation actions benefitting Delta Smelt, including in drier years, could be considered when curtailment of water exports to implement freshwater flow management for Delta Smelt is not possible.

From Forests to Classrooms: A Collaborative Model for Climate Resilience and Indigenous Knowledges

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Abstract: The Institute for Native-serving Educators (INE) is a collaborative initiative to strengthen schools serving Native American students in rural and urban communities. The INE partners with the NAU's School of Forestry through a current USDA AFRI grant and the Southwestern Mountains Climate Resiliency Center. Our partnership provides a unique professional development experience for PK–12 educators' to build their capacity to implement culturally sustaining and responsive practices. In our professional development model, utilizing culturally relevant environmental information like Traditional Ecological Knowledge and Climate is used by teachers to create STEM curriculum to reach Indigenous students and their families to build climate resilience.

Developing a Multiscale Hyperspectral Framework to Characterize Biocrusts on the Colorado Plateau

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Abstract: Biological soil crusts (biocrusts) are ecologically important components of dryland ecosystems, yet they are difficult to monitor across space and time. Traditional field methods provide detailed insights into their community composition and functions, such as carbon and

nitrogen fixation or water retention, but scaling these observations remains a challenge. Many existing multispectral remote sensing tools, which are effective for scaling vascular plant observations from field to landscape scales, perform less well when applied to biocrusts.

This presentation outlines progress toward a multiscale biocrust characterization framework that integrates ground-based spectroscopy with the Earth Surface Mineral Dust Source Investigation (EMIT) hyperspectral sensor aboard the International Space Station, incorporating airborne and drone-based hyperspectral sensors as intermediate scales.

Using field spectroscopy data collected in Arches National Park and surrounding sites, we assess spectral separability among dominant biocrust types across spatial resolutions ranging from centimeters to 60m, applying an algorithm originally developed for identifying minerals from the location, shape and depth of their spectral absorption features – the Mineral Identification and Characterization Algorithm (MICA).

While drone and airborne hyperspectral data have been collected over our sites, they are not yet available for analysis. This work therefore establishes the methodological foundation for future scaling efforts and evaluates the challenges of linking field spectroscopy data with coarser resolution hyperspectral imagery.

By examining the strengths and limitations of hyperspectral approaches across spatial scales, our study contributes to ongoing efforts to develop reliable, scalable methods for biocrust mapping and monitoring in dryland landscapes.

Expanded Conceptual Risk Framework for Uranium Mining in Grand Canyon Watershed—Inclusion of the Havasupai Tribe Perspective

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Abstract: In 2012, the Secretary of the U.S. Department of the Interior placed a 20-year limit on mineral extraction on Federal lands in the Grand Canyon watershed to permit further study of the environmental effects of uranium mining. Tribal concerns were also noted by the U.S. Department of the Interior and included in the rationale for the decision stating Tribal resource impacts could not be mitigated and cultural degradation may result should mining occur within sacred and traditional places of Tribal peoples. The U.S. Geological Survey previously developed a conceptual framework for a uranium mine in the region that defined contaminant sources and physical, chemical, and biological processes that affect contaminant transport to ecological receptors. However, published risk models have largely ignored exposure pathways relevant to Tribal communities in terms of traditional uses and existential values of the resources included. We will present an updated conceptual risk framework for uranium mining that includes indigenous knowledge components informed by the Havasupai Tribe perspective.

Culturally important plant species at the Pinyon Plain Uranium Mine

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Abstract: The Havasupai Tribe and the U.S. Geological Survey previously identified indigenous exposure pathways at the Pinyon Plain Uranium Mine (PPM) in northern Arizona that are not generally considered in typical risk assessments. The resulting conceptual risk framework revealed important exposure pathways for the Havasupai through their traditional uses of plants. In the current effort, A 2013 survey that documented 117 plant species at the PPM was used to evaluate the importance of those species to Tribes in the region and identify specific exposure pathways that need consideration for risk analyses. To date, 100 of a total of 117 (83%) of the plant species have been identified as being culturally important by one or more Tribes. This presentation will cover the process undertaken to synthesize the Tribal information while respecting sovereignty. Results can be used to refine future risk analyses near PPP and other regional mine sites.

Grazing as a climate adaptation tool leads to regional tradeoffs between fire and vegetation outcomes in sagebrush ecosystems

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Abstract: Big sagebrush (*Artemisia tridentata*) dominated ecosystems are widespread across the western U.S. and face combined threats from invasive annual grasses, altered wildfire regimes, and climate change. Livestock grazing is the most pervasive land use practice within sagebrush ecosystems. As a result, grazing has the potential to be used to help minimize the combined threats of wildfire and invasive plants, although the effectiveness and appropriateness of grazing under future climate conditions remain unclear. We used the

individual-based simulation model STEPWAT2 to estimate how the abundance of key plant functional types (sagebrush, herbaceous perennials, and herbaceous annuals) and wildfire frequency may change under future climate conditions and how those changes are influenced by livestock grazing intensity. We integrated simulation output with remotely sensed data to calculate sagebrush ecological integrity, an index that incorporates desirable components (sagebrush, perennials) and undesirable components (annuals, conifers, and human modification) of sagebrush ecosystems. Climate change reduced the abundance of sagebrush and perennials. Wildfire frequency increased, especially in the western portion of the region, primarily as a result of increases in annuals under future climate conditions and secondarily due to drier projected summer conditions. Simulations suggest that increasing the intensity of grazing reduced fine fuels, counteracting climate induced increases in wildfire. However, a trade-off emerged between the positive impacts of grazing for reducing wildfire and the negative impacts of grazing that caused declines in native plant cover and subsequent declines in sagebrush ecological integrity. This trade-off varied geographically within the region and was greatest under very heavy grazing. Overall, our simulations provide perspectives on how sagebrush plant communities may respond to the interactions among changing climate, invasive species, and fire regimes, and how grazing can be a tool to moderate these impacts.

Direct effects of precipitation and temperature on populations of three grama grass species in central Arizona semi-arid desert grasslands

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Abstract: Perennial grasses are the dominant life form in semi-arid desert grasslands of the Southwest. However, prolonged drought combined with rising temperatures may lead to a decline in the dominance of these species. The purpose of this research is to examine the demography and population dynamics of three native, perennial, warm season grass species: sideoats grama (*Bouteloua curtipendula*), black grama (*Bouteloua eriopoda*), and hairy grama (*Bouteloua hirsuta*). This study focused on data collected from 24 fine-grained (1m²) permanent quadrats in the semi-arid desert grasslands of the Sierra Ancha Experimental Forest of central Arizona. These quadrats were mapped annually from 2017 to 2024 (eight years), and life tables were developed for each *Bouteloua* species. The life table data suggest that the populations for all three species have been declining for the past eight years. The survivorship rates (lx) were 0.20, 0.00, and 0.10 for sideoats, black, and hairy grama, respectively. In addition, the size of the survivors for each species has been shrinking over time. We parameterized survival and growth vital rate regressions for each grama grass species where plant size, precipitation, and temperature were significant predictors. In addition, we developed size-based population models (integral projection models), which allowed us to explore population-level patterns that were not apparent from regression models alone. These models also showed a decline in population growth over time for all three grama grass species.

However, they highlighted the need to add reproduction data (such as number of flower stalks). Ultimately, these demographic and population data will help land managers better understand these perennial grama grass species' life histories and determine the risk of species extinction due to changing climate or a specific management action.

Management implications of recent changes in pinyon-juniper woodland complexity

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Abstract: Since the mid-1990s, pinyon-juniper ecosystems of the Colorado Plateau have undergone several tree mortality and dieback events due to severe drought and insect outbreaks. Variation in timing and intensity of these events has resulted in a wide range of woodland structures across the region. Due to these as well as expected future changes, land managers considering conservation or ecological restoration strategies are not likely to be successful when basing goals on historical patterns. Rather, management paradigms will need to target broader, more general goals such as restoration of ecological resilience and biodiversity, which in turn may be indicated by measures of structural complexity. In this study, we quantified stand conditions at 12 pinyon-juniper sites across northern Arizona and analyzed relationships between tree mortality, structural characteristics, and complexity. Attributes we examined included tree composition and size distribution, standing dead tree density, coarse wood mass, and understory plant cover and richness. Results indicated strong positive relationships between tree loss, species composition, and coarse wood mass. Tree loss and structural complexity showed a significant relationship and higher levels of complexity were associated with intermediate levels of tree loss. Findings from this research can help land managers develop strategies that reflect broad conservation and restoration goals and treatment prioritization schemes.

The evolution of managed wildfires in the Southwestern US

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Abstract: Managed fires have evolved since the 1970's when land managers started using this practice. Initially, managed fires primarily occurred after the monsoon season, in wilderness areas, and were relatively small. By the 1990's managed fires were larger but still in wilderness areas and burned mostly at low severity. In 2009, new policy guidance provided greater flexibility to use managed fires and the number of managed fires increased in some regions, but the total area generally remained the same. Similarly, after 2009, managed fires still burned primarily within or close to wilderness areas and away from WUI. The 2024 Wolf Fire may be an example of a new era of managed fires because it occurred prior to monsoon rains and adjacent to high value resources. It also is unique because it burned through old-growth ponderosa pine forest of the Long Valley Experimental Forest. Managed fires are generally less severe and result in smaller patches of high severity fires compared to full suppression wildfires, therefore this type of fire is what will be needed in order to restore

larger landscapes in the future. However, questions remain in terms of how and when to re-burn areas initially burned by low severity managed fires.

Satellite remote sensing and AI-based data processing for groundwater prediction in desert regions of the southern United States

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Abstract: Groundwater is a critical resource in the arid regions of the southern United States, where surface water is often scarce. Among various groundwater-related indicators, groundwater level (GWL) plays a central role in assessing availability, sustainability, and potential overuse. However, unlike surface water data, which can be collected relatively easily due to its visibility and accessibility, GWL data collection faces numerous challenges, including limited spatial and temporal coverage, high monitoring costs, and access or permitting restrictions. To overcome these limitations, this study proposes a novel GWL prediction model that leverages satellite-based remote sensing and artificial intelligence (AI). The model incorporates multiple input variables, including groundwater storage (GWS), evapotranspiration (ET), soil moisture, and snow water equivalent (SWE) from NASA's Gravity Recovery and Climate Experiment (GRACE), along with precipitation and temperature data from NASA's Prediction of Worldwide Energy Resources (POWER) project. The Albuquerque region in New Mexico was selected as the study site due to its representative arid climate and data availability. An artificial neural network (ANN) was employed to predict GWL, with the model being preceded by time lag and influencing factor analyses to account for region-specific hydroclimatic dynamics. Prediction accuracy was evaluated by comparing the model output with GWL data directly measured by the USGS, using the Pearson correlation coefficient and root mean squared error (RMSE) as performance metrics. The proposed model effectively reproduced observed GWL variations, including seasonal trends. Notably, incorporating time-lagged effects and dominant influencing variables tailored to local conditions significantly enhanced prediction accuracy and reduced computational demands.

Coexistence Strategies with Wildlife Shaped by Social Contexts

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Abstract: Social contexts of the communities interacting with wildlife contribute to the complexity of managing Human-wildlife interactions (HWI). Because social contexts, such as values, norms and knowledge of the communities interacting with wildlife, shape how communities perceive wildlife and strategies in place to manage HWI. However, current wildlife conservation efforts are prone to overlooking these complexities, regardless of their significance to achieving sustainable coexistence. Hence, this research aimed to understand the social contexts of farmer communities interacting with elephants (*Elephas maximus Maximus*), an ethnographic study. Eight focus group discussions were held with 10-15 farmers each in

purposely selected areas in Walsapugala village in Hambantota District in Southern Sri Lanka. This village experiences a rising number of human-elephant conflicts, including crop raiding, property damage, human deaths and injuries, as well as elephant deaths. Data collection took place over three months, from November 2024 to February 2025 and framed the coexistence strategies of farmers within the social contexts – values, norms and knowledge – and showed their intricacies. The results reveal (1) the emotional struggles of coexistence arising from the community's religious values associated with wildlife when it comes to strategies to protect their crop fields from elephants, (2) internal conflicts within the communities, and between the communities and the wildlife and land governance authorities, that show the level of community knowledge in terms of interacting with elephants and (3) the community's normative practices when interacting with elephants during crop-raiding incidents. Moreover, the findings highlighted the complexity of the interactions between wildlife and the communities, as well as the communities and authorities that govern human-wildlife interactions. This study highlights the important contribution of qualitative research on human-wildlife coexistence to the understanding of the complexities of HWI.

Status of riparian corridor health in the US-Mexico transboundary region

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Abstract: The Southwestern North America region, encompassing Arizona, California, New Mexico, and northern Mexico (Sonora and Baja California), is undergoing a long-term shift toward a drier climate. This trend, driven by climate change, is having consequences like groundwater depletion and altered hydrological regimes, and poses significant threats to the region's fragile ecosystems, including riparian corridors, montane forests, and wetlands. These environmental challenges prompt investigation into their impact on ecosystem preservation, habitat resilience, and water resource management. Our research aims to understand how ecohydrology in the United States - Mexico transboundary region is changing under ongoing climate pressures and increasing water scarcity. A central hypothesis is that vegetation indices (VIs) and evapotranspiration (ET), proxies for vegetation's health and water consumption, show a declining trend in key ecological zones, such as riparian corridors. We will employ a comprehensive framework combining Landsat-based remote sensing, evapotranspiration modeling, and machine learning techniques. Our goal is the reconstruction and analysis of historical records for VIs and ET, specifically for riparian areas. This will offer critical insights into the evolution of long-term environmental trends and help to depict future scenarios for the region. Differing national approaches to land cover mapping across the border makes it a challenge to identify and accurately delineate riparian areas. To address this problem, we will utilize the team's recently developed 30-meter resolution transboundary land cover map, which provides a consistent basis for analyzing land and water use across the United States - Mexico border and facilitates the extraction of biome-specific trends. By leveraging spaceborne remote sensing data, we expect to develop a unified cross-border framework for assessing

ecohydrological change that may be replicable for other areas of the world with similar characteristics, and to study other biomes.

Navajo Nation's Efforts to Address Drought and other Climate Concerns

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Abstract: The Navajo Nation is located within the high desert of the Colorado Plateau physiographic province with lands located in Arizona, New Mexico and Utah. The majority of the Navajo Nation is located within the Upper and Lower Colorado River Basins. The Navajo Nation has been subject to extremely dry years and developed a Drought Contingency Plan in 2003 that still provides a framework to address drought conditions today. The Navajo Nation has implemented policies, agreements and funding to address the impacts from drought and other climate concerns in an attempt to provide for a more reliable water supply and restore lands for future generations but challenges still remain.

Short and long term changes to riparian habitat and avifauna due to tamarisk beetles (*Diorhabda* spp.) herbivory and the necessity of urgent restoration.

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Abstract: Tamarisk (*Tamarix* spp.) is an exotic phreatophytic tree distributed across North America over the last century. One of the most common riparian trees found along western North American rivers, tamarisk is highly invasive and resilient. In 2001, northern tamarisk beetles (*Diorhabda carinulata*) were introduced as a biological control agent to control tamarisk in Utah and Nevada. Since the release of the northern tamarisk beetle, three other tamarisk beetle species (*D. elongata sublineata*, and *D. carinata*) have been released in the western United States. Tamarisk beetles eat tamarisk trees by consuming the leaves of the tree, often leading to complete defoliation of the plant. During defoliation events, tamarisk is limited in its ability to photosynthesize and store carbohydrates in its roots and over several years this can lead to significant branch and canopy dying back, and ultimately tree mortality. However, the degree of mortality appears to vary based on the genotype of tamarisk and the environmental conditions (i.e., soil salinity, water availability) of each plant. Landscape changes in riparian ecosystems include plant biomass, microclimate changes, and plant species diversity. Without active restoration, defoliation may result in low vegetation cover along many riparian corridors and/or the replacement of tamarisk by less desirable and faster growing herbaceous invasive plant species. These landscape changes could potentially affect riparian corridors throughout the southwest, particularly in those areas where tamarisk is the dominant overstory plant. With the release of tamarisk beetles in the United States, many conservationists are concerned about the impacts of defoliation on riparian-dependent fauna such as avifauna that breed in tamarisk,

particularly the endangered Southwestern Willow Flycatcher (*Empidonax traillii extimus*). We w discuss the short- and long-term effects of the tamarisk beetles on riparian vegetation, the resulta effects on riparian-dependent avifauna that can breed in tamarisk and the necessity of urgent restoration.

Pinyon pine seedlings acclimate to high elevation climate

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Abstract: Pinyon pine (*Pinus edulis*) is a drought tolerant tree native to the arid southwest. Regional climate continues to provide long-term drought and heat spells, necessitating the migration of pinyon trees to higher elevations as a coping mechanism against the ongoing climate stress. Moving higher in elevation comes with potential for increased frost exposure and freeze/thaw cycles that pinyon are becoming less exposed to every year. A lack of cold tolerance may inhibit pinyon's migration toward higher elevation and latitude. To further understand if cold tolerance is a trait acquired through local adaptation or acclimation to environmental stress, pinyon seeds from 10 populations across Northern Arizona were collected and planted in a multilevel common garden system. Pinyon seeds went through DNA demethylation treatment and variations in temperature during germination to assess influence of epigenetic modification and germination treatment on cold tolerance for potential restoration techniques in assisted migration efforts. In the fall, pinyon seedlings were the most cold tolerant in the cold, wet common garden and least at the warm, dry, and intermediate gardens. In the spring, seedlings in the intermediate garden had higher cold tolerance values compared to seedlings in both the cool, wet and warm, dry gardens. Germination temperature variation and demethylation treatments had no effect on cold tolerance of pinyon seedlings across the common gardens. Overall, pinyon pine cold tolerance was closer among seedlings' current environment at common gardens than seedlings source populations, showing ability to acclimate to current conditions, regardless of source climate. Pinyon's ability to acclimate to low temperatures and higher elevation climates shows the resiliency of the species and hope for the future of the pinyon-juniper woodland.

Catastrophic (unpredictable) Grand Canyon geologic hazards from Colorado River blockages caused by landslides and lava dams, and their paleolakes

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Abstract: Catastrophic geologic blockages of the Colorado River pose unpredictable geologic hazards for the Grand Canyon. Past events help us understand the scope of mitigation that would be needed for future events. The 1-2 Ma Surprise Valley Landslide set off at least 7 subsequent landslides, with continuing instability; these re-routed the river, carved Granite Narrows, and formed Deer Creek Falls and narrows. The river anticlines in Muav Gorge record a similar process of bedrock rotational landsliding on the Bright Angel Formation that is

happening today. Downstream, about 17 lava dams between 650,000 and 100,000 years ago blocked the river and formed paleolakes of still-unknown extent. At 55,600 years ago, new data suggests that a cliff collapse created “Nankoweap paleolake” that backed water to Lees Ferry and caused driftwood and slack-water deltaic sediments to be deposited high in Marble Canyon caves. Radiocarbon ages from two locations, including Stanton’s Cave, date the driftwood as $55,150 \pm 1,810$ years ($n=4$) and sediments associated with the driftwood give IRSL dates of $56,000 \pm 6,390$ years ($n=2$). A “striking coincidence” is that Meteor Crater impact happened at the same time; the combined dates are statistically indistinguishable at $55,600 \pm 1,300$ years for the impact and cave deposits. This suggests the hypothesis that the impact set off a M5.6 seismic event (attenuated to M3.5 at Grand Canyon), that caused cliff collapse, and development of a short-lived paleolake, all in a “geologic instant”. The likely durations of filling the paleolake with water in <100 years, with sediment in a few hundred years, and rapid erosion caused by the river overtopping the dam, are based on studies of modern concrete dams. Past blockages remind us of the inevitable fate of dams on the Colorado River and this work highlights seismic and landslide hazards in Grand Canyon.

Mobile apps for wildlife conservation and community engagement

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Abstract: NASA’s Earth Science Division has released a range of satellite products, including GEDI’s aboveground biomass data, which are transforming environmental monitoring. However, these products often lack ground-truth validation in areas with high biodiversity, such as the tropics. We address this gap by actively engaging local communities and citizen scientists to collect data on tree species that support validation of NASA’s aboveground biomass product. The project includes three core components: (1) collecting tree data the GLOBE Observer mobile app in areas overlapping with GEDI footprints; (2) conducting focus groups with Indigenous Peoples and Local Communities (IPLCs) to understand motivations, barriers, and desired outcomes of participation; and (3) expanding GLOBE’s reach across Kenya, Ecuador, and the United States through a best-practices framework for citizen science in and around protected areas where human-wildlife conflict is greatest. In Amboseli National Park, Kenya we are conducting in-depth case studies with IPLCs to explore how citizen science can support local knowledge systems and environmental stewardship, while also identifying the most useful data for their daily lives (e.g., agriculture or livestock). This work enhances human-wildlife coexistence by building local capacity to monitor forest structure—key to managing shared landscapes with wildlife, such as lions and elephants. By centering IPLC voices, our project strengthens both Earth systems science and human-wildlife coexistence.

Predictive Modeling of Fluvial-Aeolian Responses to Basin-Scale and Site-Specific Colorado River Management in Grand Canyon

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Abstract: Sediment erosion, deposition, and transport in semi-arid environments results from complex interactions of multiple geomorphic processes. Recent work emphasizes sediment connectivity across fluvial, aeolian, and hillslope landforms. For example, along the Colorado River within the Grand Canyon National Park (GCNP), river sandbars supply sediment for aeolian transport to adjacent dunes, illustrating the connectivity between these systems. Since the construction of Glen Canyon Dam, the Colorado River in GCNP has experienced a >90% reduction in sediment supply, loss of large-magnitude spring snowmelt-driven floods, reduced extreme low flows during periodic dry seasons and droughts, and an increase in average base flow discharge. Collectively, these changes have led to an increase in riparian vegetation and a sediment supply-limited condition for river sandbars and aeolian dune fields, which are critical for habitat, recreation, and cultural resource preservation.

We present two modeling approaches being developed by USGS and collaborators to provide river managers information related to aeolian processes for their decision making. The first uses river hydrographs to estimate 1) the supply of river sand available for aeolian transport, 2) the probability of floods that resupply sandbars, and 3) the vegetation cover on subaerial river sand deposits that limits aeolian transport. Comparing model results with field observations of topographic changes demonstrates the potential to forecast large-scale topographic volume changes and their consequences for sediment connectivity across landforms.

The second approach employs a process-based model to assess linkages between sandbar state, river stage, and local vegetation on aeolian sediment transport rates and the evolution of adjacent dune landforms. The AeoliS model, originally developed for coastal systems, is adapted here for river-adjacent dunes. We present results that demonstrate its predictive capabilities. Both approaches offer valuable tools for predicting sediment transport and guiding adaptive management, with each framework providing critical insights for understanding complexity in dryland river systems.

Physiological Responses of Pinyon Pine (*Pinus edulis*) to Drought and Elevated CO₂ in a Changing Climate

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Abstract: Pinyon pine (*Pinus edulis*) woodlands, which cover much of the Southwestern United States, are becoming increasingly vulnerable to climate driven stressors, such as prolonged drought. As global temperature continues to increase, the frequency and intensity of global change type droughts are expected to increase resulting in widespread ecological consequences to the landscape. In 2021, the southwestern landscapes endured severe drought conditions, raising concern for the future of Pinyon pine woodlands as post-drought

assessments revealed alarming mortality rates. For example, a severe drought in the early 2000's led to a 40% die-off of mature tree stands in northern Arizona (Ogle et al., 2000). It has been shown that elevated atmospheric CO₂ has been linked with increased water-use efficiency (WUE) in Pinyon pine trees. It remains uncertain whether these potential benefits are enough to help Pinyon pine trees survive the worsening impacts of ongoing prolonged droughts and water scarcity. This is especially concerning as climate change is projected to intensify such conditions. Our goal for this project is to investigate how Pinyon pine trees grow prior to and after large increases of CO₂ to determine the influence that CO₂ has on their annual ring-width growth. To accomplish this, we will be using a combination of ground truthing data to determine the amount of tree mortality along with tree ring analysis to help reveal the gradual changes of climatic variables on tree growth between high and low mortality Pinyon pine plots. We hypothesize that elevated CO₂ will initially enhance Pinyon pine growth, but once drought severity surpasses a threshold, water stress will outweigh CO₂ benefits, leading to reduced or stagnant growth.

Ecosystem recovery from acute water stress across the western United States

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Abstract: Drought stress has led to widespread decreases in ecosystem carbon uptake. Observational and modeling studies suggest that prolonged drought can lead to delayed recovery of photosynthesis and plant growth. Projected increases in the severity and frequency of droughts puts ecosystems at further risk of interrupted recovery. In addition to slow-forming and long-lasting drought, various ecosystems experience acute (rapidly evolving) water stress, often termed “flash” droughts. Flash droughts consist of rapid soil moisture declines with reported declines in ecosystem productivity. Once these flash droughts pass, ecosystems are expected to recover from the short-term impacts of the drought, but little is known about this recovery process. It is unclear whether flash droughts result in a delayed recovery that cannot be explained by ecosystem memory, where memory describes the sensitivity of the ecosystem to past environmental conditions. Thus, we ask: do flash droughts leave an impact (“legacy”) on the net ecosystem exchange of CO₂ (NEE) that cannot be explained by environmental memory? To address this, we first identify flash droughts based on rapid soil moisture declines across multiple sites in the western USA using observations of soil moisture at 2-3 depths collected at Ameriflux eddy covariance tower sites. Then, we use observations of NEE and accompanying environmental variables to fit memory-aware models that include varying effects of past environmental conditions on NEE. We identified a total of 879 flash droughts across 24 sites from 2000 to 2024. During recovery from some of the flash droughts, the observed net ecosystem CO₂ sink was either reduced or enhanced compared to expectations from the memory-aware models of NEE. Both woody and grassland sites experienced legacy effects during recovery from flash droughts. Our findings point to the need for increased understanding of the unique impacts of rapidly evolving water stress conditions on ecosystem function.

Dominant perennial grass (*Pleuraphis jamesii*) exhibits flexible responses to changes in precipitation seasonality

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Abstract: Environmental gradients are strong drivers of genetic and phenotypic variation within species. The North American Monsoon creates a precipitation seasonality gradient across the Colorado Plateau, from summer-dominated precipitation in the southern Plateau to winter-dominated precipitation in the northwest. *Pleuraphis jamesii* is a dominant rhizomatous C4 perennial grass that is useful for semi-arid grassland restoration, and its range spans this precipitation seasonality gradient. We used a common garden experiment to examine how genetic and phenotypic variation of *P. jamesii* relates to the precipitation seasonality of source locations and experimental conditions. Understanding the plasticity of plant source populations across climate gradients can improve restoration success under current and emerging climate conditions.

We investigated responses of *P. jamesii* individuals from four populations sourced across the precipitation seasonality gradient under three seasonal precipitation treatments: (1) spring-dominated watering, (2) summer-dominated watering, and (3) intermediate watering where equal water was applied during spring and summer. We quantified genetic, physiologic and growth differences using DNA sequencing, leaf water potential, net photosynthesis, and above-ground biomass.

While the four populations differed genetically, we did not detect consistent significant differences in physiology and growth metrics, within or across seasonal precipitation treatments. We did not find evidence for local adaptation to seasonal timing of precipitation, as shown by the lack of significant interaction between population and treatment across all physiology and growth models. Instead, our results indicate that *P. jamesii* is adapted to highly variable precipitation timing, even across genetically distinct populations. These results suggest that in such a highly variable environment, traits enabling flexible responses to precipitation timing may have been selected over local adaptation. If restoration goals include resistance to variable or changing precipitation seasonality, our study suggests that *P. jamesii* is a well-suited species regardless of source population.

Tradeoffs between homeothermic leaf cooling and hydraulic safety in a widely distributed warm desert riparian tree species, *Populus fremontii*

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Abstract: For many plants exposed to heatwaves, leaf transpirational cooling is critical to avoid leaf damage, but often at the risk of hydraulic failure. The inevitable tradeoff between leaf cooling and hydraulic risk taking, we anticipate, results in a continuum of plant water use strategies depending on local adaptation to atmospheric aridity and soil water availability. We hypothesize that genotypes from populations occurring at the warm edge of a species distribution maintain cooler leaves as a consequence of greater transpirational cooling during summer heatwaves, but with the tradeoff of operating with smaller hydraulic safety margins, compared to genotypes adapted to cooler locations. To test this hypothesis, genotypes of the widely distributed, southwestern US riparian tree species *Populus fremontii* (Fremont cottonwood) were grown in a common garden setting in Phoenix, Arizona near the warm edge of the climate distribution. The genotypes were sourced along a *ca.* 1500m elevation (6.7°C thermal) gradient. A brief drought treatment was also applied. Mean leaf turgor loss point (Y_{TLP}) was similar among the populations, averaging -2.9MPa. However, when maximum temperatures exceeded 45°C a record 17 consecutive days in July, mean afternoon stomatal conductance (g_s), and leaf temperature (T_{leaf}) were highly differentiated by source population, despite similarities in Y_{TLP} . Specifically, low-elevation (warm-adapted) populations maintained a higher mean afternoon g_s , and cooled leaves on average 5°C below afternoon air temperatures (T_{air}). This highly pronounced homeothermic leaf cooling corresponded with also having a lower mean midday leaf water potential than the high-elevation populations. A significant decrease in g_s and DT ($T_{leaf}-T_{air}$) occurred during the drought, with T_{leaf} exceeding T_{air} that was followed by partial canopy dieback. This study indicates that increases in heatwave duration, frequency and intensity will fundamentally reduce the hydraulic niche of many plant species that are adapted to prioritize homeothermic leaf cooling over hydraulic safety.

Community wildfire mitigation in the greater Santa Fe fireshed

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Abstract: There is no one-size fits all approach to community wildfire mitigation, and each community and landscape needs to pursue and develop approaches that fit their social, cultural, economic, and wildfire risk needs. The National Cohesive Wildland Fire Strategy recognized that fire adapted communities – communities that acknowledge and take steps to reduce their wildfire exposure – are one of the three core pillars of the Strategy. Fire adapted communities are also one of the most variable and complex elements of the Strategy and therefore need financial and programmatic support paired with intentional learning to increase the pace and

scale of the effort, and lead to better wildfire outcomes. Since late 2015 when the Greater Santa Fe Fireshed Coalition formed, it has been at the forefront of fire adaptation. This adaptation was accelerated in 2024 when the Forest Stewards Guild, a founding Coalition member, was awarded a Community Wildfire Mitigation Grant award. This new grant program afforded the Fireshed landscape with an influx of funding to expand the Fireshed Neighborhood Ambassador program, support core Coalition functions, and deploy the largest mitigation funding source to date to create defensible space around structures in communities. This led to the rapid acceleration of adaptive communication, navigation of bureaucratic challenges, implementation of treatments in wealthy neighborhoods, and expansion of access for low-income and underserved residents—all while addressing complex misinformation dynamics in the landscape. Initial findings from the first year and a half of implementation indicate that flexibility, cooperation, and organizational resilience were critical to early program success.

The Power of Place: Honoring Havasupai Gardens Through Art and Language

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Abstract: Havasupai Gardens, a popular campground and day use area halfway down the Bright Angel Trail in Grand Canyon National Park, is an important site culturally, biologically, and recreationally. The park and the Havasupai Tribe worked together to officially rename this site Havasupai Gardens in 2022, to recognize the Havasupai people that were forced to relocate by the National Park Service in the 1920s. The park and the Havasupai Tribe are collaborating on new illustrated welcome waysides for the area that will acknowledge the multifold significance of this place. These signs will have general orientation information and a map of the campground, surrounded by scientific illustrations of plants and animals native to the area. Importantly, all information on the signs will be bilingual with Havasupai—from a welcome message to the names of local wildlife. Hand-drawn illustrations of native plants and animals combined with their names in Havasupai will help people connect more deeply with this place and recognize its biological and cultural significance, whether they are passing through on a day hike or spending multiple days in this special place.

Designing Field Safety Curriculum for Early Career Biologists: A Graduate Student–Led Initiative

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Abstract: Too often, early-career field scientists are handed gear and a location, but not the tools to stay safe, advocate for themselves, or navigate inequities in the field. We set out to change that. At Northern Arizona University, we created and lead the NAU Field Safety Working Group’s graduate-level training course and, building on its success, launched *Field Safety for Early Career Biologists*—a free, two-day program tailored for undergraduates in

NSF-REU, NSF-RaMP, and other summer research programs, many recruited from Navajo Technical University and other Southwestern institutions. Over the past three years, we have trained 60 undergraduate students and 34 graduate students through these initiatives. The curriculum targets three essentials: (1) risk management and assessment methods; (2) greenhouse and field safety practices; and (3) strategies for sustaining physical and mental well-being in remote or high-pressure environments. We adapted our graduate curriculum into accessible, hands-on modules featuring peer-led discussions, real-world case studies, and role-play scenarios to help students navigate power dynamics, advocate for themselves, and recognize inequities in fieldwork. Learning objectives intentionally integrate identity-aware practices that acknowledge and address challenges faced by BIPOC, LGBTQ+, disabled, and first-generation researchers. Feedback was clear: students left with stronger technical skills, greater confidence, and the ability to speak up when conditions were unsafe. This graduate-student-led model embeds safety, inclusivity, and professional growth into early-career research training and equips the next generation of scientists to thrive in diverse and challenging field environments. Implementation of such programs has the potential to improve retention and success of students in STEM, particularly in field-based research.

OpenET Data Support for Adaptation and Mitigation Across the Colorado River Basin

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¹OpenET

Abstract: As climate change accelerates aridification in the Colorado River Basin, decision-makers require transparent, timely, and actionable data to balance mitigation and adaptation strategies. OpenET provides open-access, field-scale evapotranspiration (ET) data derived from satellites and an ensemble of well-established models, enabling consistent tracking of water use across western landscapes. This presentation highlights how OpenET supports drought response, conservation programs, and planning efforts by delivering scientifically rigorous ET data through user-friendly tools and APIs.

Lidar characterization of caves and underground rivers in the Grand Canyon

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Abstract: Karstic springs are the largest springs in the Grand Canyon by volume and are critical for supporting wildlife, vegetation, and communities. However, the mechanisms that determine spring recharge and behavior are not well understood, complicating resource

management and protection. Recent advancements in technology have enabled caves related to these springs to be mapped in three-dimensions at decimeter-scale resolution. We present what lidar scan data tells us about flow paths hundreds of meters below the North Rim. Lidar characterization enables researchers and the public to visualize over 10 km of remote cave in an intuitive format. Our data shows consistent patterns in the shape of cave passages across the plateau, which suggest present-day groundwater flow paths are dependent on existing geologic structures within the rock mass. These interactive models provide a valuable window into complex and remote sub-terranean environments, which can be vulnerable to groundwater decline and contamination.

Shedding Light on the Southwest Spring Firefly: Innovations in Survey Methods and Ecological Investigations in Arizona

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Abstract: At least 35 species of firefly have been documented in the southwestern United States with four considered vulnerable to extinction. One of these, the southwest spring firefly (*Bicellonycha wickershamorum*), is known only from Arizona, New Mexico, and Sonora, Mexico. This species was petitioned for listing under the Endangered Species Act in 2023, yet substantial knowledge gaps remain regarding its habitat needs, activity period, abundance, and dispersal ability. Additionally, methods for surveying fireflies are limited, with no efficient methods available to account for imperfect detections. To address these needs, we asked the following research questions: 1) How does firefly abundance and distribution vary with environmental features, such as vegetation cover, soil moisture, humidity, and distance to water? and 2) Is distance sampling a viable method for surveying fireflies? In summer 2024, we used distance sampling to survey fireflies at 10 locations within a preserve in southern Arizona, totaling 73 surveys over a 9-week period. In summer 2025, we expanded to over 200 locations within the preserve surveyed in late June and mid-July. Preliminary results suggest the activity period for adult southwest spring fireflies begins in early- to mid-June, peaks from late June to mid-July, and decreases from late-July into August. Most individuals were observed near a stream, though their distance from the stream appeared to increase with increasing humidity. Our findings suggest that distance sampling is a promising method for surveying fireflies when at low densities. Data collection and analysis are ongoing, and we will present additional preliminary results from the 2025 field season.

Small organisms, big impacts: Monitoring biocrust carbon cycling in response to drought and disturbance

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Abstract: Drylands are a principal driver of both the trend and interannual variability of Earth's atmospheric CO₂ concentrations. A key cover type in these systems is biological soil crust (biocrust)—assemblages of bryophytes, lichens, and cyanobacteria that stabilize soil surfaces and influence biogeochemical cycling. However, the role of biocrusts in carbon cycling remains poorly quantified, especially under changing climate and land-use regimes. We examined net soil CO₂ exchange (NSE) and associated microclimate dynamics in a biocrusted region of the Sonoran Desert over 30 months across four climate and disturbance treatments. NSE and soil microclimate data were measured hourly using transparent automated chambers; $\delta^{13}\text{C}$ of CO₂ was measured for 8 months, and soil carbon and nitrogen were sampled at multiple time points. NSE varied strongly with biocrust cover: intact biocrust communities exhibited both the highest CO₂ uptake and loss, while disturbed biocrust showed no CO₂ uptake and only respiration fluxes. In biocrusted plots, NSE was tightly linked to temperature and precipitation: cool, wet periods drove net CO₂ uptake, while warm or warm-wet periods led to net CO₂ loss. Diurnal patterns in $\delta^{13}\text{C}$ suggest a temporal disconnect between CO₂ released via abiotic and biotic processes. Biogeochemical analysis show drought-induced shifts in microbial carbon and nitrogen pools, underscoring microbial sensitivity to changes in climate. Together, these results demonstrate that biocrusted soils contain multiple components essential to understanding dryland carbon cycling—and that climate change and land-use disturbances significantly reduce their capacity for carbon uptake, with far-reaching implications for carbon storage across global drylands.

Biocrusts in a changing world: insights from climate and disturbance experiments

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Abstract: Biological soil crusts (biocrusts)—assemblages of bryophytes, lichens, and cyanobacteria—are widespread across drylands, covering approximately 12% of Earth's terrestrial surface. Biocrusts play key roles in regulating soil stability and biogeochemical cycling in these ecosystems, yet are highly vulnerable to climate change, wildfire, and land use disturbances. Here, we share findings from a suite of long-term experiments across the U.S. Southwest examining biocrust responses to wildfire, experimental warming, drought, and physical disturbance. As some of these studies approach their 20-year mark, we are synthesizing the results and reflecting on what we've learned about biocrust sensitivity to anthropogenic change, as well as the cascading effects of losing biocrusts. Biocrusts are sensitive to many disturbance types, and in many cases, their failure to recover following disturbance could result from the compounding effects of rising temperatures, invasive annual grass encroachment, and persistent ambient drought across the region. Moreover, the research shows that losing biocrust in these ecosystems triggers important ecosystem feedbacks,

including declines in soil stability and carbon sequestration and increasing soil surface temperatures. Together, these experiments offer critical insight into an essential dryland ecosystem component—biocrust—and reveal what our desert landscapes may become without them.

Constructed value of information to prioritize critical uncertainties

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Abstract: In the last decade, value of information analysis has been increasingly applied in natural resource management decision making processes. Value of information analyses have direct relevance to managers, as they quantify the expected improvement in management outcomes if all or partial uncertainties were resolved through research and monitoring. For decision contexts in which there is an urgency to act, traditional forms of value of information analysis may be infeasible due to their quantitative demands. Constructed value of information (CVoI) is a newly developed tool that can be used to prioritize uncertainties using three simple attributes that describe the likelihood that resolving the uncertainty will lead to improved management outcomes, the magnitude of the uncertainty, and the feasibility of reducing the uncertainty through research and monitoring. Each attribute can be elicited from experts in participatory settings using a simple, customizable rubric tailored to the decision problem. Results of CVoI elicitations are often visualized to highlight tradeoffs among attributes in a transparent way that is easy for participants with diverse levels of quantitative training to understand. Despite its recent development, CVoI has already been used in a variety of wildlife applications including habitat management, endangered species translocation, stewardship of trust resources, and identifying research priorities for species working groups. Here we will describe the theoretical origins of CVoI and how they map to traditional VoI, describe best practices for CVoI elicitation, and discuss potential opportunities for CVoI application within the Colorado Plateau system.

Vapor Pressure Deficit as an indicator for Fire Danger in Wildland Fire Management

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Abstract: Vapor Pressure Deficit (VPD) may be a better indicator for fire danger than the traditional Burning Index (BI) when paired with the Energy Release Component (ERC) as the seasonal dryness indicator. While comparing BI and VPD side by side for a season, they both predicted relatively the same except in two notable scenarios. In dry winters, BI may over predict fire danger outside of peak fire season. During peak fire season BI can be slower to react to atmospheric changes after moisture events that greatly influence daily fire danger and potential. The drawback to VPD is that unlike BI, wind is not part of the equation. However, the Hot Dry Windy Index (HDWI) uses VPD and wind making it potentially an equivalent replacement to BI that has a higher level of accuracy in predicting fire danger across the entire year.

Plant Based Restoration and Seed Increase Needs for the Navajo Nation

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Abstract: Grazing pressures are high throughout the Navajo Nation. Much of the land is utilized by the Diné people to raise livestock for their livelihoods but is intensified from the estimated number of 100,000 feral horses that reside on the Nation. Not only is this apparent on the grasslands that cover most of the Nation, but springs and riparian show the alarming effects from this grazing pressure. It has become apparent that the need for genetically appropriate and locally sourced plant materials is needed for restoration efforts across the landscape. The Diné Native Plant Program has worked tirelessly to collect seeds throughout the Nation, collaborate with local farmers to increase plant material production, and to have grown their own materials to successfully implement in restoration projects.

Challenges in Drought Assessment: Priority Actions & Research Needs

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Abstract: What is a drought? It is generally accepted that drought is a prolonged and impactful period of dry weather, but when it comes to measuring or assessing drought, it is not so straightforward. How dry is "dry"? How long is "prolonged"? What does "impactful" mean? These questions will have different answers for different climates, times of the year, and sectors of the economy. Do current methods for assessing drought conditions consistently and deliberately consider non-stationarity? How should drought be defined in regions that are trending hotter or drier? NOAA's National Integrated Drought Information System (NIDIS) recently worked with partners across levels of government and sectors to address these very important questions. This presentation will highlight 10 unanswered research questions or priority actions that will help progress the science of drought assessment in a changing climate.

Quantifying the effects of mechanical removal on population dynamics of invasive Channel Catfish (*Ictalurus punctatus*)

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Abstract: Invasive species are top contributors to biodiversity loss and pose major threats to ecosystems. Biological invasions cost billions of dollars annually in damages and control efforts aimed at restoring ecological communities and conserving declining species. However, efforts to reduce invasive species often fail without a comprehensive understanding of how specific actions contribute to sustainable population control and recovery of native species. Predictive models are valuable tools for analyzing invasive species dynamics over time and can evaluate how specific management actions reduce invasive populations to support native

species recovery. Channel Catfish (*Ictalurus punctatus*), a commonly introduced fish species in North America, have thrived as an invasive species in the San Juan River for decades despite mechanical removal efforts. Consequently, there is a need to assess Channel Catfish population dynamics in relation to removal efforts and identify new strategies for effective management. We used a statistical catch-at-age model to estimate changes in age-specific Channel Catfish abundance over three decades of mechanical removal efforts and to explore the effectiveness of potential alternative control strategies for reducing abundance. Our model revealed substantial temporal variation in catfish abundance throughout the removal period, with a three-fold increase in the first 14 years, followed by a gradual decline when efforts were intensified. Gear selectivity was highest for larger fish, resulting in a shift in age structure towards smaller fish. Increased discharge and temperature marginally reduced recruitment. Future projections suggest that the intensity of current removal efforts would need to increase by at least 5x to reduce biomass to 15% of the current population within 10 years. While removal efforts have been effective in reducing biomass, achieving major and sustained reductions with current approaches would require substantially more effort. Future control projects should consider fitting population models as early as data are available to guide large-scale management efforts.

Analysis of Storm Pulses and Associated Precipitation Events in North Rim Springs, Grand Canyon National Park

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Abstract: The National Park Service is interested in determining what parts of the Kaibab Plateau drain to Roaring Springs, the current sole drinking water source for Grand Canyon National Park. This will help identify critical vulnerabilities of water resources to be considered during the development of infrastructure on the North Rim. From anecdotal observations of storm pulses, water can move through the aquifer in days to weeks. This rapid movement through faults, fractures, and caves does little to filter out contaminants which makes Roaring Springs, and the numerous other North Rim springs, highly vulnerable to surface contamination. To help determine the recharge area for Roaring Springs, the NPS has employed two different approaches, (1) dye tracing to link individual sinkholes with springs, and (2) using the radar-derived spatial footprints of storms that cause a pulse in the spring's discharge. Here, we report recent results using this second method with storm pulse events from 2012-2024 at Roaring, Tapeats, and Emmett Springs. The limitations of this method come from the small number of storm pulses that have been observed and the fact that most pulses resulted from widespread precipitation events that do little to constrain the recharge area. Despite the difficulties of this approach, there are a few storm events that provide valuable information about the recharge area. Storms that hit only the northern two-thirds of the Kaibab Plateau produce pulses at Tapeats Spring but not Roaring or Emmett Springs, while storms impacting the southernmost part of the plateau produce pulses at Roaring and/or Emmett, but not at Tapeats. Although the picture these pulses paint is still imprecise, as we collect data on more storm pulses, we expect the methodology developed in this study to provide an increasingly clear image of the recharge areas for these springs.

WaterSMART Drought Response Program: Advancing Drought Resilience in the Western United States

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Abstract: The Bureau of Reclamation's WaterSMART Program plays a critical role in enhancing drought resilience and promoting long-term water sustainability across the western United States. Through a suite of technical and financial assistance programs, WaterSMART supports a broad range of water management initiatives, from infrastructure modernization and water reuse to habitat restoration and drought preparedness.

This presentation will focus on the WaterSMART Drought Response Program, highlighting its two primary components: Drought Contingency Planning and Drought Resiliency Projects.

Drought Contingency Planning provides assistance to develop locally driven, stakeholder-informed plans that assess drought risks and identify actionable mitigation strategies. These plans serve as a foundation for future implementation efforts and help communities incorporate climate data, hydrologic modeling, and risk analysis into their water management frameworks.

Drought Resiliency Projects support infrastructure and operational improvements designed to reduce drought vulnerabilities. These include, but are not limited to, groundwater recharge, aquifer storage and recovery, advanced metering, and water reuse technologies that enhance water supply reliability.

To date, WaterSMART has supported over 2,300 projects, leveraging more than \$12 billion in combined federal and non-federal investments. Gain insights into how the Drought Response Program is helping water managers across the West prepare for and respond to drought.

An overview of the Emory oak socio-ecological system: Cultural significance of Emory oaks

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Abstract: For generations, Emory oak (*Quercus emoryi*) acorns have held deep cultural, spiritual, and nutritional significance for Western Apache communities. In this session, Apache Elders will share perspectives on the vital role that acorn harvest plays in sustaining Apache identity, community well-being, and traditional lifeways. These teachings include stories, values, and practices passed down through generations that guide respectful harvest and stewardship of oak groves. They will also discuss the challenges to preserving and encouraging Emory oak groves in an era where groves are threatened by land development, climate change, and lack of traditional management techniques to revitalize and preserve this sacred connection for future generations.

Data back: Indigenous-led, community-based monitoring of pinyon-juniper woodlands

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Abstract: Recent droughts, wildfires, pests and pathogens have resulted in extensive tree die-off of dryland forests dominated by pinyon pine across eastern and southern California. Pinyon pine seeds/nuts are a culturally significant food source for Indigenous nations and communities who have been stewards of pinyon-juniper woodlands since time immemorial. However, today, many Tribal Nations cannot care for pinyon pine trees, as they previously did, because of colonial land dispossession that forced communities out of woodland ecosystems. Limitations on management of traditional gathering areas further affects stewardship of lands that are within Indigenous ancestral homelands threatening the cultural and ecological vitality of pinyon pine. In response to widespread pinyon pine mortality, the Bishop Paiute Tribe created the Tribal Citizen Wunupu (Pinyon, Pine Nut Tree) survey. The Tribal Citizen Wunupu is an Indigenous-led community-based monitoring program for pinyon health to identify populations to protect and conserve in traditional gathering areas (outside of reservation boundaries) using an easily accessible mobile app (ArcGIS Survey123). Since its development, Tribal monitors and partners have submitted 250 observations across traditional gathering areas, identifying regions of woodland resilience, seed production, and decline. Here, we present our community-based research framework that ensures that Indigenous-led stewardship is centered and respected throughout the process. We discuss how the data life cycle (e.g. collection, ownership, storage, and sharing) was determined by the Tribes and grounded in Indigenous Data Sovereignty principles. Finally, we present insights on how adaptive and community-based natural resource management can address the multifaceted challenges pinyon-juniper woodlands face through hypothesis-driven data collection and analyses that were co-produced. Overall, the framework presented here can help Tribes and researchers build community-based networks that center and uplift Tribal-led initiatives and develop innovative and adaptive management solutions that ensure the cultural and ecological vitality of landscapes like the pinyon-juniper ecosystem.

Exploring uncertainty surrounding freshwater flow management decision making for the controversial Delta Smelt

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Abstract: Freshwater management has been an area of focus and controversy in California, USA. Construction of numerous reservoirs and water diversion facilities throughout the state, while critical to the state's economy, have contributed to the decline of many native species. The endangered Delta Smelt (*Hypomesus transpacificus*) is endemic to the Sacramento-San Joaquin Delta (Delta), the heart of California's complex water conveyance system. To aid the recovery of Delta Smelt, an action to increase freshwater outflow through the Delta in the fall has been implemented in wet years since 2011, requiring a large amount of water either released from storage or made unavailable to export for human consumptive uses. Evaluating the trade-offs between different water uses is made even more difficult by uncertainties in the predicted fish response. Using examples from different iterations of a Delta Smelt individual-based model that spans the species' life cycle, we showcased how uncertainties surrounding environmental flow actions can be assessed through a structured decision-making framework. We also demonstrated when and where there was value of information in resolving structural uncertainty, and how the value of information was affected by the objective weights. Our study serves as an example of how scientific uncertainty, even if large, may not be relevant to a decision maker, and how value of information analysis can be used to guide future conservation conversation in an overallocated system such as California.

Comparing Elemental Signatures Between Fossilized and Live Biocrust in Sedona

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Abstract: Biological soil crusts, also known as biocrusts, are microbial communities that form crusts on Earth's soil surfaces. Biocrusts can be found wherever there is exposed soil, including the arid regions of the Southwestern United States. These communities provide an

array of benefits to their environments, including soil stabilization, retention of soil moisture, and increased water infiltration. Biocrusts contribute to nutrient cycling and serve as a crucial component in maintaining the health of dryland ecosystems. Additionally, soils contain nutrients necessary for plant growth, the lack of soil aggregation results in nutrients becoming less available, negatively impacting ecosystem productivity. The benefits of biocrusts may counteract these negative effects on the landscape because they are capable of nitrogen fixation and carbon cycling. However, there is still much to learn about how biocrusts transport elements laterally across the landscape. Here we present preliminary results showing how nutrients move through biocrusts laterally possibly increasing ecosystem fertility. We use a portable x-ray fluorescence spectrometer, to analyze changes in elemental composition over time. We will measure elemental composition of live biocrust, fossil biocrust, and nearby bare rock to understand how life moves elements like phosphorus and how long this change remains.

Climate-growth relationships from tree rings show no overall benefit of warming for a keystone and threatened high-elevation pine

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Abstract: Climate change poses an existential threat to biodiversity; reliable modeling approaches are needed that can accurately capture this risk. The current dominant method for assessing climate-driven extinction risk, species distribution modeling, is problematic because it relies on space-for-time substitution, which predicts the equilibrium species' geographic distribution. In order for a species to reach this equilibrium, cool-edge individuals should benefit from warming, whereas warm-edge individuals should suffer, known as leading edge-trailing edge range dynamics. In reality, the timescales of processes that influence a species' response to changing climate vary from fast to slow, and a transient risk of extinction can arise if warming exceeds individual-scale climate tolerances along with the pace of evolution and/or dispersal. Here, we focus on a high-elevation tree species to test whether its response to time-varying climate follows equilibrium expectations or instead reflects a transient risk of extinction. We evaluated this in whitebark pine using a spatial network of 255 tree-ring time series from unbiased forest inventory plots across the interior western U.S. (86% of its U.S. range). We modeled ring-width variability with a mixed effects statistical model including tree size, time- and spatially-varying climate variables, their interactions, and tree-level random effects as predictor variables. We detected a negative response of tree growth to warmer-than-average summer temperature and a positive response to total water year precipitation. A significant negative interaction between time-varying and spatially-varying temperature indicates that although the effect of warmer-than-average temperature is weaker at cold sites, cool-edge trees still do not benefit from warming. These results suggest that, for whitebark pine to persist in the interior western U.S., evolution or dispersal must outpace rapid anthropogenic climate change. In the context of other threats and analyses of its demography, active restoration and management interventions are necessary to support this species.

Implications of flow management on biogeomorphic feedbacks on the Green River, Utah

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Abstract: In the Colorado River watershed, decreases in peak flows have coincided with channel narrowing and degradation of habitat for native fishes. To better understand the channel narrowing process, we analyzed plant species occurrence, changes in elevation, and inundation duration for four consecutive years (2020-2023) in over 2000 1-m² plots along the Green River between Jensen and Ouray, Utah. Mean percent vegetative cover of plots near the channel increased during a moderately low-flow year (2021) and an average flow-year (2022), but slightly decreased in a moderately high flow year (2023). In the average and moderately high flow years, sediment deposition increased elevation of densely vegetated plots compared with sparsely vegetated plots. Plots that increased in elevation were dominated by a mix of annual herbs and grasses as well as perennial woody species, particularly coyote willow (*Salix exigua*) with lesser abundance of Fremont cottonwood (*Populus fremontii*) and tamarisk (*Tamarix* sp.). The annuals have little opportunity to influence sediment deposition due to the timing of the spring flows early in the growing season. However, the stems of the perennial woody species entrap sediment and promote sediment deposition, while their roots retard erosion. Annual drone imagery of the same 20km reach of the Green River confirms this relationship between reduced flow and channel narrowing. Our results show that encroachment of woody plants in low flow years is subsequently causing entrapment of sediment and reduced erosion in higher-flow years creating a positive feedback loop between vegetation establishment and sediment transport processes. This process may explain why multi-year droughts have been strongly associated with narrowing along the Green River. It is yet to be determined whether large floods can reverse the narrowing, how narrowing influences fish habitat, and how variation in sediment load influences this process.

Fire Science in Action: New Fire and Fuels Resources for the Southwest

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Abstract: The Southwest Fire Science Consortium (SWFSC) is advancing the accessibility and usability of fire science to support informed decision-making across the region. This session will introduce new tools and resources developed to meet the needs of fire, fuels, natural resource, and land managers, as well as researchers, educators, and community leaders. To ensure timely, science-based information reaches those working on the ground, SWFSC has broadened its outreach strategies. Recent efforts include a widely viewed webinar series—garnering over 14,000 YouTube views in two years—featuring topics such as post-wildfire recovery, fire behavior, tribal forest policy, and habitat management. A companion podcast

series, along with 53 workshops, trainings, field tours, and conferences engaging more than 6,400 participants, reflects a strong commitment to diverse, practitioner-informed formats.

SWFSC also continues to translate emerging science into practical tools. These include fact sheets and videos on identifying the best available science, wildfire prevention strategies, and an animated series on fire regimes in Southwestern ecosystems. A landmark report on fire in the Sonoran Desert and a short documentary highlighting the integration of Western Science and Traditional Ecological Knowledge in the post-fire restoration of Santa Clara Canyon offer in-depth, regionally tailored insights. Educational outreach—such as the Fire Ecology Learning Lab—has reached more than 16,000 students, helping build long-term capacity in wildfire literacy.

This presentation will guide attendees through these co-produced resources, demonstrating how they can be applied to inform planning, operations, and policy. Whether managing landscapes, engaging communities, or teaching fire ecology, participants will find tools to support more resilient, fire-adapted ecosystems in the Southwest.

Collaborative Fire Science with Tribes and Pueblos in the Southwest

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Abstract: The Southwest Fire Science Consortium (SWFSC) partners with Tribes and Pueblos across the Southwest to support Indigenous-led fire stewardship, facilitate knowledge exchange, and promote culturally grounded approaches to fire management. This presentation will highlight several current efforts that center Indigenous leadership and priorities in fire science and policy.

Key initiatives include the 2024 Arizona Tribal Fire and Climate Resilience Summit, which convened Tribal fire practitioners, researchers, and agency partners to address wildfire and climate challenges through collaborative dialogue. Planning is underway for a follow-up event in 2026. We will also share a preview of a documentary film co-produced with Santa Clara Pueblo, telling the story of post-fire restoration in Santa Clara Canyon and the cultural values that guide recovery.

Other featured projects include the Southwest Indigenous Fire Stewardship Annotated Bibliography, a resource for those seeking to learn from Indigenous fire knowledge, and a webinar series on key federal policies impacting Tribes—such as the Tribal Forest Protection Act (TFPA), Reserved Treaty Rights Lands (RTRL), and 638 authority. The presentation will also touch on efforts to recognize Indigenous Knowledge as “Best Available Science” in land management and policy.

Together, these examples reflect SWFSC’s commitment to collaborative, respectful, and reciprocal approaches that elevate Indigenous perspectives in fire management across the Southwest.

Effects of Drought and Grazing Timing on Rangeland Plant Cover

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Abstract: Plant species in dryland ecosystems face challenges to survival as water-limitations inhibit plant growth and recovery and can be further challenged by prolonged drought and livestock grazing. Here we experimentally investigate the combined effects of cattle grazing and drought at two sites located in the Indian Creek area of southern Utah, a region defined by its aridity and historical ranching. The study occurred from spring 2021 to fall 2024 through the implementation of drought shelters and vegetation removal and trampling intended to mimic the patterns of ranching herds. After two baseline sampling collections, drought shelters were installed over half the experimental plots from fall 2021 to fall 2023; monitoring continued for another year to track recovery of the droughted plot communities. The effects of grazing on the plots were simulated through biomass clipping and cow track stomping in either winter, spring, or both seasons, starting winter 2021 and ending spring 2023. Following the addition of drought shelters, perennial and annual grass cover declined over the two-year drought period but showed little to no effect from simulated grazing treatments. Annual forb cover showed a gradual decline from the drought treatment but rebounded very quickly after the shelters were removed. This can likely be explained by the non-native weedy species *Salsola tragus*' aptitude in colonizing and outcompeting more native perennial species. Bare ground also increased under the drought shelters and quickly decreased after their removal. These results demonstrate that as drought intensifies, the cover of desirable species for grazing, such as perennial grasses, is likely to decline and bare soil exposure is likely to increase. These effects may increase the threats of erosion and the dominance of invasive annual species resulting in longer recovery for the impacted communities.

Custom Climate Reports – A Tool to Improve Land Management Activities

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Abstract: Advancements in data acquisition and computational processing have led to an increase in the amount of available online climate-based tools and databases in recent decades. While these products are often used by natural resource managers to make informed land management decisions, they are frequently left underutilized due to substantial time investment needed on behalf of managers to download and process data to meet their management needs. This project aims to improve utilization of online climate-based tools and databases by working directly with land managers to develop a climate report generation system that is designed to aid land management activities. Through a collaborative process working closely with land managers (“stakeholders”), highly specialized and customizable climate reports are designed for land management units using open-source code and readily available data. Climate reports are comprised of maps, figures, and data tables summarizing weather and climate statistics of a stakeholder’s management area. Stakeholders can further customize seasonal definitions by regrouping months based on local precipitation distribution or

management schedule. Report statistics are summarized based on the number of months progressed into a season, allowing for seasonal development to be tracked to previous seasons. Furthermore, reports can be automated to generate at a monthly, annual, or customizable time intervals depending on management preference. Through initial and follow up meetings, reports are further tailored to match the stakeholder's management needs, local climatology, and data interests. A main goal of this project is to develop an adaptable and flexible code framework where custom reports can be quickly developed for any land management unit and updated frequently. We aim to publish our project code as an R-package that can automatically generate and push numerous reports at frequent intervals to managers working in different management units as a climate service or be adapted to run in-house by managers themselves.

Monarch (*Danaus plexippus*) and queen (*Danaus gilippus*) larval survival on western milkweed (*Asclepias*) species

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Abstract: Both monarch (*D. plexippus*) and queen (*D. gilippus*) butterflies have an obligate host relationship with milkweed (*Asclepias* spp.). Monarch butterflies have been experiencing well-documented population declines since the late 1980s, and restoration of native milkweed habitat is considered a critical part of conservation efforts. In the Southwestern U.S., queen and monarch butterflies share a range for many months of the year, with queens and monarchs overlapping in range in the low deserts of Arizona (from early fall to late spring, approximately September to May). Installation of milkweed habitat in these areas benefits both monarch and queen butterflies. The Southwestern U.S is also home to a high diversity of milkweed species, with 30 in the state of Arizona alone, and larval performance can vary widely on milkweed taxa. Plant cardenolide type and concentration, amount of latex, and physical leaf characteristics all impact how successfully larvae feed and grow on these plants. Through larval feeding trials, we assessed monarch and queen larval performance and survival on four species of native milkweeds (*A. angustifolia*, *A. erosa*, *A. nyctaginifolia*, and *A. subulata*) and one species of commonly available non-native milkweed (*A. curassavica*). There were differences in adult butterfly size, larval development time, and pupal mass between the five milkweed species, and monarch and queen larvae showed better performance on different milkweed species. These variations point to nuanced differences both in host quality and butterfly tolerance to milkweed defenses, and will help guide conservation planning for both butterfly species.

Diné Bá'ádeit'í: Tribal wood bank support

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Abstract: Dine Ba'adeit'i (For the People) is a nonprofit organization located in Shadow Mountain, north of Cameron, Arizona. Established as a nonprofit in Feb. 2023, Diné Bá'ádeit'í

aims to support tribal communities by providing operational assistance and delivering firewood throughout Arizona and New Mexico. Since their establishment, they have distributed over 800 cords to tribal communities. The organization is involved in the Wood for Life (WFL) program by advocating for the establishment and maintenance of wood banks, including Standing Rock, Ramah, Shiprock, and the Tinnian Wood Bank in Torreon, NM. Collaboration with individuals such as Manuel (Mannie) Lopez, the New Mexico Program Manager for the National Forest Foundation (NFF) and other non-profits, strengthens their efforts. Dine Ba'adeit'i faces several challenges, primarily funding limitations, vehicle maintenance, and capacity building. Despite these hurdles, the organization persists, utilizing grants such as the NFF Rock Creek Grant (awarded \$30,000 in 2024), an \$8,000 contribution from Water For Life via Dig Deep and grants from Alliance for Green Heat (23' and 24') to help fund their initiatives. The nonprofit operates largely on volunteer efforts, where the majority of funding goes to deliveries, equipment and maintenance. For its founder and director, Ames Meyers, the work is rooted in memory and Dine identity, fueled by a deep cultural and personal commitment to supporting elders and preserving traditional practices. He recalled his days spent gathering firewood for his family during the winter and returning home to a hot meal prepared by his nali (grandmother). The mission is to keep alive the values that they cherished: community, resilience, and care for our elders.

Characterize Uncertainty and Data Limitations in Predicting Seasonal Reservoir Release Temperatures

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Abstract: Temperature is a key water quality parameter that drives the phenology, physiology, and population dynamics of many aquatic organisms. Large reservoirs have dramatically changed downstream thermal regimes globally. In the Colorado River basin, a combination of ongoing aridification and consumptive water use has led to declining reservoir water levels and warmer water releases from fixed water withdrawal structures. The ability to forecast changes in water quality due to changes in basin hydrology and management is needed to ensure protection of threatened aquatic ecosystems. While mid-term water quality forecasting has been carried out in specific reservoirs and reaches of the Colorado River for many years, there have been limited efforts to characterize uncertainty and assess reasonable periods of these forecasts. Here, using a hydrodynamic water quality model for Lake Powell, we compared historical water quality forecasts to reanalysis simulations using observed boundary condition information. Forecast and reanalysis model outputs were compared against observed water temperatures within Lake Powell and below Glen Canyon Dam over two years that represent high and low reservoir storage conditions. Our results focus on metrics including the timing of temperature targets and the magnitude of release temperatures as these predictions are of greatest interest to stakeholders. We anticipate this work shaping future forecasting frameworks in the Colorado River basin. Overall, this analysis has advanced our ability to

conduct aquatic resource planning while highlighting key drivers and data limitations for reservoir water quality forecasting.

Advancing paleontological research, science communication, and resource conservation at Grand Canyon National Park

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Abstract: Grand Canyon National Park exposes an extensive geologic record and a diverse assemblage of paleontological resources, offering valuable insights into ancient terrestrial and marine ecosystems. Fossils within the park span from Proterozoic stromatolites to Pleistocene megafauna remains in caves, with a wide range of Paleozoic life in between—including Cambrian trace fossils, tetrapod and arthropod trackways preserved in eolian environments, an extensive record of Permian flora, and fossils from various ocean reef systems through time.

Despite the park's global recognition as a geological haven, paleontology resource management remained limited for decades due to funding constraints and minimal staffing. This long-term neglect contributed to a widespread lack of public and academic awareness regarding Grand Canyon's paleontological significance.

Following the release of a comprehensive Grand Canyon paleontological resource inventory report in 2019, these fossils have recently gained renewed attention which has prompted an increase in research interest and a growing demand for strategic resource management. Recent investigations have yielded new records of chondrichthyan specimens from Permian seas, new Permian plant species, revised trilobite biostratigraphy refining Cambrian ages, a vertebrate trackway locality suggesting early herding behavior, and the identification of a brand-new Cambrian species of priapulid worm.

This presentation demonstrates the significance and diversity of Grand Canyon's fossil record by highlighting recent discoveries and emphasizing the importance of ongoing research and paleontological resource protection.

Using functional ecology to monitor the ecological integrity of bird communities in the Western USA given past, present, and future forest management

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Abstract: Ecological integrity—the degree to which an ecosystem supports ecological structure, composition, diversity, function, and connectivity typical of natural conditions—has been a guiding principle in ecosystem monitoring around the world. However, in terrestrial ecosystems, integrity-based monitoring often excludes animal communities, even though they are critical drivers of integrity. We illustrate how describing animal communities in terms of functional ecology can provide a generalizable approach to incorporating animal communities into integrity-based monitoring across taxa and ecosystems. We use an example from a long-term monitoring dataset with 15 years of data and information on occupancy of over 100 bird species across Arizona and New Mexico, USA to show how we can use functional ecology metrics to understand the status of bird community integrity in relation to past and current forest management variables. These analyses and insight we gain from them are possible because of these long-term datasets and the growing availability of databases on animal traits we know to be important for ecosystem functioning. Our understanding of the status and trends of bird communities are crucial to understanding the impacts of past and current management, wildfire, and future management aimed at a variety of goals, including ecological restoration and wildfire mitigation.

The relationship between Pinyon Jay abundance and pinyon pine seed availability in the Southwest USA is lagged and dependent on climate and habitat context

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Abstract: Many tree species across the globe depend on seed-dispersing wildlife to move seeds across the landscape and increase germination and survival of new individuals. In pinyon-juniper ecosystems of the western USA, pinyon pines benefit from the seed dispersing and caching behaviors of the Pinyon Jay (*Gymnorhinus cyanocephalus*), which has evolved to take advantage of pinyon pine mast seeding events. However, Pinyon Jay populations have been declining in the region due to a set of unknown factors. Pinyon pines have seen a concurrent shift in demography, range, and reproduction due to climate change. Understanding how these two patterns are linked, as well as how they play out in time and across a variety of ecosystem and climate contexts is imperative for the conservation of these species and ecosystems. In this study, we used data from the participatory science platform eBird combined with regional maps of seed availability for pinyon pine and other mediating climate and habitat variables to examine 1) what is the magnitude and timescale of the relationship between jays and seeds and 2) how is this relationship mediated by habitat and climate context? We found that jays nest more in places that had more seeds last year, likely since birds nest near seed caches. We also found that jays have stronger relationships with seed availability in “stressful” times when climate variables make nesting more challenging. Finally, we observed that jays have weaker relationships with seeds in more suitable environments, likely due to the availability of other food options. This study provides valuable insight into the time scales and context-dependence of the mutual relationship between the Pinyon Jay and pinyon pine in the face of changes in this ecosystem type. These results can inform prioritization of conservation and management actions for pinyon-juniper ecosystems and the wildlife these landscapes support.

FLUXNET's New Data Platform: Early Results from Dryland Ecosystems

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Abstract: Eddy covariance has been used to measure the exchange of carbon, water, and energy between ecosystems and the atmosphere for decades. High-quality and continuous measurements are now available for hundreds of sites worldwide, including for a range of dryland ecosystems. FLUXNET is a global network of over 480 eddy covariance sites tracking carbon, water, and energy fluxes across diverse ecosystems. In 2025, the FLUXNET community is launching a new data system that improves access, enhances site discoverability, and supports global syntheses.

This presentation introduces the new platform and shares preliminary results from the first FLUXNET annual analysis. I will also outline plans for recurring analyses, and regional summaries to support broad scientific and applied use. We highlight patterns of interannual variability in GPP, NEE, and evapotranspiration, with a focus on the challenges and opportunities in monitoring dryland ecosystems.

Primary production responses to extreme changes in North American Monsoon precipitation move up an elevation gradient through time

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Abstract: Primary production in dryland ecosystems is limited by water availability and projected to be strongly affected by future shifts in seasonal precipitation. The North American Monsoon contributes 40% of annual precipitation in the southwestern U.S. and is projected to become more variable but there is large uncertainty on whether this variability will be expressed as extreme wet or dry years. We experimentally imposed extreme drought and heavy rainfall for six years, during which ambient summer rainfall declined to reach near historic lows (2019-2020) and subsequent highs (2021), to understand production sensitivity along a 1,000-meter elevation gradient. We found that the effects of Monsoon precipitation extremes varied by plant functional type, with responses dependent on the number of treatment years that occurred across sites along the elevation gradient. C₄ perennial grasses were most responsive to precipitation manipulation treatments, followed by C₃ perennial grasses and annuals, while perennial forbs and shrubs had no responses. The effects on responsive plant functional types were generally stronger or occurred earlier at low elevation sites, while high elevation sites were initially more resistant and then showed responses over the long term. The upward advance of primary production responsiveness from single- to multi-year extreme changes in warm-season precipitation suggests more immediate shifts in functional composition and carbon cycling at low elevation, while high-elevation ecosystems may become less resistant as the effects of extreme precipitation compound through time.

Water Use and Habitat Health Across Arid and Semiarid Biomes

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Abstract: Evapotranspiration (ET) plays a crucial role in hydrological processes and plant water consumption. We quantify ET and water use efficiency in the Sonoran and Mojave Desert Bird Conservation Region 33, a diverse landscape with limited water resources spanning the U.S.-Me

border. Using a decade-long dataset from the Landsat 8 Operational Land Imager (OLI) (2013–2022), we explored if rising ET demand rates may be disrupting the already fragile regional water cycle consequently impacting wildlife habitat. Our study utilizes 30-meter, 16-day, Landsat-8 imagery. Vegetation indices (EVI and EVI2) were used to monitor the regional vegetation dynamics and Image Quality Assessment (QA) metrics were used to filter unreliable observations, particularly clouds, while climatological data from the 1 km resolution DAYMET dataset were used to compute the reference ET (ET_o) using the Blaney-Criddle method. Additionally, a newly developed regional cover map that standardized the classification systems across the US-Mexico border to assist conservation efforts will be used to constrain the land cover-based analysis of water use patterns.

The ET model was applied at Landsat resolution and then geospatially clustered to estimate water use and efficiency per land cover class type. Vegetation indices were also used to assess habitat quality serving as a proxy for ecosystem services and wildlife support. Time series, statistical, and spatial anomaly analyses were conducted to track changes in water use, efficiency, and plant productivity across land cover classes, identifying areas experiencing the greatest stress due to climate change and human activities. Initial findings provided insights into the relationships between vegetation dynamics, water use, regional droughts, and habitat quality, with implications for restoration and conservation efforts. The study also presents a detailed analysis of biome-specific ET trends over the past decade, highlighting the hydrological variable for key regional water resource management, with implications for land cover and wildlife management.

Tribal Engagement & Adaptation Planning through the Southwest Climate Adaptation Science Center

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Abstract: This presentation will cover the tribal engagement efforts led by the Southwest Tribal Community Resilience Liaisons in collaboration with the USGS Southwest Climate Adaptation Science Center (SW CASC), as well as their work through the American Indian Higher Education Consortium (AIHEC). The primary role of Tribal Community Resilience Liaisons is to assist Tribes and Tribal Colleges and Universities with their climate adaptation needs and efforts by providing relevant data, tools, and technical expertise. This approach to Tribal engagement is to ensure that, as Tribes and Tribal Colleges and Universities (TCUs) are building their capacity to develop adaptation plans, they are also equipped with the knowledge and understanding of implementing those plans within their communities and homelands.

Southwestern Tribes and TCUs can request assistance through the SW CASC Tribal Liaison Assistance Request Form, arrange a meeting with the liaisons, and others at the SW CASC. This opportunity allows both the SW CASC and the Tribes and TCUs to build working relationships to ensure Tribes and TCUs have the necessary information to be successful in their planning, assessment, and implementation of various climate adaptation strategies and actions.

This presentation will also highlight the success of a recent 7-part Southwest Tribal Climate Resilience webinar series, discuss the presentations, and planning for another series in 2026.

Using a Social-Ecological Systems Framework to examine wood bank establishment and management

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Abstract: Thorough and constant fuel reduction treatments are necessary for forest management efforts in the southwest. As a result, biomass will continue to be available for use towards economic and social goals. Wood banks and fuelwood distribution are one such use. Increasing our understanding of the social-ecological factors that improve wood bank establishment and operation can therefore benefit forest management and social uses of wood resources. This research examines how collaborative conservation in forest restoration projects in New Mexico that include wood banks benefits forests and communities by asking three main research questions: (1) What social and ecological factors are influencing wood bank establishment and management?, (2) How do community attributes, especially social capital, influence the activities and processes within wood banks?, and (3) What are the perceived and potential social equity outcomes from wood banks? The preliminary results for this presentation will focus on research question 1. For this question, the Social Ecological Systems Framework (SESF) was used to develop a semi-structured qualitative interview instrument. We interviewed more than 15 individuals working with federal, nonprofit, or research entities that were associated with wood banks in New Mexico and Arizona. Interviews were transcribed and analyzed with both a deductive and inductive approach to identify variables included in the SESF for natural resource systems and to uncover additional variables that influence wood banks. Examining wood banks through a SESF allows for the identification and diagnosis of social and ecological factors leading to beneficial social outcomes and beneficial forest resource use outcomes that can ultimately help improve the effectiveness and equity of wood banks.

Diné College Land Grant Office and Northern Arizona University (NAU School of Forestry) Collaboration

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Abstract: Diné College, a 1994 Land-Grant Institution, in collaboration with Northern Arizona University's School of Forestry, brings significant expertise in ecological restoration, forestry, and sustainable land management on the Navajo Nation. Our partnership is grounded in two previously funded Tribal College Research Grant Program (TCRGP) projects: 1. "Ecological restoration of native plant communities in forests and woodlands on the Navajo Nation" and 2. "Forest and woodland dynamics supporting food and agriculture on the Navajo Nation". Through these projects, we have developed two long-term experimental woodland and forest research sites on the Navajo Nation, conducted collaborative undergraduate and graduate research, built integrated training, academic, and outreach programs that strengthen ties between Diné College and NAU, and advanced knowledge and capacity in ecological restoration and land stewardship aligned with Navajo priorities. These accomplishments

demonstrate our capacity to effectively manage, implement, and expand research and education initiatives that support sustainable forestry, food security, and natural resource management on tribal lands.

Global change effects on demography and disease dynamics of Emory oak

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Abstract: The Emory oak (*Quercus emoryi*) is an evergreen red oak species native to the southwestern U.S. and northern Mexico, where it plays critical ecological and cultural roles. For generations, Western Apache and other Indigenous communities have relied on the Emory oak for subsistence and ceremony purposes related to harvesting acorns. Despite the tree's cultural significance and ecological prominence, multiple stressors—climate change, altered fire regimes, and emerging pathogens—threaten its long-term viability. While adult trees remain widespread, Indigenous knowledge holders report declining acorn production and seedling recruitment. Such reproductive failures raise concerns, especially as Emory oaks remain underrepresented in ecological research. Among emerging threats, the fungal pathogen *Biscogniauxia*, known to affect drought-stressed trees, has been increasingly observed in Emory oak stands across the Southwest. This study investigates how environmental factors interact with this emergent pathogen to affect Emory oak health and regeneration.

Approximately 5,000 trees were surveyed across 100 sites within the species' range to assess size, health, and regeneration status over a two-year period. Generalized linear and mixed-effects models revealed that canopy dieback was the strongest predictor of *Biscogniauxia* infection at the tree level, while plot-level infection was positively associated with BIO15, a measure of relative monthly rainfall variability. Year over year seedling fecundity was best predicted by low vapor pressure deficit, low BIO15, and high canopy cover, while seedling survival was strongly predicted by canopy cover and annual precipitation. Future targeted models will further confirm predictor variable importance for these relationships. These findings highlight the complex, multi-scalar interactions driving decline in this culturally and ecologically vital species. By linking disease dynamics and demographic vital rates with environmental stressors, this work advances our understanding of how climate and ecological structure influence Emory oak demography and resilience.

Shifts in suitability of pinyon-juniper communities: A climate adaptation framework for range-wide management of arid woodland resources

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Abstract: Pinyon-juniper (PJ) woodlands are a diverse ecosystem type providing a wealth of ecosystem services across western North America. Managing PJ woodlands in the 21st century entails balancing multiple conservation objectives, and resource managers and policy-makers working to sustain PJ woodlands need spatially explicit information about current PJ woodland conditions and how they may be impacted in coming decades in the context of wildfire risk and changing climate. Here, we address knowledge gaps and provide information that improves the long-term value of conservation and restoration actions in PJ woodlands. To this end, we merged projections of future environmental suitability for nine PJ species with wildfire risk and locations of mature and old-growth (MOG) woodlands to assess spatial variation in PJ woodlands with differing threats and management opportunities. We identified potential climate refugia with enduring high community suitability and low burn probability (3% of study area) that may persist with relatively little management. We found promising locations of PJ-MOG forest type with high future suitability (12% of areas) that could be prioritized for fire risk reduction to maintain high-value woodlands. Despite a 38% mean community suitability decline under future climate conditions, some locations (7% of areas) may act as climate refugia where future climate conditions can support current PJ woodland composition and structure. We share these results through demonstrating how this information can be integrated into a conceptual framework to inform regional conservation decisions and to help prioritize climate adaptation in PJ woodlands.

Broad-scale assessment of bird biodiversity exposure to future high severity fire: a management prioritization tool

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Abstract: Fire is a pervasive biogeographic process that shapes biodiversity globally and is now experiencing unprecedented changes. Despite well documented impacts of fires on biodiversity, we do not know where biodiversity might be most vulnerable to changing fire regimes, leaving a significant knowledge gap for management under future conditions. We leveraged recent advancements in fire forecasting and species distribution modeling to assess the exposure of bird species richness, community uniqueness, and functional richness to changing fire regimes in the western United States. We found that 55-58% of biodiversity

hotspots were classified as “refugia”, where high biodiversity intersected with areas predicted to burn at low severity. In contrast, 24-30% of biodiversity hotspots were classified as “areas of concern”, where high biodiversity intersected with areas expected to burn at high severity. Over half (52-60%) of “areas of concern” occurred in geographies with historically low-severity fire regimes; a fire regime mismatch indicating a potential threat to biodiversity. We found that species with a preference for high-density vegetation and with shallower beak depth were most likely to be exposed to high severity fire across their populations, indicating a potential for future habitat losses for species with these traits. Our findings reinforce calls for active and targeted management to reduce impacts of future fire where it is predicted to be outside the historical range of variation.

Early warning of climate and wildfire risk in the southwestern US

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Abstract: Rapid warming trends and land use history are contributing to changes in fire regimes in recent decades across ecosystems in the southwestern United States. Changes in wildfire dynamics increase ecosystem vulnerability to invasive species, type conversions and other types of disturbances. Regional expressions of a changing climate are placing increasing stress on ecosystems even in the absence of wildfire. To mitigate these challenges, researchers and land managers need to identify areas where these interactions may be most challenging to ecosystem recovery and resilience. We modeled interactions of climate stress and wildland fire using spatial data for Arizona and New Mexico, including projected climate stress to 2090 CE derived from the Climate Change Vulnerability Assessment (CCVA, version 2); fire severity from 1984-2021 obtained from the Monitoring Trends in Burn Severity (MTBS); and future wildlife risk estimated from the US Forest Service Southwest Region Quantitative Wildfire Risk Assessment. We built a visualization tool in Google Earth Engine (GEE) to facilitate analysis of spatial patterns. All stress factors were evaluated among varying plant community types (Ecological Response Units, ERUs) to assess and visualize vulnerabilities within different ERUs in New Mexico and Arizona. Combinations of low or high climate stress with low or high past fire severity, along with positive or negative future wildfire risk, reveal a gradient of vulnerability within different ERUs and geographic areas. Most areas in the Southwest are projected to experience significant climate stress in coming decades, reflected by areas where climate is projected as two or more standard deviations from the current mean for a current ERU. Among biomes, grasslands are among the most vulnerable to climate stress and wildfire, followed by ponderosa pine forest, mixed-conifer forest, interior chaparral, and certain types of woodlands. Spatial visualization of climate and fire vulnerability highlights geographic and ecological areas at highest risk in the southwest region. Our study highlights the benefits of mapping ecosystem vulnerabilities among different vegetation communities, which can be used to provide an early warning system about priority areas for conservation and management.

Social-Ecological Interactions and Rangeland Management: A Systematic Literature Review

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Abstract: Rangeland management practices in different rangelands of the world, especially in Africa yield mixed outcomes on livelihoods and conservation. Studies report that approaches such as transhumance, community conservancy, and pasture-user unions often enhance social and livelihood outcomes by increasing herd productivity, widening community participation, and diversifying income sources. In 30 documented cases, these practices align with improved social or economic indicators, while 18 instances show positive ecological effects that include improved vegetation cover, wildlife abundance, or reduced erosion. Conversely, several approaches also result in negative outcomes. Three cases note adverse social impacts such as increased poverty or restricted mobility, and 11 instances demonstrate ecological degradation through intensified resource competition or encroachment.

The evidence further demonstrates that integrated management methods, which combine community participation, traditional knowledge, and livelihood diversification, support socio-ecological balance. However, the main challenges include climate variability (noted in 20 studies), pervasive land degradation (cited 46 times), resource conflicts (23 studies), and policy constraints (24 studies). Adaptive strategies such as community-based conservation (reported by 30 studies) and participatory approaches (27 studies) are aligned with mitigating these challenges and strengthening both social cohesion and ecosystem resilience.

Social-Ecological Interactions and Rangeland Management: A Systematic Literature Review

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Beyond Places and Assets: Reframing Valuation in Quantitative Wildfire Risk Assessments (QWRAs) to Capture Stakeholder Perceptions and Values

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Abstract: Quantitative Wildfire Risk Assessments (QWRAs) evaluate wildfire risk and prioritize treatment planning at a landscape scale and have been used as a collaborative framework in wildfire management for several years. These assessments document the quantitative outcomes of wildfire risk from a management implication perspective but often fail to articulate the nuances of the collaborative process and usability of QWRAs for the diverse stakeholder group. Highly Valued Resources and Assets (HVRAs) are a primary component of the QWRA process; showing where these values and assets are found on the landscape and how they respond to different degrees of fire severity. We sought to understand how stakeholders' perception of wildfire risk and value prioritization influence the HVRA valuation process. We conducted semi-structured interviews with 21 participants involved in land management in northern and central Arizona. We had participants rank HVRAs from a predetermined list of values from a standardized QWRA. Our results revealed that the Wildland Urban Interface (WUI) and perennial rivers and streams were the most prioritized values. Participants' criticism of the HVRA list focused on missing values such as watersheds and cultural values, as well as the list's overemphasis on the build environment and neglecting ecological values. Our results further explore how different types of valuation and values are represented, and mis-represented in the HVRA ranking process. We discuss this theme further in participant selection of HVRAs. These findings highlight potential predispositions in the QWRAs and call for improvements to the valuation process to better include non-anthropogenic values. More research and development are needed on response functions to address these biases in the qualitative valuation process that then impact the quantitative output of risk assessments.

Vegetation change in two iconic national parks in Arizona: Developing statistical modeling approaches for complex monitoring designs

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Abstract: The National Park Service implemented a nationwide inventory and monitoring (I&M) program in 1998 to collect data on the status and trend of the health of park ecosystems. The program monitors a suite of natural resources, including counts of individual plant species and estimates of vegetative cover. Each national park has its own iconic ecosystems and management goals, resulting in different I&M protocols; some parks use line-point intercept while others use ocular quadrat methods to estimate species cover and occurrence. Importantly, multiple sources of data could strengthen inference on the drivers of vegetation change across diverse ecosystems, but sampling differences challenge data synthesis across multiple parks. Hence, our objective is to develop statistical methods for integrating data from multiple parks that employ complementary sampling methods to identify drivers of species occurrence in iconic parks, with the goal of informing park management decisions. We developed a hierarchical Bayesian framework that can be adapted to different sampling methods, account for detection error, and quantify drivers of species occurrence. To demonstrate the framework, we apply it to both line-point-intercept and quadrat data and estimate the effects of moisture stress on the probability of occurrence for 192 grass and forb species from five ecosites within two national parks in Arizona. Results indicate that detection errors vary from 5%-38% (median=14%) false absence reporting. Focusing on a desert shrubland at Glen Canyon National Recreation Area, climatic water deficit during the spring reduced the occurrence of C3 grasses, whereas greater soil moisture during the previous spring increased the occurrence of C3 forbs. We will apply this framework to I&M data from 29 parks spanning >1300 plots to understand the broad-scale drivers of vegetation change in the western USA, with implications for the impacts of climate extremes (e.g., chronic and episodic drought) on iconic national parks.

Collaborations between monitoring programs and external scientists lead to land management relevant science

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Abstract: Long-term vegetation monitoring datasets are valuable for tracking plant community change over time and in response to environmental drivers. These large, well-documented and organized datasets can be used for many purposes, though, since they typically cross environmental gradients and document land use patterns. Maintaining the quality of these datasets requires lots of time and diligence, so monitoring personnel often do not have time to fully utilize these datasets. Interactions between monitoring staff and stakeholders, land managers, Tribal representatives, and recreational users lead to questions that could be answered using the datasets if there was time and the appropriate tools to analyze the data. Similarly, scientists with expertise to answer those questions may not be aware of the need or understand the study area context well enough to appropriately address the questions. Collaborations between monitoring personnel and external scientists can expand the ways

long-term vegetation monitoring datasets can be used to meet pressing, relevant land management needs. Collaborations between the USGS Grand Canyon Monitoring and Research Center's vegetation monitoring program and Northern Arizona University have led to new, productive studies spanning niche modeling, genetics, physiology, traits, and advanced modeling of monitoring data. Niche modeling has used monitoring data to predict changes to plant habitat under altered dam operations. Patterns in monitoring data have led to greenhouse studies on understudied species. Monitoring data and restoration needs have led to plant genetic studies. Advanced modeling of monitoring data has revealed the influences of understudied environmental pressures. The methods and skillsets derived from these collaborations have also been used to improve monitoring methods and analyses. The projects illustrate the breadth of land management relevant topics that can be addressed when external skillsets and time are combined with study area expertise and research questions developed from land manager needs.

A synthesis of dryland riparian plant community water needs

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Abstract: A multidecadal drought in western North America is reducing water availability and increasing the need for detailed water budgets. Assessing ecosystem water use, particularly evapotranspiration (ET) and transpiration from riparian vegetation (collectively, “plant water use”), is a key component in developing sound water management approaches. Questions related to both removal of vegetation to salvage water and budgeting water to maintain valuable riparian areas have led to a wealth of studies on riparian plant water use across dryland river systems in North America. Towards evaluating broad patterns in riparian plant water use, we synthesize results from a wide range of studies, with the goal of informing water policies and supporting rapid management decisions in water crises. In particular, this study leverages over two decades of riparian plant water use research to answer the questions: (1) Do some riparian plant communities exhibit lower plant water use than others? (2) Do riparian plant communities have higher water use under hotter climates? (3) Can models based on existing data, plant communities, and climate data be used to predict water use for unmeasured locations? Using hierarchical Bayesian models to evaluate annual and daily-scale plant and ecosystem water use, we found that marshes, cottonwood-willow stands, and healthy tamarisk use larger amounts of water at the annual scale than other plant communities. All riparian plant communities have higher water use in hotter climates at the annual scale, which is likely related to a longer growing season. The models based on existing data, plant communities, and climate data provide bounds on plant water use that can be applied to unmeasured locations and be used to facilitate water budgeting and conversations among water-users. We discuss the implications of possible increased water use under hotter conditions for both restoration and water salvage purposes.

More than monarchs: Insect community ecology on four species of milkweed

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Abstract: Milkweeds (*Asclepias* spp.) are valued in habitat restorations, community gardens and home gardens because of their role as the obligate host for monarch butterflies. Due to their common use in landscape plantings, we sought to highlight the insect community visiting milkweeds beyond monarchs and other herbivores in the Sonoran Desert. With the use of traps and visual observations, we recorded arthropod visitation to four different milkweed species native to Arizona, in two different locations. The four species we used were *Asclepias subulata*, *A. subverticillata*, *A. linaria*, and *A. angustifolia*. In one month (April 2017) we recorded the presence of 3110 arthropods. Ninety-seven percent were able to be identified to order and more than 92% of those to family or superfamily. Eleven orders (plus arachnids) and 70 families or superfamilies were represented. The orders with the most representation were Diptera (44%) and Hemiptera (30%). Most insects were found on *A. angustifolia* and *A. linaria*, with *A. angustifolia* having the highest diversity of insects. Interestingly, it is also one of the most preferred milkweeds for monarchs in central and southern Arizona. Milkweeds support a wide variety of insect pollinators, predators, herbivores, and sap-feeders, providing more benefit to natural and urban habitats than just a monarch host.

Resin-based defenses in *Pinus edulis* are only reduced after long-term drought

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Abstract: Constrained carbon allocation towards defense is a common explanation for widespread drought-related beetle-kill in conifers. We challenge the generality of this explanation. Along with drought stress (Ψ_{pd}), we tracked both carbon reserves (NSC) and chemical defenses (terpenes, phenolics, resin flow, and $\Delta^{14}\text{C}$ -age of resin) in mature *Pinus edulis* trees experiencing either short-term (three-year) or a “legacy” long-term (13-year) drought treatment, plus a control. Bark beetles killed 72% of study trees, allowing us to assess whether defenses were related to survival. We found concentrations of certain defenses (leaf phenolics, twig monoterpenes) actually increased with drought stress, even in dying trees. Dying trees had similar bark terpenes (94%) and enhanced bark phenolics (139%) relative to control trees. Only “legacy” trees, after a decade of drought, had reduced bark terpenes (-49%) and resin flow compared to a control. $\Delta^{14}\text{C}$ -age of resin could be up to 10.2 ± 0.5 years old, where the oldest resin was exuded from the most moisture stressed trees with low sugar concentrations and more negative Ψ_{pd} . Our results suggest short-term drought imposes a weak constraint on carbon allocation to resin-based defense. We primarily found evidence of enhanced defenses under drought, even in dying trees, but found ~50% reductions in defenses after 10+ years of drought. $\Delta^{14}\text{C}$ ages demonstrate resin was old and/or built from old carbon reserves, and thus unlikely to be depleted by a short drought. Persistent allocation of carbon to defense, additionally supported by past investments in defense, appears to preserve or enhance defenses even under lethal drought stress in *P. edulis*.

When does climate matter for tree growth?

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Abstract: Tree growth is a primary driver of terrestrial carbon storage and a key indicator of forest function and health. Tree growth also exhibits long memory of past climate conditions that may complicate prediction as future climates begin to look less like the past. We sought to use tree rings to identify the seasonal time periods when precipitation and temperature conditions were most important for tree growth. The conditions driving tree growth may also differ across species or across space, so we applied our models to all available tree ring data in the continental US. This dataset was gathered from the Forest Inventory and Analysis program, the International Tree Ring Data Bank, plus assembled unpublished tree ring data, and comprises 7.5 million tree ring widths representing >100 tree species from 9,277 sites. We found precipitation and temperature phenology often differs: winter temperature conditions important for tree growth often occur at different times than the most important winter precipitation. The timing of important climate also differs across space: clusters of sites with a longer winter precipitation season (6-9 months) are distributed across the eastern Rocky Mountains and the eastern US, while the western US contains more sites with a shorter winter precipitation season (3-5 months). We also find more negative effects of winter temperature at southern latitudes. Major groups of species show differences in when climate matters: Pinaceae (pines, firs, spruce, etc.) and Cupressaceae (junipers, cypress, cedars, etc.) have

comparatively shorter winter precipitation seasons to the Fagaceae (oaks, hickories). We expect to produce a data product containing seasonally-resolved antecedent climate variables for other researchers and land managers to use in future modeling and data-informed decision-making for forest management.

Mapping *Tamarix* and Native Riparian Vegetation to Monitor Response to Hydro-Climatological Conditions

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Abstract: Invasive tamarisk vegetation has exhibited increased water stress during intensifying drought conditions and is linked to larger and more severe wildfires within the riparian floodplain of the Upper Gila River watershed in east-central Arizona. Our intent is to develop a comprehensive understanding of the spatial extent of tamarisk and its responses to environmental conditions to support more effective management of these riparian lands. We first developed a simple, replicable, phenology-based riparian classification approach for mapping tamarisk and the surrounding native riparian vegetation types using Sentinel-2A imagery along the San Carlos and Gila rivers for the year 2023. Next, we quantified how each riparian vegetation type — including native woodlands, understory grasslands, and mixed forest and woodland — responded to variable hydrological and climatological conditions using a 5-day temporal series of Sentinel imagery from 2019 through 2023. By applying timeseries analyses, temporal lags, and seasonal pivot point analyses, we observed unique vegetation responses in the different riparian systems, each experiencing distinct hydro-climatological conditions. The pivot point analysis revealed that vegetation along the San Carlos River was generally less responsive to changes in precipitation, exhibiting greener vegetation from 2021 to 2023 compared to vegetation along the Gila River. In contrast, greater negative vegetation anomalies were present across all vegetation types along the Gila River during this period, likely a result of increased wildfire activity. Additionally, we found that vegetation types exhibited different responses to seasonal precipitation, with tamarisk that had been defoliated by the tamarisk beetle showing greater positive and negative greenness anomalies compared to other vegetation types. The varied behavior of vegetation types and the differentiated hydro-climatic characteristics of each watershed highlight the necessity for a unique management approach for each system. These results can inform the development of a framework for riparian vegetation management, with potential applications for other regional riparian systems.

Following the water tanker to interrogate real-estate development and groundwater policy in Northern Arizona

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Abstract: Climate change is accelerating, resulting in increased uncertainty in water supply issues across Northern Arizona. As temperatures rise and precipitation decreases, groundwater becomes even more important across the region. In Coconino County around forty-four percent of the water supply comes from groundwater: supplying potable water to urban and rural residents. This research outlines the connections between rural household water security, groundwater policy, and environmental change in Coconino County through the experiences of households in one area with limited centralized water delivery infrastructure. Throughout Coconino County a number of households rely on water hauling for potable water provisioning. Rather than being supplied through a piped connection or a well, households either haul their own water or have water delivered to their property in a tanker and store it in a tank for later use. This study uses semi-structured interviews with residents who rely on water hauling to better contextualize water hauling as a decentralized water provisioning process and examine the links between water hauling, real-estate development, and water (in)security in rural Northern Arizona.

A glimpse into the past: using historical satellite and aerial imagery to anticipate woodland population dynamics in the western US

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Abstract: Despite being comprised of long-lived, slow growing tree species, pinyon-juniper (PJ) woodlands across western North America have been highly dynamic over the last several thousand years, including widespread increases over at least the last few hundred years. Recently, however, observations of increased mortality and declining recruitment are common. The ability to anticipate continued population growth and expansion or increasing vulnerability could aid management action. For example, population-level forecasts of woodland dynamics could be used to predict future rates of expansion or the population-level effects of declining recruitment. Earth observatory programs such as Landsat or the National Agricultural Imagery Program now offer several decades of historical data on the distribution and abundance of PJ woodlands. We present two approaches for predicting woodlands dynamics at a population level. In our first approach, we built a spatiotemporal population model, trained on 31 years of remotely sensed tree cover. We found that density dependent growth and dispersal processes can accurately predict shifting abundances along a historical range margin. While population models built on fractional tree cover may perform well at predicting changes in cover in the near-term, they may mask variation in demographic performance across life-stages (e.g. declining recruitment and survival of juvenile trees). In our second approach, we are developing a structured population model, using tree crown maps derived from 60 years of aerial imagery. A key step in this process is accounting for biases in size structure data—we found that the magnitude and direction of the detection error for tree crowns varies significantly by size. By continuing to test which population-level mechanisms best predict observed woodland dynamics, we can only improve our ability to anticipate future woodland

conditions. This challenge will likely require bringing together diverse data, as well as consideration for forecast horizon and species-specific processes.

Pinyon-Juniper Shrublands: Overlooked and Undercut

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Abstract: Pinyon-juniper shrublands have been recognized as a distinct vegetation type in the scientific literature, but intentional and informed management of this vegetation type is often lacking in pinyon-juniper removal projects on federal public lands. I provide a brief review of the distinctions within both pinyon-juniper types and phases in the literature before discussing whether and how these distinctions have been employed in project implementation and federal agency guidance. An examination of projects primarily in Utah demonstrates that pinyon-juniper shrublands have often been overlooked as a unique vegetation type, resulting in their removal. The widespread removal of this vegetation type is cause for ecological concern, including for imperiled pinyon jays considering their close association with the woodland-shrubland ecotone. I provide some suspected drivers for why pinyon-juniper shrublands have been overlooked, and some ideas for how the scientific community could assist with the recognition and intentional management of pinyon-juniper shrublands.

Mapping the Subsurface beneath the San Francisco Volcanic Field Using Seismic Data

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Abstract: The San Francisco volcanic field, located at the southern margin of the Colorado Plateau, is a distributed volcanic field consisting primarily of monogenic volcanoes and ~4 intermediate/felsic-composition volcanic centers. Despite the numerous vents (>600) and large size of the field (>5000 km²), the subsurface plumbing beneath these volcanoes is not well understood. To better constrain the volcanic behavior and source and location of melt, we use seismic data to calculate receiver function common conversion point stacks across the field. This approach allows us to map subsurface features and assess how they vary across the volcanic field. Receiver functions are a seismic technique that uses P-waves from distant earthquakes, which are partially converted to S-waves by velocity contrasts in the earth, to locate and characterize these boundaries. To calculate receiver functions, we use data collected by an array of ~580 nodal seismometers deployed across the area with dense (~4 km) spacing. We use these results to map out the depth and lateral extent of several large-scale contrast in seismic velocity beneath the field. Strong negative arrivals in the center of the field indicate that melt is likely still present beneath San Francisco Mountain, the only true stratovolcano in the field, at both upper and lower-crustal depths. A sharp increase in velocity, interpreted as the base of the crust, is observed and deepens from west to east across the field. These results indicate that large-scale crustal structure concentrates melt in this system and that melt is retained beneath San Francisco Mountain.

Fuel treatment impacts on post-fire vegetation in Gambel oak shrublands: a case study from northern Utah

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Abstract: Gambel oak (*Quercus gambelii*) shrubland is the second most abundant shrubland in the American Southwest. Because it is often found in the wildland-urban interface, oak-dominated shrublands are increasingly targeted for fuel treatments intended to modify wildfire behavior. We studied the interactions of fuel treatments and wildfire in a northern Utah Gambel oak ecosystem and their impacts on woody plant biomass, plant cover, and plant biodiversity. The study centered on three masticated units and two thinned units which were implemented in 2017 and subsequently burned in the Bald Mountain Fire of 2018. In the summers of 2024 and 2025, we collected woody biomass and understory diversity measurements from plots across shrubland and woodland oak ecosystems in treated and untreated areas, as well as burned and unburned areas. We also stratified plot locations by fire severity, which varied widely across the plots, ranging from unburned to high severity. Treated areas and areas that burned at higher severity were associated with increased understory diversity. Tree and shrub biomass, as well as plant cover, varied widely with treatment and fire severity. Our findings demonstrate that fuel treatments and wildfire severity can have complex impacts on plant structure and diversity. These interactions may have long-term implications for biodiversity, fuel dynamics, and ecosystem resilience in oak-dominated shrublands.

Botanical Gardens as local hotspots for butterfly pollinators in the arid southwest

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Abstract: Urbanization and intensifying aridity present urgent challenges for biodiversity conservation in the southwestern United States, particularly for insect pollinators whose populations are declining due to habitat loss, rising temperatures, and water scarcity. Botanical gardens, though occupying a small fraction of urban land, could be refugia for butterflies and other pollinators in arid cities. Our study leverages over 10,000 community science butterfly observations from eButterfly and iNaturalist, comparing species richness and diversity within six botanical gardens to those in their surrounding metropolitan areas across Arizona, California, New Mexico, and Texas. We found that botanical gardens consistently support disproportionately high butterfly species richness and diversity, often exceeding the 75th percentile of comparable city samples. In some cases, gardens like Tohono Chul in Tucson and the Chihuahuan Desert Gardens in El Paso surpassed all city-based replicates, underscoring their role as urban biodiversity hotspots. Botanical gardens in the arid southwest provide reliable microhabitats with consistent water and floral resources, supporting pollinator communities even as urban and climatic pressures intensify at least to a certain physiological tipping point. Thus, these spaces may be an important component to include when thinking

about linking urban, suburban, and exurban landscapes in conservation and management decision making.

Landscape settlement patterns on southern Cedar Mesa, Utah

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Abstract: Glen Canyon National Recreation Area (GLCA) manages 1,229 acres of land on the southern rim of Cedar Mesa in San Juan County, Utah. Northern Arizona University surveyed 160 of those acres in 1987 and Museum of Northern Arizona inventoried the remaining 1,069 acres during three projects in 2020-2024. Including rock art sites recorded by GLCA in 1994, the area contains 83 archaeological sites comprising 89 temporal components. These sites are exclusively Archaic, Basketmaker II, and Pueblo I-III Ancestral Puebloan in cultural/temporal affiliation, with sites of each interval strongly associated with specific local environmental zones that form contiguous strips: mesa rim, dune ridge, and dune fields. Absent are Basketmaker III, single component Pueblo I, and Protohistoric components. The Cedar Mesa Project of the 1970s did not identify any Archaic sites but did identify early Basketmaker III sites, otherwise the recent inventories found similar site types, temporal components, and site locations.

Landscape settlement patterns on southern Cedar Mesa, Utah

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Abstract: Glen Canyon National Recreation Area (GLCA) manages 1,229 acres of land on the southern rim of Cedar Mesa in San Juan County, Utah. Northern Arizona University surveyed 160 of those acres in 1987 and Museum of Northern Arizona inventoried the remaining 1,069 acres during three projects in 2020-2024. Including rock art sites recorded by GLCA in 1994, the area contains 83 archaeological sites comprising 89 temporal components. These sites are exclusively Archaic, Basketmaker II, and Pueblo I-III Ancestral Puebloan in cultural/temporal affiliation, with sites of each interval strongly associated with specific local environmental zones that form contiguous strips: mesa rim, dune ridge, and dune fields. Absent are Basketmaker III, single component Pueblo I, and Protohistoric components. The Cedar Mesa Project of the 1970s did not identify any Archaic sites but did identify early Basketmaker III sites, otherwise the recent inventories found similar site types, temporal components, and site locations.

Challenges, opportunities, and applications of a regional landscape analysis

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Abstract: This presentation offers an overview of the Regional Landscape Analysis of Water Security and Leadership in the Colorado Plateau spearheaded by NAU's Water, Society and Policy Lab through the Arizona Water for All (AW4A) Network. This study seeks to enhance collaborative approaches to addressing water security by identifying shared challenges and intervention areas, and exploring local perceptions of effective leadership within the realm of water security. To this end, our team is conducting semi-structured interviews with stakeholders involved in water issues across varying jurisdictions, sectors, and cultural groups. In this presentation we review the process, challenges, and opportunities afforded by this research approach, inviting consideration of its application for the study of other complex issues like fire management.

Advancing an Indigenous Forestry Professorship: Position Development and Indigenous Faculty Recruitment at Northern Arizona University

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Abstract: Indigenous Peoples steward a high proportion of forested lands in North America but remain highly underrepresented in professional and academic positions. Building on the Northern Arizona University School of Forestry's relationships with Tribes and Indigenous Peoples, we describe the development, recruitment, and implementation of an Indigenous Forestry professorship. Creating the position required stepping out of traditional frameworks, since no such position existed in a Society of American Foresters-accredited Forestry program at the time. We advertised for any Forestry-related discipline with interest and experience in an Indigenous context. Selected from a small but well-qualified applicant pool, the new faculty member and School leaders faced a seeming inconsistency between typical expectations of university faculty vs. the essential connection of Indigenous Peoples to culture, ceremony, responsibility and place. Through self-advocacy of the new faculty member and collegial support focusing on the broad context of the university's commitment to Indigenous Peoples, sufficient flexibility was found on all sides, but this is only an initial step. The continued work of supporting wayfinding for Indigenous faculty toward successful careers in STEM academia is an important broader consideration. We provide recommendations from our mutual experience as the candidate, faculty, and administrator, and share ideas to help other Indigenous and minoritized faculty and university natural resource programs that might navigate similar circumstances.

Multi-Scale Density-Dieback Relationships Inform Woodland Management

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Abstract: Drought-induced tree dieback in pinyon-juniper ecosystems has accelerated in many regions, potentially countering historical processes of woodland expansion and with important implications for resilience to environmental change. Recent research has found a positive relationship between stand density and tree dieback, suggesting that resource competition increases susceptibility to drought effects. Alternatively, other studies suggest that facilitative interactions may occur among trees, as trees in closer proximity may offer a buffering effect. The role of stand structure in buffering or exacerbating drought-induced dieback remains poorly understood for semiarid systems. To investigate these dynamics, we conducted an observational study in semi-arid southwestern Colorado and assessed the relationship between stand structural characteristics and tree canopy dieback in pinyon-juniper woodlands at different spatial scales. We collected field measurements from 192 plots across a 750-acre area characterized by diverse topography, tree sizes, and stand densities.

Linear mixed-effects models were used to examine the effects of environmental and stand structural covariates on canopy dieback at the plot (10-meter radius) and individual tree scale. At the plot scale, greater canopy dieback was associated with larger trees, higher variation in canopy diameters, greater tree densities, greater dominance of pinyon, and lower elevations. At the tree scale, trees with denser local neighborhoods had increased canopy dieback for both pinyon and juniper species. Additionally, larger tree diameters for juniper species had increased canopy dieback. Plot-level models for canopy dieback showed consistently greater explanatory power than tree-level models. Results highlight that spatial patterns of canopy dieback can be understood in the context of stand structure and environmental variability at multiple scales and are not limited to the direct influences of resource competition or facilitation from neighboring trees. These findings support the development of silvicultural treatments aimed at enhancing woodland resilience to drought by fostering spatially and structurally heterogeneous woodland landscapes.

Microclimate Responses to Thinning in Pinyon-Juniper Woodlands

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Abstract: Pinyon-juniper (PJ) woodlands are characterized by patchy and uneven-aged forest structures, where structural heterogeneity influences microclimate and resource availability for trees. Silvicultural treatments in PJ woodlands that reduce stand basal area, such as thinning,

have the potential to reduce resource competition and lower risk of drought-induced tree mortality. However, the effects of thinning on the local water balance are complex and uncertain, as influences of local stand structure on evaporation and transpiration may vary over fine spatial scales. Water availability can be increased by thinning due to reduced plant water use but can also be decreased if warmer soil temperatures lead to greater evaporation. Using a management-scale experiment in southwestern Colorado, we explored the hypothesis that thinning practices designed to foster structurally heterogeneous PJ woodlands can increase soil water availability. Across 12 randomized replicate blocks, we implemented four treatments: (1) high-intensity uniform thinning (30-m spacing), (2) low-intensity uniform thinning (15-m spacing), (3) heterogeneous thinning with variable-sized clumps, gaps, and tree size classes, and (4) an untreated control. During the first post-treatment growing season we recorded hourly measurements of soil volumetric water content at two depths, as well as bihourly soil surface temperature. Based on precipitation patterns, two seasons were delineated for analysis: a dry-down season associated with snowmelt (March-mid June) and a summer monsoonal season (mid June-September). Treatment effects were stronger at deeper soil depths and for areas with greater canopy removal. Seasonal differences between treatments were also more evident at deeper soil depths, with snowmelt sustaining moisture during the dry-down period, while monsoonal rains led to rapid infiltration and evaporation. These findings inform management in PJ woodlands, highlighting potential benefits and limitations for thinning practices aimed at enhancing drought resistance.

Adaptive silviculture for drought resilience of pinyon-juniper woodlands in southwestern Colorado

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Abstract: Pinyon-juniper woodlands are a widespread vegetation type across the U.S. Southwest that has a large proportion of remaining old-growth, supports numerous wildlife species, and is culturally important to many Indigenous peoples across the region. These woodlands have experienced widespread drought- and heat-related tree mortality events coupled with extreme wildfire behavior over the past several decades in many portions of its range. In contrast to other forest types where the management has been on the silvicultural enhancement of ecosystem resilience and restoration of structural heterogeneity, methods for improving drought resilience in these semiarid woodlands are poorly understood. Through a large collaborative effort with university and federal agency researchers and managers, we have set up a replicated experimental study to assess the efficacy of different silvicultural treatments at enhancing pinyon-juniper ecosystem health and reducing fire risk in southwest Colorado. This involved close collaboration with Bureau of Land Management partners at the local field office and Colorado state and southwest district offices to design prescriptions that are operationally feasible to implement and vary in intensity and spatial heterogeneity. This talk will share about the current state of knowledge of how to manage for pinyon-juniper woodland resilience and provide insights and lessons learned from the first two years of this adaptive silviculture project.

Determining Successful Management and Restoration Strategies for Pinyon-Juniper Communities in the Face of Changing Climate and Wildfire

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Abstract: Pinyon-juniper (PJ) woodlands in the western U.S. are vital, extensive ecosystems, which provide numerous critical environmental, economic, and cultural benefits. Despite their

importance, the stress put on PJ woodlands by increasing wildfire and other forms of environmental change are resulting in population declines in some parts of their range. Further, thinning is used to safeguard forests from fire and to increase climate resilience, but there is a limited understanding of how fire and thinning affect the structure and function of PJ systems. Such changes to PJ woodlands lead to uncertainty for land managers on best practices for protecting the ecosystems from stand replacing fire, and for restoring PJ communities when wildfire does occur. To address these uncertainties, a collaborative of researchers and land managers came together to study two core questions: (1) How does an improved understanding of the ways tree thinning and wildfire affect PJ woodlands lead to improved management options? and (2) What innovative restoration techniques can restore PJ communities following fire in the face of anthropogenic change? We examined vegetation structure, microclimate conditions, and PJ regeneration dynamics following fire and thinning in Mesa Verde National Park and on Ute Mountain Ute lands. We assessed the success of restoration plantings with different combinations of fungal partners and microclimate conditions. Burned areas did not show signs of returning to their previous intact PJ state after two decades and we found a lower abundance of late successional biological soil crusts and lower soil moisture values in burned ecosystems. Thinning also created distinct plant communities and served as an intermediate between intact and burned plant and biocrust communities. Importantly, more intensive thinning had a larger impact on community structure and recruitment than less intensive thinning, suggesting a “sweet spot” for thinning where stand replacing fire could be avoided and intact ecosystem health could be maintained. Restoration treatments also pointed to options for successfully planting PJ following fire. Taken together, while these results indicate a vulnerability of some PJ systems with increasing wildfire and altered environmental conditions, they also highlight management actions that can promote PJ re-establishment and resilience.

New advances in biocrust science: how technology is helping us understand, scale, and restore these foundational communities like never before

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Abstract: Scientific advances are transforming our understanding of biological soil crusts, significantly improving our capacity to quantify, scale, and forecast biocrusts’ critical roles in ecosystem function, resilience, and restoration success. Although biocrusts are increasingly recognized as dynamic communities that stabilize soil, retain moisture, influence plant function, and bring carbon and nitrogen into ecosystems, our quantification of the controls over and contributions of biocrusts has remained relatively poor. Fortunately, new technological approaches to assess biocrusts and their responses to change now provide unparalleled opportunities to understand their foundational communities, their responses to change, and the options we have for successfully managing and restoring biocrusts in the face of accelerating change. Advances in remote sensing, global networks, precision trace gas exchange measurements, and experimental ecology have uncovered the complexity of biocrust

interactions and their sensitivity to change. This talk will provide an overview of a range of diverse but complementary stories about the need and opportunities for using new science to address age-old questions for biocrust science.

Biological soil crust recovery following heavy disturbance in the Mojave desert

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Abstract: Desert ecosystem soils across the Southwest United States are frequently stabilized by biological soil crusts, which are highly susceptible to damage and loss through disturbance. Biocrust recovery from disturbance is often thought to take decades to centuries; however, little is known about specific recovery timelines for biological soil crust communities through passive restoration techniques. Camp Granite and Camp Iron Mountain are the sites of two WWII era Desert Training Center camps, located on Bureau of Land Management lands, in the Mojave Desert, which were heavily used for training exercises in the early 1940s and have since then been relatively undisturbed. To determine the efficacy of passive restoration at several disturbance intensities, we measured biological soil crust cover across three different land-use areas of both camps: tent areas, heavy vehicle parking locations, and control locations outside of the camp boundaries. We found similar cover of lichens and dark cyanobacteria in tent and vehicle parking locations to controls at Camp Granite, but generally lower cover in these disturbed areas than controls at Camp Iron Mountain. Similarly, we found greater coverage of bare soil in disturbed areas than controls at both camps. We additionally found similar levels of chlorophyll-A in soil samples across all sites and disturbance intensities, indicating comparable levels of photosynthetic cyanobacteria. These results show partial biological soil crust recovery facilitated by passive restoration. Our findings demonstrate that biological soil crusts in Southwest dryland ecosystems can show recovery if left minimally disturbed for extended periods of time, but legacy effects of heavy disturbance remain, even after 75-80 years.

Lessons from 25 years of Mexican wolf coexistence programs

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Abstract: Humans are responsible for the majority of carnivore mortality and extirpations in the wild. Ultimately, the willingness to coexist with large carnivores such as Mexican wolves on the landscape is essential to advance the meaningful recovery of these apex carnivores. Using a framework that defines coexistence as ensuring thriving carnivore populations and human endeavors with well-managed and mitigated human-carnivore conflict and human-human conflict, we sought to explore if and how these pillars of coexistence were utilized in

the design and implementation of human-Mexican wolf coexistence programs. To do so, we conducted a document analysis of the records, reports, and meeting minutes from 25 years of Mexican wolf coexistence programs in Arizona and New Mexico. Coexistence programs in these states are those that are focused on livestock depredation compensation, payment for the presence of wolves, incentives, livestock husbandry tools, hazing tools, education and outreach, provisionary feeding of wolves, and the management removal of wolves due to conflicts. Our preliminary findings provide insight into the benefits and challenges of these programs, the most common approaches utilized to pursue coexistence, and gaps in approaches, identified through comparing them to the four pillars of coexistence. In this talk, we share lessons learned and provide policy recommendations to improve resilient human-carnivore coexistence programs in the future.

Pinus edulis radial growth increases following high-intensity silvicultural thinning

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Abstract: Dryland forests and woodlands have experienced mass die-off events over the past few decades due to increasingly severe droughts and insect infestations. Finding management solutions to address these concerns will be critical as global climate changes and drought conditions worsen. Silvicultural thinning treatments are often done to reduce competition for limited resources, yet the efficacy of these treatments is unclear, particularly in semi-arid ecosystems where canopy shading can strongly reduce soil evaporation rates. As part of the Pinyon-Juniper Adaptive Silvicultural Project, we implemented a replicated silvicultural thinning experiment to assess how variability in thinning intensity and spatial heterogeneity impact tree health and fire behavior in a semi-arid pinyon (*Pinus edulis*)-juniper (*Juniperus osteosperma*) woodland. Here, we assess how these thinning treatments affect pinyon pine (*Pinus edulis*) growth rates and the associated mechanisms driving tree responses, using dendrometers and soil moisture sensors. We found that on average trees experiencing high intensity thinning had an intra-annual radial growth nearly 1.5 times higher than that of trees in control plots in the first year following treatment, and this was largely driven by increases in soil moisture during the early monsoon period. We also found a negative relationship between basal area density and total yearly radial growth increments. Notably, our results were consistent across the 350 m. elevational gradient, which encompassed the mid- to high-elevation band of *P. edulis* in our study region. These results highlight how thinning pinyon-juniper woodlands in moderate to wet climate conditions can increase the growth rate of residual trees by increasing water availability. Further work assessing growth and mortality responses over a longer period and under drought conditions will help determine the strength and drivers of these patterns and whether that translates to increased drought resilience, which are critical given the ecological and cultural importance of *P. edulis*.

Short-term takeaways from silvicultural thinning in pinyon-juniper woodlands and effects on *Pinus edulis* radial growth

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Ute Mountain Ute Climate Change Adaptation Planning

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Abstract: The Ute Mountain Ute Tribe has taken significant steps toward climate change adaptation planning for their lands and people. Following the publication of their Climate Action Plan in 2020, the Tribe's Environmental Programs Department has moved toward more targeted climate-informed resource stewardship. We share and reflect on these recent advances, including the development of a small set of climate-resource scenarios; the identification of potential next steps based on these scenarios; subsequent and ongoing work

related to the management of the culturally and ecologically significant Mancos Canyon; and lessons learned from sustained collaboration between resource managers and scientists.

Positive drought feedbacks increase tree mortality risk in dry woodlands of the US Southwest

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Abstract: Global changes in temperature and aridity are increasing the frequency of extreme drought events. Such changes can have pronounced impacts on dryland plant communities which exist at the margins of plant physiological tolerances. Pinyon-juniper (PJ) woodlands – a dryland forest type spanning 40 million ha in western North America – is a model system for the impacts of drought, where recurrent short-interval drought events may trigger feedback mechanisms that influence future drought resistance. We utilized the oldest continuously surveyed forest monitoring network in PJ woodlands of the United States (US) Southwest to understand how interactions between recurrent drought events influence tree mortality risk. We developed generalized linear mixed models to predict patterns of recent (i.e., 2014-2023) tree mortality based on biophysical variables, ontogeny, and prior drought-driven changes (ca. 1998-2014) in forest conditions. We then used these models to quantify how mortality risk has shifted over time. Throughout our study period, density and basal area declined throughout much of our study area. Mortality was ca. 30% higher than rates of tree regeneration, and nearly half of surviving trees experienced partial crown dieback since 2014. Tree size influenced biotic interactions and responses to environmental conditions, and soil organic matter and mycorrhizal communities buffered individuals against drought. Overall, shifts in woodland demographics (e.g., reduced stand densities, increases in crown dieback) led to a 10% relative increase in tree mortality risk between 2014 and 2023. Recent drought events have had lasting effects on PJ woodlands in the US Southwest, triggering widespread tree mortality and dieback since the late 1990s. Positive feedbacks between short-interval drought events are increasing tree mortality risk in arid woodlands, overcoming system inertia provided by local edaphic conditions and compensatory responses. Recent patterns of mortality and tree regeneration in PJ woodlands suggest that continued shifts towards shrubs and herbaceous species are likely over upcoming decades.

Sonoran Desert adaptation to altered fire regime

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Abstract: Fires in the Sonoran Desert have traditionally been rare and small, requiring minimal fire prevention efforts. However, climate change and invasive species have increased the frequency and size of wildfires in this ecosystem, causing widespread changes in vegetation and declines in native species. Managers are beginning to adapt by reducing fuel loads and exploring new methods to slow fire spread, such as fire breaks or weed barriers covered with biological soil crusts (biocrust). They are also working to improve postfire restoration efforts, including seeding native plants, restoring biocrust, and removing invasive species. We surveyed natural resource and fire managers in the Sonoran Desert to identify which techniques they currently employ in fire prevention, suppression, and post fire management. We are also modeling human and natural ignitions across the Sonoran Desert and quantifying relationships with independent variables such as elevation, aspect, roads, and buildings. These results we will share are part of a larger project involving workshops with managers designed to evaluate the benefits, effectiveness, and costs of innovative strategies and assist practitioners in integrating these options into their management strategies.

Differences between germination and seedling traits of wild-grown plants and their farm-grown descendants

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Abstract: In the western United States, managers commonly use farmed varieties of native seed to meet demand for restoration. Farmed seed is cost-effective, reliable and does not over-tax native seed stock in natural ecosystems, compared to wild-collected seed. However, seeds originating from a farm-grown environment may demonstrate trait shifts from their wild-collected ancestors. For example, plants may be inadvertently selected for limited phenological characteristics, based on when seeds are harvested from fields, compared when seeds might be naturally released by their wild ancestors over a greater timeframe. Critically, shifts may occur in early germination or seedling traits. The life-stage transition from germination to establishment is often a point of high mortality, and a bottleneck for long-term persistence and reproduction, two critical restoration outcomes. In this research, we compared germination and seedling traits among wild-collected populations and their farm-grown descendants for a species of restoration interest across the Colorado Plateau. We found shifts in dormancy and seed size between the seeds of the two origins, which may translate into differences in establishment and performance when used in a restoration setting. This work helps inform

native plant material development and provides a framework for testing differences in early life stages between wild-collected and farm-grown seed.

Take your science from the journal to the field: Preview of a skill-building workshop on coproduction and actionable science for early career scientists

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Abstract: The National Environmental Policy Act requires the use of science, but agency staff rarely have time to stay current with all the science on management-relevant topics, especially as articles are published at an ever-increasing rate. In this new series of learning modules, we aim to provide scientists with essential tools, skills, and strategies for coproducing actionable science products with and for federal land managers to support their decision making. In module 1, participants will learn how land managers make decisions, how they use science in their decision making, and the challenges of doing so. In module 2, participants will learn about actionable science and coproduction, and practice applying coproduction tools to help assemble a project team, decide on the right level of coproduction for a given project, and plan for product delivery. In module 3, participants will learn the characteristics of actionable science and practice creating actionable science products, with a focus on synthetic products that can support federal planning and permitting processes. Modules can build off each other, or be used on their own, depending on participant interests, skillsets, and needs. We can also work with science teams to help customize modules for the partners they work with and the decisions those partners make. Currently, we are piloting the modules with groups of early career scientists and refining the modules based on scientist and land manager feedback. Materials will then be published and broadly available to any interested parties. In the future, we hope to connect scientists using these modules in workshops with land managers to put these new skills into action.

Reservoir Operations for Sustainable Sand Management in the Colorado River in Grand Canyon

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Abstract: Sandbars are a valued resource in Grand Canyon, providing ecological, cultural, and recreational benefits. Following the construction of Glen Canyon Dam in 1963, widespread sandbar erosion was observed. This was a result of the dam cutting off the upstream supply of sand and changing the flow regime. Today, maintaining and building sandbars is one of the

goals of the Glen Canyon Dam Adaptive Management Program. Controlled floods known as High Flow Experiments (HFEs) are implemented following tributary sand inputs to redistribute sand from the channel onto sandbars. Our study reach lies between the two largest reservoirs in the Colorado River Basin, intertwining the problem of sand management with broader water management goals. Here, we used semi-empirical numerical models for sand transport rate and sandbar morphodynamics to predict changes in sand availability and sandbar size due to reservoir operations. First, we describe how these sand models were used to modify the protocol for implementing HFEs to make it easier to implement HFEs amidst ongoing drought. In cases where fall HFEs are precluded due to low reservoir elevations, implementing HFEs in spring results in larger sandbars. Next, we used a simplified reservoir model to develop new strategies for dam operations for improved sand management while meeting water needs. We found that reservoir operational strategies which allowed flexibility in the annual release better avoided high monthly releases which cause rapid sand erosion. Strategies that maintained higher reservoir levels in Lake Powell allowed for more frequent HFEs, resulting in larger sandbars. Additionally, we found that implementing HFEs in fall (when reservoir elevations permit), closer to the timing of tributary sand inputs, resulted in larger sandbars. Finally, we describe how sediment modeling is being used to inform the development and assessment of potential strategies for future operations of the Colorado River basin.

Assessing fuels near power lines and their susceptibility to fire using several remote sensing techniques

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Abstract: As wildfire activity continues to increase in the southwestern United States, critical infrastructure is more likely to be damaged by fire and smoke. Power lines are of exceptional concern, both because of their societal necessity and because they run through vulnerable forested areas. Thus, there is a need for better categorization of the fuels nearest to power lines. In order to prioritize quick and accurate fuels assessments, we investigated the potential of using various remote sensing techniques to categorize hazardous fuels. We collected both airborne Light Detection and Ranging (LiDAR) measurements and Uncrewed Aerial System (UAS) photogrammetry at several power line corridors throughout Arizona. We then used these data to produce tree-level metrics for each area. We input the tree metric data into the Fire and Fuels Extension (FFE) of the Forest Vegetation Simulator (FVS) to highlight areas of potentially hazardous fuels. We also compared the LiDAR and photogrammetry outputs to each other and to ground level data, allowing us to assess the accuracy of each method. Ultimately, we will use our hazardous fuels outputs in the development of a tool for land managers to identify areas of greatest concern when it comes to fire activity.

Declining water levels of Lake Powell and Lake Mead have caused rapid geomorphic changes at their deltas

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Abstract: Lake Powell formed by Glen Canyon Dam (1963) and Lake Mead formed by Hoover Dam (1935) in the Colorado River Basin have fluctuated in water level greatly due to water management and substantial changes in unregulated flow. Due to prolonged drought, in 2022, each reservoir reached its lowest level since filling (<30% full). Decreases in reservoir levels of >50 m have exposed hundreds of linear kilometers of delta sediments deposited over decades by the San Juan and Colorado Rivers in Lake Powell and the Colorado River in Lake Mead. Additionally, reservoir rise and fall has caused the displacement of historical river channels due to pre-dam channel infill and new channel establishment through erodible reservoir sediments. Here, we measure changes in Colorado River geomorphology at the former deltas of Lake Powell since 2020 and Lake Mead since 2021. We used global navigation satellite systems, multibeam sonar, and lidar to construct water surface profiles and repeat maps of the reservoir-affected reaches of river, including the new river channel beds and exposed sediment banks. At Lake Powell near Hite, UT, we find Colorado River incision downward through reservoir sediments of up to 17 m in less than three years. At Lake Mead, the Colorado River has incised through over 15 m of reservoir sediments and now flows directly over bedrock, forming a dangerous, waterfall-like rapid. In the reach above the rapid, we find channel widening and reworking, rather than downward incision, since rapid formation. We also developed a hydraulic model of the Lake Mead study reach to better understand channel change in response to experimental releases for resource management from Glen Canyon Dam. Here, we compare the nature and magnitude of changes between the two reservoirs and contemplate future channel forms as reservoir level fluctuation continues in the Colorado River Basin.

Unsettled grounds: process-based forward simulations of soil carbon flux under steady-state and transient assumptions in southwestern US

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Abstract: CO₂ efflux is a major component of the carbon cycle, which might be altered by environmental perturbations. Process-based carbon cycle models are often used to explore the potential impacts of climate change on carbon storage and fluxes. To do so, these models must accurately represent CO₂ production, transport, and efflux. However, capturing this complexity creates computational challenges, so researchers often simplify by assuming steady-state (SS) conditions—under which soil respiration is taken to equal microbial and root CO₂ production—instead of modeling transient non-steady-state (NSS) dynamics. The objective of this study is to evaluate the implications of implementing SS versus NSS assumptions for the modeling of soil respiration across varying environmental conditions. Our study relies on two complementary process models. First, the SOILWAT2 ecosystem water balance model used weather data to simulate daily soil water for different vegetation cover (grassy vs. woody) and soil (clay-, silt-, and sand-loam) scenarios. Next, the B-DETECT model used outputs from SOILWAT2 to estimate CO₂ production, transport, and efflux. We ran B-DETECT under both NSS and SS assumptions and quantified differences in NSS- and SS-estimated daily soil respiration across 337 sites, 10 years, and 6 vegetation-soil scenarios. Exploratory analysis suggests clay-loam soils had the largest and most frequent SS–NSS flux discrepancies, sandy-loam outputs agreed most closely, and silt-loam SS underpredicted soil respiration during extreme spikes of soil water content. Vegetation type had no clear effect on flux differences. In summary, our results confirm that ecosystems with silt- and clay-loam soils are highly sensitive to extreme changes in soil water content, such that SS models tend to underpredict soil CO₂ efflux relative to NSS conditions. In the context of ongoing shifts in temperature and precipitation, these results provide insight into the validity of the SS assumption for modeling soil and ecosystem carbon pools and fluxes.

Investigating extracellular polymeric substances for reclamation and radionuclide treatment on an abandoned uranium mine in Cameron, AZ

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Abstract: Abandoned uranium mines (AUM) on the Navajo Nation present an ongoing environmental and public health hazard due to persistent heavy metal contamination, such as uranium and arsenic. Conventional remediation methods can be expensive and ecologically disruptive, demonstrating the need for alternative solutions. Biological soil crusts (biocrusts) produce extracellular polymeric substances (EPS) that immobilize metals through cell surface adsorption, binding interactions, and biomineralization, posing a possible remediation technique. This study explores the potential of biocrusts to remediate heavy metal-contaminated soils in a secure greenhouse environment. Soil with three distinct uranium and arsenic concentrations was collected from an AUM in Cameron, AZ. We conducted a full factorial experiment with biocrust inoculation, crossed with soil origin, and high or low watering treatment (72 units, n=6). Surface and subsurface extraction will be completed and prepped through dry ashing and acid digestion using nitric acid and hydrofluoric acid, then analyzed using EPA method 6020 on an Agilent 8900 triple quadrupole inductively coupled plasma mass spectrometer. EPS chemical extraction and quantification will be completed using

phenol, sulfuric acid, and BioTek Synergy HTX fluorescence microplate reader. Though still a work in progress, anticipated results include metal immobilization and trapped effect caused by EPS. Higher uranium concentrations may lead to a decreased sequestration rate due to higher contaminant toxicity. Higher water treatment may enhance biocrust growth but decrease EPS binding metal ability due to the higher movement of soluble metals. Increased soil stability and reduction in water and wind erosion can contribute to the decrease of metal mobilization in soil and increase ecosystem restoration. Ongoing observations of the plots will be completed with further analysis to ultimately assess biocrust effectiveness as a nature-based solution for metal reclamation.

Trends in Low-Tech Process-Based Stream Restoration Outcomes in Western Rangelands

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Abstract: Healthy river corridors – including channels and floodplains – provide critical functions to ecosystems, economies, and communities. Across the western United States, historical and modern changes in land use, infrastructure, and regional climate have stressed river corridor health by changing the availability of water, sediment, and habitat, which has led to river corridors showing signs of physical and ecological degradation. Low tech process-based restoration (LTPBR), including the use of beaver relocation, beaver dam analogues, and rock structures in the channel, is increasingly being used to combat signs of river corridor degradation and to increase resilience to current and future stressors. To date, monitoring studies on LTPBR projects that implemented wood and rock structures have broadly shown that structures can decrease streamflow velocities, allowing for the upstream ponding of water and sediment and the storage of nutrients and carbon, resulting in increased vegetation establishment and growth. However, most studies have focused on single watersheds or projects, with limited cross-project syntheses to understand how project location, design choices, and local climate can impact the magnitude and direction of post-restoration change. To better quantify trends in the physical outcomes of LTPBR, monitoring data was synthesized from 65 LTPBR projects in the western U.S. that tracked changes in sediment storage, water storage, discharge, stream temperature, and riparian vegetation following the implementation of natural beaver dams, beaver dam analogues, or one-rock dams. Magnitudes of response to LTPBR were correlated to mean annual precipitation, time since restoration, project latitude, and structure type. Trends show that LTPBR outcomes are largely resilient to changes in climate variables (i.e., precipitation), but sensitive to design choices. Cross-project comparisons increase our quantitative understanding of how and why river corridors respond to LTPBR projects and provide insight into how future LTPBR projects may respond to new sites and under a changing climate.

Changed Seasonality and Forcings of Peak Annual Floods in Ephemeral Channels at Flagstaff, Northern Arizona, USA

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Abstract: Flood variability with environmental change is of increasing concern around Flagstaff, Arizona, where hydrology is influenced by a biannual precipitation regime and the unique geologic setting of the San Francisco Volcanic Field at the southern edge of the Colorado Plateau. Limited regional gauging of channels draining developed lands and dry coniferous forests has created a spatiotemporal gap in observation-based assessments of flood patterns. We present new data from over 10 years of monitoring using crest stage gauges and other records from multiple agency sources to assess inter-decadal patterns of flood change, emphasizing how various controls and disturbances have altered the character and seasonality of peak flows. Methods of analysis included: using Fisher's Exact Test to compare flood seasonality between historic data spanning the 1970s and contemporary data obtained since 2010; summarizing spatial data and meteorological timeseries to characterize catchment conditions and changes between flood study periods; and relating spatiotemporal patterns of seasonality and occurrences of notably large floods with catchment characteristics and environmental changes. Our results show systematic patterns and changes in Flagstaff-area flood regimes that relate to geologic and topographic controls of the catchment systems, and in response to records of climate variations and local catchment disturbances, including urbanization and, especially, high-severity wildfire. For most catchments there has been a shift from predominantly late winter to spring snowmelt floods, or mixed seasonal flood regimes, towards monsoon-dominated flooding, patterns which may relate to observed warming and precipitation changes. Post-wildfire flooding has produced extreme flood discharges which have likely exceeded historical estimates of flood magnitude over decade-long monitoring periods by one to two orders of magnitude. We advocate for continued monitoring and the expansion of local gauge networks to enable seasonal, magnitude-frequency analyses, improved climate and environmental change attribution, and to better inform ongoing flood mitigation works.

Ecological drought projections to inform long-term land management and climate adaptation

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Abstract: Climate change and associated alterations in disturbance regimes are reshaping ecosystems across the Colorado Plateau and beyond. These impacts affect soil moisture, drought stress, and wet/dry-cycles with widespread ecological implications for water-limited dryland regions and more mesic ecosystems. Understanding and anticipating ecological drought conditions and impacts is challenging when relying solely on temperature or precipitation due to complex interactions between weather, soil conditions, and vegetation. Because of the importance of soil moisture information for recognizing ecological drought, natural resource managers could benefit from datasets about contemporary and future water balance and soil moisture patterns that are both ecologically relevant and encompass the variability in projected future climate conditions. To address this challenge, we are quantifying 21st-century projections of soil moisture and ecological drought across the contiguous U.S. This work utilizes a process-based ecohydrological model to simulate water balance and soil moisture dynamics with a daily resolution and multiple soil layers, capturing rapid changes in particular soil layers and interactions with vegetation. To validate the model's output, we compared simulated soil moisture at c. 1000 stations across the contiguous U.S. against observed values, and we found favorable performance based on Kling-Gupta Efficiency. These results indicate that the model generates outputs that reflect ecologically relevant conditions and provide insights into ecological drought, which can be used to inform contemporary and long-term climate adaptation strategies. Our research emphasizes the value of integrating soil moisture-based ecological drought metrics into long-term drought assessment. This approach can guide spatial and temporal intervention prioritization, address the complex challenges posed by ecological drought, and enhance adaptive management in response to impacts of climate change.

Rainbow trout growth across western U.S. tailwaters is determined by temperature and prey: implications for future management

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Abstract: River segments downstream of dams (i.e. tailwaters) often provide ideal conditions for cold-water sport fisheries that generate millions of dollars for local and regional economies. Despite their societal importance and heavy management focus, these novel environments face many threats including a hotter and drier climate, changing water storage decisions in upstream

reservoirs, and alterations to prey. Understanding how these factors influence fish performance is thus crucial for informing management of these valued fisheries moving forward. Here, we first parameterized drift foraging-bioenergetics models of Rainbow Trout (*Oncorhynchus mykiss*) using estimates of water temperature and invertebrate drift collected at 10 Western U.S. tailwaters during 2022-2023. Following model validation, we explored the impacts of temperature and prey characteristics on trout performance (e.g., growth rate and maximum body size) by constructing scenarios that altered these variables in isolation and combination. Our results show that trout performance will be strongly influenced by future warming with a majority of tailwaters in our study predicted to experience increases in Rainbow Trout performance owing to current temperatures being cold and suboptimal. However, such responses were context dependent and modified by prey availability. Additionally, shifts in the timing of temperatures that led to asynchrony between prey and thermal regimes resulted in declines in trout performance despite no changes to the total amount of prey or mean annual temperatures. Together, our findings suggest that management strategies emphasizing interactions among thermal regimes, prey, and environmental context can benefit tailwater fisheries in a rapidly changing world.

Subcrusts are a preeminent source of soil biocrust resilience

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Abstract: Cyanobacterial biocrusts, common in arid and semi-arid environments, show resilience in the face of disturbances. We examined resilience by monitoring recovery after removing the upper layer of light, dark, and lichen biocrusts, exposing the subcrust layer. Our data suggests the primary means of recovery is re-emergence from a microbial “seed bank” present in the subcrusts. Regrowth from displaced biocrust aggregates does not appear to play a significant role in recovery. Further, we observed that subcrust layers have fewer saprophytic heterotrophic bacteria (prevalent in the biocrust layer), which may hinder incipient biocrust growth. Current biocrust restoration strategies, largely ineffective, focus on replacement of the biocrust layer. However, our data suggests that a subcrust based restoration would better mimic natural systems and may improve restoration outcomes.

Landscape-scale drought assessment and reporting for the Bureau of Land Management

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Abstract: While public lands managed by the Bureau of Land Management (BLM) include over 190,000 miles of perennial streams and 20,000 square miles of wetlands and riparian areas, more frequent and severe drought is shrinking freshwater availability. The BLM is addressing this challenge through the 2024 National Drought and Water Availability policy (IM2024-034), which provides guidance for integrating consideration of drought conditions and water availability into planning and decision-making processes. This policy aims to inform

decision-making and improve the long-term drought resilience of public lands, supporting the agency's multiple-use and sustained-yield mission. A cornerstone of this approach is landscape-level, interdisciplinary assessments of drought severity and water availability. Recognizing that no single indicator suffices, the policy encourages the use of multiple drought indicators, including US Drought Monitor as a trigger for additional assessment with advanced remote sensing data. To facilitate this, the BLM partners with the Desert Research Institute, utilizing their web-based application offering on-demand, cloud-computed drought insights from decades of satellite observations and climate data. Among other things, this platform allows BLM staff to generate standardized reports on current and historic drought and vegetation conditions. The BLM and DRI are also working to serve riparian-focused datasets, to bolster whole-landscape assessments. This presentation will explain how BLM utilizes these tools and policy directives to support decision making, detail the DRI's drought reports and the BLM partnership, and offer examples of BLM land management activities that incorporate drought assessment.

Spectral landscape ecology of a foundation tree species

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Abstract: Intraspecific genetic diversity underpins species' adaptive potential to changing environments, yet climate change and habitat fragmentation are reshaping spatial genetic structure in ways that may reduce adaptive capacity. We integrated imaging spectroscopy with landscape genetics to study the spectral ecology of *Populus fremontii*, a foundation riparian tree species in the southwestern U.S. Using NEON Airborne Observation Platform data, we classified *P. fremontii* across 17 sites and two watersheds in Arizona, Colorado, and Utah. From these classifications, we extracted *P. fremontii* canopy reflectance and associated environmental information to assess spatial patterns of spectral variation. Intraspecific spectral variation peaked at intermediate maximum temperatures, consistent with the stress-reduced variability hypothesis. Functional beta spectral diversity was best predicted by a resistance-to-gene-flow surface integrating stream order and seasonal precipitation. Thus, habitat fragmentation and climate change may reduce *P. fremontii* adaptive potential.

Contrasting Sensitivity to Vapor Pressure Deficit between *E. angustifolia* and *P. fremontii* in Southern Utah

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Abstract: Riparian zones are important conservation areas, featuring high levels of biodiversity and productivity in comparison to surrounding areas. Water availability in these ecosystems is becoming increasingly scarce due to climate change and water diversions. Therefore, evaluating vegetation response to drought and heat stress is important to inform and predict potential ecosystemic shifts. In the western US, *Elaeagnus angustifolia* (Russian olive) is a common riparian invader. However, little research exists on its vulnerability to heat and drought and how it compares to native species. This study elucidates the differences in response to vapor pressure deficit (VPD) between *E. angustifolia* and a native (*P. fremontii*) riparian tree species in the Grand Staircase Escalante National Monument in Southern Utah. We hypothesized that *E. angustifolia* will be more tolerant to heat and drought than *P. fremontii*, (i.e., less drought sensitive).

Sap flux density was measured in 24 trees (12 native, 12 invasive) using Granier thermal dissipation sensors from June 2024 until September 2025. Stomatal conductance and leaf water potentials (predawn and midday) of three trees of each species were measured from May through September in 2024 and 2025. We found that sap flow and stomatal sensitivity to VPD differed between species, with native sap flow having greater sensitivity to increasing VPD. This sensitivity is reflected in conserved midday water potentials in the native species, which was held at an average of -1.5 (± 0.33) MPa across measurement months. Comparatively, the invasive species had more negative water potentials, with an average of -2.7 (± 0.82) MPa, indicating a more plastic and drought-tolerant response to dryness. These data support that *E. angustifolia* is more resilient to heat and drought stress, indicating that it may be better equipped to survive a warming climate with less water available than a foundational native riparian tree species.

Quantifying vegetation state transition probabilities following fire and drought in the Upper Colorado River Basin

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Abstract: State-and-Transition Models (STM) describe mechanistic transitions among observed ecological states in areas with similar climatic and edaphic conditions (Ecological Sites). STMs are powerful conceptual tools for land-use planning, ecosystem management, and restoration. They are useful for predicting effects of management and response to wildfire. However, transition probabilities are generally not well quantified, forcing land managers to make subjective estimates of future states. Our objective was to quantify state transition probabilities in response to wildfire and drought in the Upper Colorado River Basin using a time series of published state maps. We chose an abundant, fire-prone Ecological Site Group (ESG) in the Upper Colorado River Basin. This ESG is dominated by pinyon-juniper woodlands but includes grasslands, sagebrush shrublands, and oak woodlands, in addition to an increasing proportion of habitat invaded by non-native annual grasses. We used a machine learning model to quantify the effects of static and time-varying covariates, including drought and fire, on transition probabilities. We observed above-normal winter precipitation increased the probability of annual grass invasion while below-normal winter precipitation increased the probability of bare states (reduced herbaceous cover). Additionally, fire decreased woody states and increased bare states in the short term, but these effects reversed with increasing time since fire. Drought generally increased transitions to bare states and transitions from certain states to invaded in the short term, while woodland states increased with increasing time since drought. Our models allow direct quantifiable predictions of fire and drought effects as well as the ability to simulate effects under various environmental conditions. This framework, quantifying ecosystem dynamics and predictions resulting from mechanistic drivers, strengthens inference from STMs, which increases confidence in the effects of management, disturbance, and changing climatic conditions. This represents an important step toward data-driven STMs and improving their utility for conservation and planning.

A web-based decision support tool for planning and prioritizing riparian restoration

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Abstract: Ecosystem restoration is most successful when project implementation follows rigorous planning and prioritization. We developed a web-based decision support tool to support riparian restoration efforts along the Bill Williams River in the southwestern USA, where native vegetation communities have been altered for decades due to streamflow regulation, invasive species expansion, drought, and wildfire. The tool, Environmental Flows for Riverine EcoSystem Habitats (E-FRESH), uses algorithms that integrate environmental inputs (such as geospatial data layers and hydraulic model results) with knowledge of species requirements to estimate habitat suitability for aquatic and riparian species. We tailored E-FRESH to the specific application of vegetation restoration along the Bill Williams R. Data layers used to determine site suitability for plants that are common targets of riparian restoration in the southwestern USA included depth to groundwater, elevation above the low flow channel, and past and present vegetation, as well as management factors such as site accessibility, potential for irrigation, and planting depth. We have produced outputs for 240 scenarios that include different combinations of these environmental and management

variables and represent various common restoration methods for taxa that are more mesic (*Populus*, *Salix*) or xeric (*Prosopis*). At present, the riparian restoration module of E-FRESH is being applied along the Bill Williams R.; however, the framework is transferrable to other river systems with similar management needs, provided that key data layers are available and appropriate modifications are made to the algorithms used to estimate site suitability.

RestoreNet: a field trial network to improve restoration outcomes across environmental gradients

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Abstract: Land managers need effective strategies to restore and rehabilitate degraded rangeland ecosystems. RestoreNet is a restoration field trial network co-produced by scientists and land managers that since 2018 has systematically tested restoration treatments across a growing network of 21 rangeland sites that span environmental gradients in the Southwest U.S. RestoreNet treatments include different seed mixes, periods of seeding, outplanted greenhouse-grown seedlings, soil surface modifications, invasive control measures, soil microbial inoculations, seedballs, and targeted livestock treatments. Here, we summarize what we have learned from RestoreNet over the past seven years and distill results into best management practices for land managers and restoration practitioners. Overall, we found that seed mixes with species adapted to historical climate conditions performed equally well or better than mixes adapted to future warmer, drier conditions. Using soil surface treatments with seeding promoted up to 3× greater seedling emergence densities compared with seeding alone, and soil

pits (small depressions in the soil) were the most effective treatment across the network. Near-term precipitation relative to seeding and treatment was critical to seeding success. Emergence from direct seeding was positively correlated with outplant survival in the cooler sites but had no relationship in the hotter sites, suggesting that outplanting may be necessary at hot, dry sites. Seedballs, soil microbial inoculations, and targeted livestock treatments had varied success across the environmental gradient and may be viable options at certain locations. Taken together, RestoreNet results provide successful restoration strategies and RestoreNet sites can serve to further test effective treatments across rangelands in the Southwest.

Looking to the past to anticipate the future of pinyon-juniper woodlands: A demographic perspective

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Abstract: Research on pinyon-juniper (PJ) woodlands paints a confusing and often conflicting picture about the current state and likely future of PJ woodlands. Widespread dieback events have occurred in both pinyon pine and juniper in response to hot-drought, suggesting emerging vulnerability of climate change. However, at the same time, woodlands are continuing to increase in density and expand, often at low elevations where the warmest, driest conditions occur, suggesting resilience in the face of emerging global change drivers. Leveraging ecological theory and data on historic changes in pinyon-juniper abundance from dendrochronology, remote sensing, and FIA, I will attempt to reconcile these contrasting views. Using dendrochronology data, we find that although many pinyon-juniper woodlands have likely been expanding for more than 200 years, declining demographic performance began to emerge over 100 years ago with declining recruitment rates. Despite declining recruitment, populations have continued to increase in many locations as recruitment has still outpaced mortality. Forest inventory data and remote sensing indicate that declining recruitment and survival is likely driven by warming, drying conditions but also increasing stand densities and negative density dependence, often resulting in counter-intuitive spatial patterns of expansion and decline. Together our results suggest that climate disequilibrium may be masking emerge vulnerability in pinyon-juniper woodlands and population declines are likely to emerge in heterogenous and sometimes counter-intuitive ways due to climate conditions and stand history. Finally, our results highlight a need for greater consideration of the endogenous processes that underly population growth in interpreting past and anticipating future changes in PJ distribution and abundance.

Succession as community evolution

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Abstract: Hypotheses on community organization have stimulated considerable theoretical debate; yet they must also inform restoration practices employed during global change. Neutral

and species-sorting hypotheses suggest that chance alone drives community structure. We assert instead that ecological communities begin because within and among species, individuals possess heritable phenotypes that are well- or poorly-suited for colonizing novel substrates. By arriving first and persisting, favored colonists become foundation species in a literal sense. As no species lives in isolation from other species, symbionts are expected to associate with foundation colonists for food, shelter or other survival needs. Genetic variation likely underlies variability in symbionts' ability to colonize certain hosts, and genetic interactions between symbionts and their foundation hosts must generate variation in community phenotype. Because genetically-based interactions among species must influence the relative fitness of community members as well as of the communities themselves, we expect multilevel selection leading to the evolution of successional communities to be ubiquitous. The following predictions test this overarching hypothesis: If no genetic basis underlies successional processes, foundation colonist species and their symbionts will be interchangeable among habitats. That is, no significant differences will exist in the composition of communities associated with foundation hosts within and among habitats. However, this hypothesis is rejected if particular genotypes of colonizing species associate with particular habitats, AND if particular genotypes of community members become associated with particular foundation host genotypes. Such results provide evidence that (1) phenotypic variation in successional community composition has a genetic basis, (2) selection in a community context within successional communities has occurred, and (3) successional community evolution is underway. Drought and climate change in the Southwest US may significantly alter historical patterns in these evolutionary processes as well as their outcomes. Thus, land managers must incorporate a community approach for successful habitat management and restoration.

Bridging Landscapes: Exploring the Intersection of Art, Science, People, and the Grand Canyon

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Abstract: Scientists generally focus on how to best communicate their findings within their own scientific community and sharing results with non-scientist stakeholders and the public can at times be overlooked. Art can bridge the science communication gap and allow for greater research impact as it allows connections to broader audiences, including utilization by decision makers. The broad array of stakeholders for scientific studies in the Grand Canyon region includes the public, Native American tribes, non-governmental organizations, scientists, state and federal resource managers, and elected officials. To present scientific results to this audience, we have incorporated art and scientific results in fact sheets and publications. In these formats, we present visual art – both paintings and illustrations that were created in a partnership between artist and scientists – to enhance science communication beyond what is typically achievable using conventional publications. The resulting illustrations and paintings form two fact sheets that summarize the hydrological connects to and environmental effects of breccia-pipe uranium mining in the Grand Canyon region. The vivid images are visually appealing and also incorporate scientific research and findings. Each image is designed to appeal to the broad group of stakeholders affected by the summarized scientific research. In publication, each image is accompanied by jargon-free prose that succinctly describes the work

being done. It is our hope that through these newly conceived fact sheets we convey understandable results or our studies to a broad spectrum of the public and decision makers.

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Abstract: Scientists generally focus on how to best communicate their findings within their own scientific community and sharing results with non-scientist stakeholders and the public can at times be overlooked. Art can bridge the science communication gap and allow for greater research impact as it allows connections to broader audiences, including utilization by decision makers. The broad array of stakeholders for scientific studies in the Grand Canyon region includes the public, Native American tribes, non-governmental organizations, scientists, state and federal resource managers, and elected officials. To present scientific results to this audience, we have incorporated art and scientific results in fact sheets and publications. In these formats, we present visual art – both paintings and illustrations that were created in a partnership between artist and scientists – to enhance science communication beyond what is typically achievable using conventional publications. The resulting illustrations and paintings form two fact sheets that summarize the hydrological connects to and environmental effects of breccia-pipe uranium mining in the Grand Canyon region. The vivid images are visually appealing and also incorporate scientific research and findings. Each image is designed to appeal to the broad group of stakeholders affected by the summarized scientific research. In publication, each image is accompanied by jargon-free prose that succinctly describes the work being done. It is our hope that through these newly conceived fact sheets we convey understandable results or our studies to a broad spectrum of the public and decision makers.

Ecological forecasts to support post-fire restoration seeding of perennial grasses

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Abstract: Restoration seedings in the western United States are often hampered by low and variable rates of plant regeneration from seed, contributing to widespread transformation of native plant communities. Here, we describe ecological forecasts for landscape-scale post-fire restoration seedings of perennial grasses. The ecological forecasts that we present are based on models of plant establishment that we developed by combining records of land treatments, fire

perimeters, and vegetation monitoring surveys with high-resolution simulations of soil moisture and temperature. Our approach integrates three major efforts aimed at documenting and monitoring trends on rangelands from agencies including the US Geological Survey and Bureau of Land Management: the Land Treatment Digital Library, wildfire perimeter maps, and landscape monitoring programs like the Assessment, Inventory and Monitoring Program. We identified 100-200 seeding treatments and over 300 monitoring surveys for several key grass species used in restoration: *Poa secunda*, *Pseudoroegneria spicata*, *Agropyron fragile*, *Achnatherum hymenoides*, and *Elymus elymoides*. We used historical weather data, soil maps, and an ecosystem water balance simulation model to reconstruct environmental conditions in the months and years following seeding at each surveyed location. We modeled recruitment from seed as a function of environmental drivers at multiple temporal scales including long-term climate, annual weather, and short-term influential time periods. We used these models to evaluate how much of the variance in seeding outcomes could be explained by specific environmental drivers and timescales. To develop and test a predictive model, we split our data into training and evaluation sets that we used (1) for cross-validation and variable selection and (2) to approximate model performance on new seedings. We describe how these models will be integrated with an existing forecast system to generate establishment forecasts and support restoration seeding decisions.

Sub-Alpine Canopy and Wood Growth Phenology in Aspen and Mixed Conifer Forests

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Abstract: Growth of high-elevation forests in the Southwest is limited by cold winters and dry summers. Increasingly, these forests are experiencing warmer temperatures, decreased snowpack, and more variable monsoons than in the past. There is considerable uncertainty about how the seasonal timing of growth and photosynthesis will be impacted by these changes. This research seeks to understand how canopy and radial growth phenology of aspen (*P. tremuloides*), spruce (*P. engelmannii*), and sub-alpine fir (*A. lasiocarpa*) respond to interannual and elevational differences in temperature, snowpack, and Monsoon rains. From 2022-2025, we measured radial wood growth with dendrometers and canopy phenology with PhenoCams along an elevation transect from 2890-3363 meters near Crested Butte, Colorado. In the conifer stands, spring and autumn phenological transition dates, associated with changes in canopy pigments, occurred on day 143 ± 10 and 282 ± 5 , respectively. In the aspen stands, the

same dates, associated with leaf out and senescence, occurred on day 161 ± 5 and 266 ± 8 , resulting in an active period of 140 ± 10 days in the conifer stand and 104 ± 11 days in the aspen stand. The wood growth period between aspen (55 ± 19 days) and spruce (52 ± 28 days) trees did not differ. Yet, sub-alpine fir trees had significantly shorter wood growth period than aspen and spruce, 40 ± 15 days. The start and end of the growing season for both canopy and wood varied as much or more year-to-year than by elevation. The strongest response occurred at the start of the growing season, with spring wood phenology advancing 0.25-0.4 days per day earlier bare ground. Earlier snowmelt had minimal effect on the end of growing season and growing season length. This suggests that these forests may be able to shift their growth period earlier with advancing springs, but it remains unclear how earlier springs may impact the duration of the entire growing season.

Experimental evidence of a biocrust degradation - climate warming amplification feedback

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Abstract: Biocrusts – communities of cyanobacteria, lichens, and mosses living on soil surfaces – represent about 12% of the global land surface and play a substantial role in dryland ecosystem function. Yet, our understanding of how climate change will affect biocrust functional types and the processes they regulate is far from complete. We addressed this knowledge gap by integrating multi-scale remote sensing techniques within a long-term experiment with treatments that reflect the expected future climate for the Colorado Plateau. Climate warming and projected changes in rainfall drove on average a ~27% decrease in fractional coverage of late-successional mosses and a ~36% increase in fractional cover of early-successional light cyanobacteria, which in turn resulted in a ~46% reduction in

photosynthetic potential, ~105% decrease in surface moisture, and a ~22% increase in surface temperature at the plot scale. These findings are evidence of a biocrust degradation - climate warming amplification feedback, whereby warming is driving biocrust structural and functional degradation and a net reduction in climate regulation potential, which in turn is accelerating warming. This amplification feedback is likely accelerating dryland degradation across global biocrust-dominated regions.

Madrean oak woodlands and savannas: Coupled human-ecological systems

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Abstract: Coupled human and ecological systems refer to two interdependent systems—one social and one ecological—in which the function and persistence of each influences the other. The Madrean oak woodland and savanna region, stretching from the Mogollon Rim into northern Mexico, supports numerous oak species, including Emory oak (*Quercus emoryi* Torr.). Emory oak acorns are a traditional food source of Western Apache people and critical to traditional ceremonies and lifeways. Emory oak habitat has undergone profound social and ecological transformation since the 1800s, when colonization replaced Indigenous land stewardship with Western land management practices. These changes have increasingly threatened the western Apache tradition of Emory oak acorn harvest. Fire suppression, the introduction of domesticated livestock, shifts in land use, and climate change have collectively degraded Emory oak ecosystems. These ecological changes, along with the fragmentation of land ownership, have diminished acorn production and access to harvest sites. Simultaneously, cultural changes have disrupted the intergenerational transmission of harvesting practices. The talks in this session will explore both the social and ecological dimensions of the western Apache–Emory oak system, highlighting collaborative efforts to support its resilience and long-term continuity.

Managing Rangelands in a Changing Climate: Using a Heritage Cattle Breed to Maintain Ecosystem Function Under Livestock Production

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Abstract: The Colorado Plateau, USA is an iconic western dryland landscape, home to dozens of national parks and monuments as well as several UNESCO World Heritage Sites. This richly diverse environment is also a hot-spot for climate change. This threat poses significant risk to the future of livestock production, a key economic activity in this region. We are

testing a novel climate adaptation strategy for livestock producers: the use of Raramuri Criollo (RC) cattle, a heritage breed adapted to the arid rangelands of Mexico, as an alternative to conventional breeds such as Red Angus (RA). RC cows are 300-500 lbs lighter than RA cows, with previous studies in the Chihuahuan Desert finding that RC range farther from water, eat a broader diet containing more shrubs, and navigate more rugged terrain than conventional breeds. We are determining if these behavioral differences also occur—and whether RC traits may be advantageous in the face of a changing climate—on the Colorado Plateau at the Dugout Ranch, located in San Juan County, UT. Based on the results of a step selection function, both breeds preferred areas closer to water, but RC to a slightly greater extent than RA. Additionally, both breeds avoided areas with more rugged terrain, but RC to a greater extent than RA. We are using DNA metabarcoding of fecal samples to examine whether these traits are associated with different diet preferences, and preliminary results suggest that a significant portion of both breeds' diets are composed of shrubs, particularly in the dormant season (October through March). Finally, we are using both field-based and remote sensing approaches to weigh these potential differences between RC and RA cattle against their impacts on range condition, and the production of ecosystem services therein.

Predicting Landscape-scale vegetation structure and biomass under diverging global change scenarios

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Abstract: Explaining the relationship between climate, weather, and the distribution of vegetation across landscapes has been a motivating endeavor for ecologists since the discipline began. Considerable effort has been dedicated to describing how the abiotic environment drives the global distribution of vegetation at a coarse taxonomic and spatial scales such as biomes, as well as at very fine scale such as an individual species. However, we lack a quantitative description of these relationships at intermediate taxonomic and spatial scales such as vegetation functional composition. These relationships would facilitate predictions of how vegetation structure and function may shift as abiotic drivers change in the future, and would do so at a scale that is both pragmatic and relevant to landscape conservation and management.

To help fill this gap, we used LASSO regression to fit a series of models that use soils, climate, and weather variables at a site to predict vegetative biomass as well as cover for seven functional groups: broad-leaved and coniferous trees, warm-season and cool-season grasses, forbs, shrubs, and bare ground. We trained these models using 1 km-gridded, historical climate data from dayMet, and vegetation cover and biomass data from across the continental United States (CONUS) that were synthesized from several sources, including vegetation monitoring and remotely sensed data. Using these equations, we predicted vegetation composition and biomass quantity across CONUS at the end of this century under RCP 8.5, based on modeled climate and weather data from both cold-dry and warm-hot models from CMIP5. We also plan to utilize these relationships to inform hydrologic soil-vegetation feedbacks in a process-based

model of soil moisture, which we will then use to generate forecasts of soil-moisture for CONUS under different CO₂ emissions pathways, providing invaluable, high-resolution, ecologically-relevant forecasts of drought over the next century.

Drivers of Colorado Plateau rangeland health

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Abstract: Dryland vegetation is experiencing multiple interacting stressors today, including aridification, warming, and land uses like livestock grazing. Understanding rangeland ecosystem resilience to these factors facilitates informed and flexible land management decision-making. However, anticipating how dryland vegetation responds to these stressors is complicated by the fact that drivers of vegetation change are confounded with one another and act synergistically. Consequently, when a site experiences multiple drivers, it can be challenging to disentangle the ultimate causes of vegetation change. Structural Equation Modeling (SEM) is an approach for modeling complex relationships and estimating direct and indirect effects of multiple drivers simultaneously. Using the study area of The Nature Conservancy's Canyonlands Research Center in southeastern Utah as a test case, we apply SEM to explore the relative effects of site characteristics, recent cool and warm season weather anomalies, and grazing intensity on C3 and C4 perennial grass cover, biological soil crust (BSC; mosses and lichens), and soil stability.

We found many significant driver-response relationships, but only mapped soil texture consistently had some of the largest total effects: mosses were associated with sandier soils while C3 and C4 perennial grasses were found where soils were finer. Soil stability was highest where mosses were abundant, grazing intensity was low, and soils were sandier—due partly to the positive effect of sandy soils on mosses. Surprisingly, grazing had a positive total effect on C3 perennial grasses, likely because grazing use tends to be higher where soils are finer. Cool season precipitation and temperature had large effects on lichens (positive and negative, respectively) while cool season precipitation had a large negative effect on C4 grasses, perhaps due to competition with C3 grasses. Overall, our results demonstrate that different aspects of vegetation and BSC respond to different suites of drivers, with soil texture one of the most important determinants.

The pollination and reproductive biology of two endemic cacti of northern Arizona (*Pediocactus peeblesianus* var. *fickeiseniae* and *P. paradinei*)

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Abstract: The conservation of rare plants may require attention to the disruption of plant-pollinator interactions, as rare species may be especially vulnerable to pollinator limitation due to their small population sizes and often narrow habitat requirements. In the House Rock Valley and Kaibab Plateau region of northern Arizona, two endemic cacti may depend on the conservation of their pollinators. The closely related *Pediocactus peeblesianus* var. *fickeiseniae*, a federally endangered species, and *P. paradinei*, a species of concern, have exhibited population declines and likely rely on insect pollination. However, little is yet known about the cacti's pollination and reproductive biologies. Meanwhile, low rates of pollinator visitation have been observed in recent years, potentially due to declines in pollinator abundance and diversity in the region. Here, we investigated the cacti's pollinators, flower visitation rates, level of self-compatibility, and reproductive output through multiple years of flower visitation observations and one year of pollination treatment experiments, germination experiments, seed viability tests, and tracking of fruit and seed set. We found that both cacti are likely pollinated by a range of bee taxa, in particular sweat bees (Halictidae), but the frequency of visitation and diversity of bees visiting can shift dramatically from year to year, potentially leading to low rates of pollination in some years. We also found that *P. paradinei* is likely partially self-compatible and can produce viable seeds through autogamy. However, the species may still depend on insect pollination to sustain populations. These findings highlight the importance of long-term monitoring of populations and pollination systems to assess how reproductive output fluctuates from year to year in response to shifts in pollination rates and to understand drivers of pollination rates. In collaboration with land management, this research is essential to inform pollinator habitat restoration efforts that may help prevent further declines in these rare cacti.

Community-climate disequilibrium impacts the productivity of western US rangelands

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Abstract: As the climate changes, species that cannot migrate or adapt rapidly may become poorly matched to conditions within their ranges. Community-climate disequilibrium measures that mismatch at the community scale and is likely to increase over this century and affect ecosystem functioning. In water-limited rangelands, primary productivity depends on efficient water use and may be sensitive to community-climate disequilibrium. We studied patterns of net primary productivity (NPP) at ~60,000 sites across 14 states in the western US and estimated the influence of species composition relative to the effects of inter-annual climate variation. We quantified species' realized climate niche optima using independent geographic occurrence data, estimated community-climate disequilibrium using on-the-ground BLM Assessment, Inventory and Monitoring species composition data, and calculated NPP climate sensitivity using remotely-sensed data from the Rangeland Analysis Platform and historical climate data from DayMET. We found communities had a roughly symmetrical distribution of positive and negative temperature disequilibrium: There were as many communities dominated by relatively hot- and cold- tolerant species. In contrast, rangelands were skewed toward negative precipitation disequilibrium: Most communities were composed of relatively hydrophilic species that tend to be found in wetter places than the study sites. We found that, after accounting for spatial differences in climate, NPP was maximized when temperature disequilibrium was near zero. In contrast, NPP was maximized when precipitation disequilibrium was positive, with increased productivity when the climate was wetter than that to which communities were adapted. Our findings suggest that western rangelands are currently far from equilibrium with climate and that decreases in water availability will further increase this disequilibrium. Our findings underscore that, to make accurate forecasts of productivity, we must take into account both the direct effects of climate on ecosystem functioning as well as ecological lags that cause disequilibrium between communities and the climate.

Integrating hydraulic analyses and population models to estimate effects of floodplain restoration on the endangered Rio Grande Silvery Minnow

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Abstract: Habitat suitability index (HSI) models are frequently used by agencies like the U.S. Army Corps of Engineers to evaluate the ecological consequences of restoration projects. Given the limitations of HSIs, augmenting their use with advanced models may improve restoration decision-making. However, even where management-relevant models exist, many are technically inaccessible to practitioners or not framed to inform site-scale management decisions. We present a case study in which we re-scale and re-package a published model on the endangered Rio Grande Silvery Minnow (RGSM) for direct use in restoration decision-making. Floodplain restoration is widely used to bolster RGSM populations, but existing RGSM population models cannot directly predict how restoration projects will affect the species. To address this need, we developed a 2D hydraulic model of the Middle Rio Grande (MRG) that estimates floodplain inundation extent at several discharges. Then, we incorporated output from the hydraulic model into an RGSM integrated population model to quantify the effect of floodplain inundation extent on RGSM recruitment. Using the adapted population model, we predicted the change in RGSM recruitment in each year from 1993 to 2020 in response to three scenarios: 1) floodplain restoration at eight MRG sites totaling 47 acres; 2) flow augmentation (10,000 acre-ft over 25 days); and 3) temporary channel modification designed to cause floodplain inundation. Floodplain restoration led to only modest increases in recruitment (< 2% over baseline recruitment levels on average), whereas channel modification caused larger increases in recruitment (15-34% increases in several years), and flow augmentation had the largest effect on recruitment (16-55% increases in half of the years). We also packaged our adapted model into a customizable web application. Along with the availability of river engineering analysis, this tool could enable managers to compare and contextualize specific water management and restoration scenarios.

Precipitation from tropical cyclones stimulates disproportionately higher productivity across ecosystems in the southwestern USA

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Abstract: In the southwestern USA (“Southwest”), ecosystems regularly receive precipitation in the winter or during the summer from the North American Monsoon, which drive productivity dynamics. Tropical cyclones are less well-studied but regularly make landfall during the end of the growing season (September and October), bringing large pulses of moisture to the region. In some years, these storms contribute up to one-third of the annual precipitation budget for areas in the Southwest. These storms are brief and occur during periods when vegetation is transitioning to a more dormant state, raising questions about how these storms influence vegetation productivity. Thus, the goal of our study is to evaluate how tropical cyclones impact productivity across the Southwest. We used a high-resolution (8-day, 0.05°) dataset of solar-induced chlorophyll fluorescence (SIF; a proxy of gross primary productivity) and historic tropical cyclone storm track data. We identified 23 tropical storms across the Southwest during 2000-2022, leading to a total of 297 days receiving precipitation from tropical cyclones. We analyzed productivity (SIF) dynamics during and for one week following each storm. We found that tropical cyclones exert a disproportional influence on vegetation productivity with some storms producing periods with >300% higher productivity than the same periods in years without tropical cyclones. Additionally, heightened productivity during some storms can account for up to 40% of annual productivity in areas despite only occurring for two weeks or less. Our findings suggest that moisture inputs from tropical cyclones are capable of stimulating brief but extremely productive periods in Southwestern ecosystems. Previous work has shown that alterations to winter precipitation and the North American Monsoon have already occurred, and continue to occur, under climate change, and it is possible that the heightened productivity from tropical cyclones could offset winter and summer drought impacts on ecosystem carbon cycling.

Seed pellet composition and amendments improve seedling emergence and inform restoration approaches in drylands

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Abstract: Over half of drylands are degraded globally, driven by anthropogenic forces, making restoration of these fragile and essential landscapes a critical priority. Due to the large extent of drylands in need of restoration and cost limitations, restoration efforts often employ active interventions, including herbicide treatments and/or seed-based restoration approaches. However, most dryland restoration efforts result in little or no establishment of desirable species. Seed-based restoration in drylands faces many major barriers to success, including abiotic limitations, seed predation, invasive species prevalence, and degraded soils. Innovative, science-based restoration strategies are needed to support positive restoration outcomes. Seed pellets (also called “seed balls”), a type of low-cost seed enhancement technology, offer one approach to overcoming barriers to restoration success. Seed pellets are an agglomeration of seed, clay, amendments, and water used to protect seeds, improve germination and establishment, allow for precision delivery of amendments, and allow for ease of distribution across the landscape. However, key knowledge gaps remain in best practices for seed pellet

synthesis and amendment additions to overcome restoration barriers, including invasive species management through herbicide application. We conducted a series of greenhouse experiments to improve our understanding of seed pellet synthesis best practices including testing variable composition and activated carbon additions in the context of chemical weed management. Across all experiments, we have found a positive effect of seed pellets on seedling emergence compared to broadcast seeding, limited impacts of composition on emergence, and a protective effect from activated carbon when used in conjunction with preemergent herbicide. Results from these experiments have informed seed pellet and soil health treatments implemented across a subset of the networked RestoreNet restoration trials and will allow for comparison between controlled greenhouse and field conditions.

Impacts of Climate and Stand Structure on Singleleaf Pinyon Pine Seed Production

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Abstract: In an era of climate change and rapid forest die-offs, it is crucial to understand the drivers of forest regeneration to forecast future changes and identify potential management solutions. In this study, we assessed how climate and stand density impact cone production in single-leaf pinyon pine (*P. monophylla*). In 2024, we sampled 36 pinyon pine populations across their range from eastern California to western Utah (1287 to 2653 meters, 34.0307° to 41.0418° lat.), recording stand density, current year cone and seed production, and historic (past 15 yr) cone production using the cone-scar method. We found a strong negative association between climate water deficit (CWD) and proportion of viable seeds, and a strong positive association between tree basal area and current-year cone crop, historic cone crop, and total seed weight. We found a weak negative association between stand density and historic cone production, and a positive association between percent live crown and historic cone production; we found no association between stand density and current-year cone crop, total seed weight per tree, mean viable seed weight, or proportion of viable seeds. Furthermore, we found that while cone production was not directly associated with CWD, it was indirectly negatively associated with CWD through its impact on tree size and percent live crown. In sites with higher CWD, higher stand density led to lower crown health, but in sites with lower CWD, it had a limited effect on crown health. These results suggest that the effects of stand density, tree size, and percent live crown on seed production in single-needle pinyon pines may all be driven by climate effects on overall resource availability. Furthermore, resource competition between single-needle pinyon pine trees may be less relevant to their cone and seed production than overall resource availability.

Integration of plant–soil feedbacks with resilience theory for piñon-juniper woodlands under drought

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Abstract: The resilience of ecosystems to climate disruption requires internal feedbacks that support the stability of ecosystem structure and function. Resilience can be decomposed into feedbacks that affect ecosystem resistance to initial disruption or recovery after disruption. If feedbacks degrade, ecosystems may be pushed over thresholds to state transition. Such feedbacks may include positive plant-soil feedback (PSF), which develops when a plant grows better in soils that have been conditioned by itself than in soils influenced by other plant species. Positive PSFs are common between piñon pine (*Pinus edulis*) and ectomycorrhizal fungi (EMF) but have not been studied in a resilience context. Piñon-juniper woodlands are the largest old-growth forests in the western USA, which provide vital resources for wildlife and sustain carbon storage. Yet, these woodlands are increasingly vulnerable to climate disruption, with drought causing massive mortality of piñon pines. Natural post-drought regeneration of piñon has been limited; therefore, management strategies may benefit from enhancing feedbacks that promote pinon resistance to or recovery from disruption. We are evaluating hypotheses that integrate PSF into resilience theory and interrogate feedback thresholds for pinon under drought. (1) Positive PSF is a stabilizing mechanism that increases resistance to and speeds recovery of piñon from climate disruption. (2) Keystone microbes regulate how much positive PSF boosts resilience of piñon, and (3) Positive PSF promotes resilience of piñon up to a threshold of climate disruption. Understanding how, when, and where plant–soil interactions may improve the resilience of ecosystems to climate change could improve the ability to manage systems that face climate disruption. Specifically, the restoration of disrupted positive PSF may increase the resilience of piñon-juniper woodlands to drought.

Place-Based Geoscience Education in Kinłani (Diné Bikéyah–Hopitutskwa) Using the Paleoclimate Reconstruction Storehouse (PReSto): Activating STEM Identity and Teaching Confidence through łeezh (Dust)

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Abstract: This study examines how place-based geoscience professional development can activate STEM identity and build teaching confidence among educators in Northern Arizona. Twelve teachers (5 preK–5, 5 grades 6–8, 2 grades 9–12) participated in a one-day workshop at the Merriam-Powell Research Station in Kinłani (Flagstaff, Arizona), within Diné Bikéyah and Hopitutskwa.

Workshop activities combined constructivist 5E lesson design, place-based geoscience education principles, Diné traditional ecological knowledge, and standards alignment. Using the Paleoclimate Reconstruction Storehouse (PReSto), teachers engaged in hands-on investigations and interactive mapping, with łeezh (dust) as the anchoring phenomenon.

Pre-survey results showed low confidence in geoscience teaching across all domains. Post-survey analysis revealed notable gains: geoscience field understanding increased 87%, teaching confidence 75%, and place-based pedagogical practices 52–80%. Standard deviations decreased by 62%, indicating greater consensus at higher confidence levels. Thematic analysis

of open-ended responses showed clear STEM identity activation, with teachers shifting from uncertainty to strong expressions of competence.

Findings indicate that brief, intensive, culturally grounded professional development—integrating Indigenous and Western knowledge—can meaningfully enhance teacher confidence and identity. Such approaches hold promise for addressing the geoscience teaching gap in underserved Indigenous-serving schools, while connecting science education to place, culture, and lived experience.

Landsat-derived rainfed and irrigated-area product for Conterminous United States (CONUS) for the nominal year 2020: A study of irrigated and rainfed areas at the state, and county level for the CONUS

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Abstract: Accurate, high-resolution maps of irrigated and rainfed croplands are essential for evaluating global food and water security. Irrigated croplands typically yield 2–4 times more grain and biomass than rainfed systems. To meet the rising demand for food and nutrition driven by a growing global population, more and more of the world’s 1.8 billion hectares of cropland are being brought under irrigation. Since 80–90% of all human water use is devoted to agriculture, understanding the spatial distribution and dynamics of irrigated and rainfed croplands is critically important.

This study presents a high-resolution (30 m) map of irrigated and rainfed croplands for the conterminous United States (CONUS), derived from Landsat-8 imagery for the years 2019–2021. The resulting product, termed **LRIP30 CONUS 2020**, uses median-value composites of 8 Landsat bands (blue, green, red, NIR, SWIR1, SWIR2, TIR, and EVI) generated every 16 days over three years. These composites formed a harmonized and standardized 96-band analysis-ready data cube (ARD-MFDC). A cropland mask was applied to isolate agricultural areas from non-agricultural lands.

Training and validation data for machine learning (ML) classification were sourced from very high-resolution imagery (VHRI), the USDA Cropland Data Layer, field observations, and other ancillary data. Classification was performed using two ML algorithms: 1. pixel-based supervised Random Forest classifier, and 2. pixel-based unsupervised CLUSTER algorithm.

The LRIP30 CONUS 2020 product achieved an overall accuracy of 93.9%. For irrigated croplands, producer’s and user’s accuracies were 90.2% (errors of omissions = 9.8%) and 90.8% (9.2%), respectively. For rainfed croplands, producer’s accuracies were 95.7% (errors of omissions = 4.3%) and user’s accuracies 95.4% (errors of commissions = 4.6%). The total net cropland area (TNCA) mapped was 139.4 million hectares (Mha), with 94.9 Mha (69.3%) classified as rainfed and 44.5 Mha (30.7%) as irrigated. The study also provides state-level statistics on irrigated and rainfed croplands, highlighting regions with the highest agricultural water use and discussing implications for national food and water security.

How long do shrub communities require to recover after severe disturbance?

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Abstract: Disturbances drive large changes in plant composition and ecosystem functioning in drylands, but current understanding of how recovery following disturbance depends on the environment is limited due to challenges in analyzing effects of disparate disturbances across abiotic gradients. We combined remote sensing and field observations across 5600+ km of natural gas pipeline corridors and adjacent undisturbed vegetation to investigate how recovery from a uniform, severe disturbance varied with factors that influence water availability in drylands.

We found that recovery of net primary production (NPP) often remains incomplete, with only 42% of our sites projected to fully recover within 100 years. NPP recovery was quicker and more complete in regions that receive most of their annual precipitation at low temperatures and have fine-textured soil; recovery of total shrub cover (median timing of 81 years) was faster on fine-textured soils in locations that receive most of their annual precipitation at high temperatures. Locations with quick recovery of shrub cover were linked with a shift in dominant shrub species and incomplete NPP recovery. Recovery of NPP and shrub cover in drylands were driven by different environmental factors. For both NPP and shrub cover, locations with high pre-disturbance values required more time to recover to adjacent undisturbed levels than locations with low pre-disturbance values. Quick recovery of shrub cover or productivity was generally linked with a shift in dominant plant species or plant functional group.

Restoring traditional fire regimes in Emory oak woodlands

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Abstract: Fire is a critical process in many oak-dominated ecosystems that shapes structure, function and diversity. Indigenous cultural burning has been used in many oak-dominated ecosystems across the U.S. and Mexico with diverse goals often focused on habitat management for forest products including the critical food source of acorns. To better understand what is known about indigenous fire management in oak-dominated ecosystems, we conducted a systemic review of 59 peer-reviewed studies. Specifically, this literature review aimed to ask: 1) How has cultural burning shaped oak ecosystems through time? 2) What social and ecological outcomes have resulted from the disruption or removal of cultural fire? 3) What pathways exist for revitalizing cultural burning to support both ecosystem function and Indigenous sovereignty? We identified four emergent themes: 1) evidence for Indigenous influence on fire regimes, 2) ecological effects of cultural burning and traditional land management, 3) description of cultural burning practices, and 4) benefits of cultural

burning for ecosystems and interacting human populations. We will present these findings and connect them to a Social Ecological framework, emphasizing how restoration of traditional practices may bolster coupled system resilience in the face of global change.

Arizona Wildfire Initiative: Community resilience, workforce development and education and science communication to support wildfire in Arizona

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Abstract: Launched in 2023 with support from the Arizona Governor’s Office, the Arizona Wildfire Initiative (AZWI) is a coordinated effort to strengthen wildfire resilience across the state through workforce development, science communication, and community engagement.

Workforce Development and Education

AZWI is addressing the growing demand for trained professionals by creating new academic and training opportunities. These include a B.S. in Applied Wildland Fire Science, B.S. and M.F. degrees in Applied Forestry, and an online M.F. in Forest and Natural Resource Management. Internship programs and continuing education further support a diverse and skilled workforce.

Science Communication

AZWI builds on the strengths of the Southwest Fire Science Consortium to better connect researchers and practitioners. By enhancing access to applied science and fostering collaboration, the initiative ensures that science supports real-world fire management challenges in Arizona.

Community Resilience

To help communities live with wildfire, AZWI engages local leaders in a three-step process: (1) establish relationships with fire chiefs, HOA leaders, and elected officials; (2) assess community-specific perceptions of wildfire and post-fire risks; and (3) identify and close gaps in preparedness. Key outcomes include a Business Continuity Planning Workbook, community chipper days, and other locally tailored resources.

AZWI’s integrated approach supports a more fire-adapted Arizona—one that is better equipped to meet the complex challenges of a changing wildfire landscape.

A tiny moth and an iconic desert tree: Investigating the eastern Joshua tree and its specialist pollinator

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Abstract: Joshua trees are iconic trees endemic to the Mojave Desert of the USA Southwest. They occur as two species, or varieties depending upon the taxonomic source, and are mostly separated geographically. Each is dependent upon a pollinating moth in an obligate mutualism wherein the moth requires the Joshua tree’s fruit pods for larval food and habitat and the Joshua tree requires the moth for pollination. The eastern form of the Joshua tree (*Yucca jaegeriana*) depends on the specialist moth, *Tegeticula antithetica* and the western counterpart (*Yucca brevifolia*) depends on a sister moth, *Tegeticula synthetica*. As temperatures increase

with climate change, so do concerns about the continuity of the obligate association between the Joshua tree species and their respective moths. Little is documented on the ecology of the association and the factors influencing the synchrony between the moth and tree that allow for successful pollination and seed production. We studied the pollination ecology of the eastern Joshua tree in 2022 and 2023 to better understand moth floral visitation, pollination success, and associated environmental factors during two flowering seasons. During the first year, Joshua trees flowered abundantly, and we detected 56 moths using sticky traps attached to Joshua tree inflorescences. The second year, flowering was less frequent, and we detected only 14 moths, despite a longer trapping period and more replicate sticky traps. Fruiting pods with viable seeds were produced in both years, indicating pollination had occurred. Yet we found that the percentage of tagged inflorescences that produced viable seed pods was substantially less in the second study year and more inflorescences wilted with no production of seed pods. In our presentation, we illustrate our findings and suggest the questions to continue exploring so to better understand the phenology and ecology of the moth - eastern Joshua tree mutualism.

Preserving Indigenous Ancestral Knowledge from the Grand Canyon through Legacy Leader Development

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Abstract: Many Indigenous Tribes living around the Coconino Plateau consider the Grand Canyon a place of emergence and a sacred place. The Grand Canyon region consists of many cultural and sacred sites now identified and managed by Federal agencies. Tribes in the region lost connection to many sacred sites, oral stories, medicinal plants, animals and songs due to Tribes being forced onto reservations by the Federal government; this action displaced many families from their original homelands. This displacement of communities caused the Havasupai and other tribes to no longer have access to their sacred mountains like Red Butte (Wii'i Gdwiisa) and San Francisco Peaks (Wii Haginbaja) where traditional medicines and natural foods were collected to sustain their lifestyle (see map on page 8). Displacement caused traditional knowledge and ancient teachings to become lost or forgotten. Through this leadership project, we will return back to our sacred mountains relearn, practice prayer, and songs for the landscape. We will reach out to the Federal agencies who manage these areas and learn how they manage our sacred places located on Federal Forest Service Lands. Through creating a working relationship with the Federal agencies staff who manage our sacred sites is very important step in this process. With their help we will gain access to archeological information near our sacred mountains and relearn about the stories of our sacred trails and mountains. This project will allow us to return to our ancestral homelands and teach the federal agencies that we still have cultural connection to our sacred mountains.

Leveraging seasonal tree-ring growth to assess species climate adaptations to water stress

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Abstract: Southwestern forests experience a bimodal precipitation regime, mediated by ENSO oscillations. This variance increases uncertainty in climate change predictions for seasonal precipitation, posing challenges to land managers when planning climate resilient forests. Many dominant native tree species depend primarily on snowpack, rather than monsoonal rains, for growth. Species at the northern edge of their range may have a competitive advantage as temperature, drought severity, and drought duration continue to increase. We developed earlywood (EW) and latewood (LW) chronologies of Chihuahuah pine (*Pinus leiophylla*) at the northern edge of its range in central Arizona and New Mexico. Sub-annual EW and LW widths allow us to better understand how precipitation timing affects growth. We sampled tree cores from 270 trees at 16 spatially balanced sites to assess growth responses to climate variables (temperature, precipitation, and VPD). LW was highly associated with monsoonal precipitation, while EW was strongly correlated to precipitation from the fall preceding the growing season until the spring, indicating that Chihuahuah pine growth is influenced by winter and monsoonal precipitation. Southern populations formed more frequent “false” rings, indicating sensitive growth response to precipitation fluctuations, a trait that will likely become more important for survival as climate changes. Identifying species with flexible growth responses will allow managers to efficiently allocate restoration efforts around species that have been previously underrepresented in forest planning. Employing strategies that create diverse pathways for forest persistence will improve chances for restoration success and preserve vital ecosystem services.

Enhancing vegetation monitoring for conservation area management: Remote sensing applications at Palo Verde Ecological Reserve, Lower Colorado River TRETO, V.¹

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Abstract: The Lower Colorado River Multi Species Conservation Program (LCR MSCP) supports the conservation of covered native mammal, bird, fish, amphibian, reptile, invertebrate and plant species through habitat creation and management, population monitoring, and species research. The program has made recent advancements on an approach utilizing remote sensing technology to monitor 7,500+ acres of created habitat and assess habitat suitability for 27 covered species. We piloted an enhanced remote sensing framework utilizing historical and current orthoimagery and LiDAR data to monitor vegetation dynamics at Palo Verde Ecological Reserve (PVER), a 1,300-acre conservation area established in 2006 featuring Cottonwood-Willow and Honey-Mesquite land cover types. Components of our monitoring approach include LiDAR-derived canopy height models, vegetation density mapping, and multispectral analysis using both programmatic high-resolution (0.5m) and open-source lower-resolution (Landsat, 30m) orthoimagery. The framework derives critical vegetation metrics—canopy height, canopy closure (percentage area with vegetation ≥ 1.2 m), and Enhanced Vegetation Index (EVI2)—as quantitative indicators of vegetation health and structural development trajectories. Data are analyzed at multiple scales—from individual fields to the entire conservation area—enabling detailed tracking of habitat development as the

program continues its implementation of a 50-year Habitat Conservation Plan (HCP). The remote sensing framework offers advantages over traditional ground-based monitoring: increased spatial coverage and accuracy, temporal consistency, minimal wildlife disturbance, and rapid assessment capabilities. Future developments include incorporating enhanced canopy structure metrics, integration with wildlife survey data, and development of weighted vegetation indices with management trigger thresholds. This presentation will demonstrate practical applications of remote sensing tools for vegetation monitoring in arid riparian restoration, supporting evidence-based adaptive management strategies critical for maintaining river corridors along the Lower Colorado River system.

Getting by with a little help from their friends: Nurse shrubs and live soil inoculum improve tree seedling replanting success in a post-wildfire landscape

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Abstract: The establishment of long-lived woody plants after wildfire is a critical bottleneck to the recovery of native plant communities in southwestern woodlands. Mycorrhizal fungi have been shown to improve pine seedling tolerance of heat and drought, yet important taxa may be lost through stand-replacing wildfire, and shifts in soil communities may persist for decades. We tested the effect of live whole-soil inoculum sourced from intact (unburned) pinyon-juniper (*Pinus edulis* and *Juniperus osteosperma*) woodlands on pinyon and juniper seedling growth and survival when planted into an area that had burned in stand-replacing wildfire twenty years prior. We evaluated this in combination with other replanting techniques, including planting near nurse shrubs, nurse logs, and in interspaces. We found that pinyon seedling survival was improved by the presence of a nurse plant compared with the log and interspace treatments, while juniper seedlings did equally well with or without a nurse shrub. Live soil inoculum did not influence seedling survival, but both species of seedlings had a positive growth response to the inoculum treatment even two years after establishment. Our findings suggest that replanting efforts may benefit from consideration of both plant and soil communities at the restoration site, and that active restoration of soil communities and choosing sites with nurse shrubs may improve tree seedling success. This is of particular importance as land managers face increasingly variable climate and fire regimes, necessitating new approaches to ecosystem restoration.

Hide and Seek: Can Biocrust Buffer the Effects of Climate Change on Soil Microarthropods Across an Elevation Gradient?

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Abstract: Soil is the foundation of terrestrial ecosystems and houses ~59% of Earth's biodiversity, which performs critical biogeochemical processes. However, the soil organisms that perform functions such as nutrient and carbon cycling are sensitive to changes in climate. As our climate warms and precipitation becomes more variable, determining these effects is important for soil health. Biological Soil Crusts (biocrusts) are a community of cyanobacteria, lichen, moss, and other organisms living on the soil surface that may buffer changes in soil moisture and temperature. Soil microarthropods are a group of organisms that utilize the resources from biocrusts in soils and play an important part in both the soil food web and biogeochemical processes. The ways biocrust affects microarthropod communities under changing climates is largely unstudied, but key in understanding the impacts of climate change on dryland soil systems. We conducted an observational study to determine if biocrusts buffer soil microarthropods from changes in precipitation and temperature by sampling along an elevational gradient. We collected cores that had 80% or higher biocrust cover and cores that had less than 5% biocrust cover (n=5 each at 6 sites, for a total of 60 samples). Vascular plant data was collected on site and soil chemical analyses will be performed in the lab. Microarthropods will be identified to the lowest possible taxonomic level in order to analyze the relationship between elevation, biocrust presence, and microarthropod biodiversity. By understanding how soil microarthropod communities are affected by biocrust cover across different climates, we aim to gain insight into how these communities may react to climate change.

webDART: A web application for evaluating effectiveness of land treatments

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Abstract: New and improved remote sensing products have improved our ability to assess land condition across the US. However, to accurately interpret these new data products in the context of land treatment or management effectiveness, it is important to have a reference or control that provides context to any observed change. With appropriate reference areas (i.e., those with similar ecological potential), resource managers, landowners, and other stakeholders can better interpret changes in land cover, production, and other land health metrics. Increased availability of continuous data for soil, topographic, and land cover characteristics has made it possible to retrieve data pertinent to ecological potential and selecting well-matched reference areas across the contiguous US. The Disturbance Automated Reference Toolset (DART) was developed by the U.S. Geological Survey to harness these powerful datasets to better characterize land treatment and management effectiveness. To increase accessibility of this tool for land managers and other stakeholders interested in assessing treatment effectiveness, we developed webDART, a companion web application for DART. The webDART application provides a user-friendly interface with which to analyze land disturbance and treatment responses as well as graphing, data, and reporting outputs that users can place in decision documents or analyze further.

Harvester ant ecology: how ants may affect and be used in restoration of drylands

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Abstract: Harvester ants (*Pogonomyrmex* spp.) are abundant on degraded dryland sites across the western United States. Historically, these ants were considered pests that denuded rangelands by removing vegetation. However, now ecologists consider harvester ants keystone species due to their many important ecological roles that affect nutrient cycling, seed dispersal, and ultimately, plant communities and primary productivity. Here we explore both the literature and our own studies in northern Arizona to help clarify how harvester ants impact plant communities and what this means for restoration. Two key attributes of harvester ant ecology seem important for restoration: 1) enhancement of vegetation along nest-rims creating plant refugia, and 2) selective seed harvesting which may affect broad-cast seeding initiatives and invasive plant success. By enhancing vegetation along nest-rims, harvester ants can buffer the effects of drought, grazing, and fire, becoming points of recovery for vegetation following disturbances. However, this vegetation may be native or invasive, depending on which species can use nest-rim habitats. By selectively harvesting native grass seeds, harvester ants may decrease success rates of broad-cast seeding efforts. However, we argue that ants are far less impactful than other causes of seed mortality, may cause beneficial short-term dispersal, and in some cases prefer nonnative seeds reducing invasive species. We discuss how restoration efforts can avoid the negative impacts of seed harvesting and potentially use harvester ants as an ally in restoration.

Collaborative post-fire restoration of singleleaf pinyon pine on a cultural landscape

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Abstract: Pinyon-juniper woodlands in the Great Basin are experiencing local declines from wildfire and drought, mirroring trends of forest decline in other regions of western North America. These disturbances are resulting in major ecological impacts, including habitat losses for woodland-obligate wildlife species and non-native plant invasions. Declines in pine nut production, drought-induced tree mortality, and increasingly large fires have also greatly impacted Indigenous communities and imperiled vital cultural connections to the landscape. This presentation will describe recent approaches to post-fire restoration of singleleaf pinyon pine (*Pinus monophylla*) through collaborative experiments between the Washoe Tribe of Nevada & California and ecological researchers. Field trials on Washoe Tribal land assessed

abiotic and microsite influences on outplanted seedling performance, while a complementary experiment evaluated the effects of artificial shade and soil inoculation. Overall, we observed about 35% seedling survival in the first year after planting, and our results highlight the critical importance of shade and microsite selection for increasing post-fire restoration success in dryland environments. This collaborative restoration effort is embedded within a community-based adaptive management project, which facilitates long-term monitoring and provides a culturally meaningful path for ecological stewardship in the face of increasing fire risks and invasive species challenges.

Advancing understanding of dynamics and resilience in socio-ecological systems

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Abstract: The traditional harvest of plant species from natural environments is a prime example of a social-ecological system. Our research focuses on the interactions between Western Apache Tribes and Emory oak trees and specifically the harvest of acorns by tribal members. This is a traditional practice that remains a key aspect of Western Apache identity and culture. Harvesting acorns often involves travel and harvesting trips are becoming less common. We examine a framework for understanding factors that might be influencing the resilience of the acorn harvest practice. We examine the ability to access good quality acorns (connectivity), knowledge retention and transfer (refugia), and how others support acorn harvest (diversity). Using 57 personal interviews we find that connectivity has been severely reduced by privatization and land development, degraded infrastructure including poor road conditions, and ecological changes, notably finding a 78% reduction in active harvest sites. Knowledge refugia reside largely with elders, whose declining numbers and limited knowledge transfer to younger generations threaten the continuation of traditional harvest practices and sharing of cultural knowledge across generations. Finally, diversity in terms of institutional support is minimal, with little collaboration from external stakeholders, which shows a need for broader partnerships to sustain both ecological and cultural resilience. We also found additional factors influencing acorn harvesting, including Western cultural influence and internal community support and collaboration. These insights highlight the importance of integrating Apache perspectives in oak management, improving access to groves, and strengthening both internal and external collaboration to sustain the cultural and ecological resilience of Western Apache acorn harvesting for future generations.

Creating a Decision Support Tool for Setting Sustainable Raptor Take Limits under Future Environmental Nonstationarity

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Abstract: Current environmental stochasticity is already exerting discernible influence on raptor populations – altering migration strategies and affecting key vital rates – and its impacts are projected to intensify in the future. However, the decision-making framework currently employed by the U.S. Fish & Wildlife Service to set allowable raptor take limits for anthropogenic activities, including wind energy, assumes stationarity with respect to future environmental conditions. Combining small scale, long-term monitoring and banding programs with continent-wide surveys (e.g., breeding bird surveys) from 1980s to the present we developed integrated population models (IPMs) for four species of raptors, the Golden Eagle (*Aquila chrysaetos*), Peregrine Falcon (*Falco peregrinus*), Swainson's Hawk (*Buteo swainsoni*), and the Cooper's Hawk (*Accipiter cooperii*). These IPMs incorporate age-specific demographic rates and the relative importance of climate variables on model subcomponents (i.e., nest productivity). With these estimates we will build prescribed take limit models. The outputs generate counts of individuals permissible for take, ensuring population stability while balancing the competing objectives of renewable energy development. This work is undertaken in tandem with a decision science component to engage stakeholders across the Central Flyway, a region with significant potential for wind energy development, and elicit expert opinion on demographic parameters and levels of risk tolerance over the range of outcome uncertainty. Our objective is to provide informed decision-support tools that account for future climate nonstationarity, to aid management decisions and policies surrounding sources of anthropogenic mortality on raptors.

Broadening engagement in the Collaborative Forest Landscape Restoration Program (CLFRP)

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Abstract: The U.S. Congress authorized the creation of the Collaborative Forest Landscape Restoration Program (CFLRP) in 2009, which seeks to “encourage the collaborative, science-based ecosystem restoration of priority forest landscapes” (Public Law 111-11). CFLRP

provides financial and technical support for cooperation between selected forests and interested and affected entities in the landscapes connected to these forests to make Forest Service management more inclusive, collaborative, and effective. We administered a survey to participants in all currently funded CLFRP projects between 2021 and 2023. Respondents primarily participated in CFLRP projects to restore forest resiliency, reduce community wildfire risk, increase the pace and scale of restoration, and improve relationships and trust. The majority of respondents found their CFLRP project to be collaborative and believed that the collaborative process helped build trust, relationships, and legitimacy. Respondents suggested several improvements to the collaborative process, including better alignment of expectations for collaborative engagement with the Forest Service throughout planning, implementation, and monitoring. Many respondents wanted to better understand how Forest Service decision making worked and how collaborative members outside the agency can inform these decisions. Projects faced disruptive challenges such as high personnel turnover, limited agency capacity, wildfires, limited industry capacity, and unsuitable timing and limited amount of financial resources. Common recommendations for improved collaboration and outcomes included the need to broaden inclusion of Tribes as rightsholders and more interested and affected entities as stakeholders through early and frequent collaborative engagement. We are currently expanding our work into examining two selected CLFRP projects – the Western Klamath Restoration Partnership in northern California and the Zuni Mountains Collaborative in New Mexico – to better understand their approaches for broadening engagement to achieve mutual restoration goals.

A needs assessment for northern Arizona's Wood For Life partnership: assessing firewood need and local capacity

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Abstract: The Wood For Life (WFL) partnership began coalescing in 2019 to connect biomass removed from forest restoration operations, particularly on National Forest land, to growing Tribal firewood heating needs. The Ecological Restoration Institute completed a needs assessment for the partnership to determine the scale of local firewood needed and wood bank capacities among the Western Navajo Agency and Hopi Tribe, Tribal communities that are closest to the Coconino National Forest. We found that firewood was the most common heating source, with 90% of households relying on firewood at least in part for home heating. An average household used an estimated 5-10 pickups (2.5-5 cords) of firewood each winter. Overall, 25,000-50,000 cords of firewood are needed annually for the entire Hopi Tribe and the Western Navajo Agency (22% of the Navajo Nation's population). In recent years, the partnership has grown rapidly to become one of the largest firewood suppliers in the region, making thousands of cords of firewood available, although there is continued need for firewood. Additional growth of WFL will require addressing the need for sufficient delivery and storage space, well-maintained heavy equipment, and support for staff at wood banks to process, distribute, and deliver firewood to households. Transportation of firewood remains a key challenge, and the partnership continues to explore several models of wood access. Future efforts could include formal agreements between federal land agencies and local Tribes to support forest restoration goals and enhanced Tribal management of ancestral lands.

Gamma radiation and soil concentrations of U, As, Cu, and Mo during mining and reclamation of breccia-pipe U deposits, Arizona, USA

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Abstract: Breccia-pipe uranium deposits are solution-collapse features containing uranium-rich mineral deposits. The deposits are enriched in uranium (up to about 1 percent U₃O₈ by weight) as well as arsenic (As), copper (Cu), and molybdenum (Mo). The deposits are mined using underground techniques, and each site typically has a fenced industrial mine yard covering a small area (< 7 hectares on average). The environmental footprint of mining this deposit type is not well documented.

Undeveloped and mined deposits located in similar geologic, topographic, and ecosystem settings were sampled for surface gamma radiation and soil concentrations of U, As, Cu, and Mo to represent various points in the mine life cycle. Sampling sites included EZ2 (pre-mining, undeveloped); the Pinyon Plain mine (PPM-pre-mining development); the Pinenut mine (PM-active mining); the Arizona 1 mine (AZ1-post mining); and the Kanab North mine (KN-sampled both post mining and post-reclamation). Data were collected from 2009 to 2018.

Results indicated increased mean radiation and soil concentrations within the mine yard at KN post mining compared to EZ2 pre-mining conditions. After reclamation, mean values in the KN mine yard remained slightly elevated compared to EZ2 pre-mining mean values, indicating decreases after reclamation. However, some areas in the mine yard where the ore pile and waste rock had been stored remained more elevated. Reclamation does not occur outside the mine yard. Consequently, mean radiation and soil concentrations were elevated outside and generally downwind from the mines relative to EZ2, indicating possible redistribution of dust generated on the mines. Soil with elevated radiation ranged in distance downwind from the mine yards from about 0.3 kilometer (km) at KN to about 1 km at AZ1. This study indicated that reclamation most likely decreased radiation and soil concentrations in the mine yards but also indicated some potential issues remain within and outside mine yards.

Community Science Reveals Spatiotemporal Patterns of Avian Diversity and Distribution

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Abstract: Community science platforms like eBird have revolutionized biodiversity monitoring by enabling widespread public participation in ecological data collection. In biodiversity-rich yet data-limited regions like Southeast Asia, where citizen science is rapidly expanding, eBird serves as a powerful tool for tracking avian diversity across space and time. This study analyzes 185,939 eBird checklists submitted between 2005 and 2025 across Bangladesh, Cambodia, and Indonesia, comprising over 20.7 million bird observations and 2,359 unique species, to evaluate how observer behavior, data structure, and geographic context influence biodiversity trends and monitoring reliability. Effort-corrected Poisson models revealed that Bangladesh had the highest standardized bird abundance (7.02 birds per checklist), while Cambodia showed the strongest model fit (pseudo- $R^2 = 0.37$), suggesting consistent and structured effort reporting. Indonesia showed a negative correlation between

checklist length and group size in bird counts, indicating detection saturation or diminishing returns under higher-effort conditions—insights with significant implications for protocol design and data interpretation. Temporal beta diversity was highest in Bangladesh (Bray-Curtis = 0.85), reflecting rapid community turnover likely driven by urbanization, habitat degradation, and migratory shifts. Indonesia exhibited peak species richness, particularly among forest-specialist clades like Pycnonotidae (bulbuls) and Timaliidae (babblers), highlighting both ecological diversity and potential observer identification challenges. Seasonal ARIMA models projected continued growth in eBird activity through 2030, with Cambodia expected to experience the steepest rise. Time-series decomposition and stationarity diagnostics revealed strong annual periodicity and post-2015 structural shifts aligned with the global expansion of community science participation. Differences in protocol use and locality types—notably personal locations in Bangladesh versus shared hotspots in Cambodia and Indonesia—also shaped detection patterns and spatial resolution. These findings highlight eBird’s vital contributions to biodiversity science and provide a transferable, data-driven framework for adaptive conservation planning and more strategic engagement with the eBirding community in ecologically vulnerable, data-scarce landscapes.

Migratory hummingbirds as drivers of genetic connectivity in isolated populations of crimson monkeyflower (*Mimulus verbenaceus*)

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Abstract: Genetic connectivity via gene flow impacts evolutionary trajectories in natural plant populations by affecting genetic diversity, local adaptation, and population persistence. Animal pollinators mediate much of this gene flow, yet we know little about how seasonal migration of animal pollinators influences plant genetic connectivity. In this study, we investigate whether migratory hummingbirds facilitate long-distance pollen dispersal and connect isolated populations of crimson monkeyflower (*Mimulus verbenaceus*), a riparian, hummingbird-pollinated species. We sampled populations across the species’ range from southern Utah to northern Mexico and estimated pairwise genetic distances using PCA distances from RADseq data. We will model migratory hummingbird mediated pollen gene flow using landscape resistance surfaces. We will assess these resistance surfaces as predictors of genetic differentiation in a generalized dissimilarity model (GDM) against other predictors such as Isolation by Distance (IBD), Isolation by Environment (IBE) and riparian connectivity. By integrating migratory pollination networks, we expect to improve the predictive power of landscape genetic models and reveal rare but influential long-distance gene flow events. Our results will clarify how migratory pollinators drive plant population connectivity and highlight the importance of protecting migratory corridors to conserve genetic diversity in riparian plants of the arid Southwest.

Tools for understanding genetic variation in pinyon pines and their application to ecology and management

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Abstract: Awareness and understanding of the distribution of genetic variation and climate-related traits in pinyon pine species in the Southwestern US has the potential to improve models and management. Needle number per fascicle is one potential climate adaptation which has long been used to distinguish *Pinus edulis*, Colorado or two-needle pinyon, and *Pinus monophylla*, single-needle pinyon. Additional needle morphological traits such as dimensions, resin canals, and stomatal rows further distinguish other groups sometimes labelled as species, subspecies, or types which are in turn associated with different climatic conditions. Genomic data is beginning to further clarify the relationships among these groups and show the extent to which hybridization and gene flow shape the climate responses of pinyon pine. Models of pinyon range, demography, growth, and cone production that take into account genetic and trait variation across the range should help continue to improve predictions. In the Arizona portion of the range there is a one-needle type “*fallax*” that is genetically more similar to *Pinus edulis* and hybridizes extensively with *P. edulis*. It’s inclusion in models of responses of *P. monophylla* to climate change are likely to be misleading. The same can be said for inclusion of hybrid sites in analyses of *P. edulis* response. Furthermore, because of the extremely high level of gene duplication in pine genomes, whole genome sequencing and assembly are crucial to fully understand the distribution of loci and alleles that will influence climate responses. This additional understanding will allow us to start modelling the relative importance of in situ selection in climate change response versus the potential for improved performance of pinyon in the future if assisted gene flow is added to the management toolbox.

Comparing climate change with the Black Death: Evolutionary events with long-term legacies

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Abstract: Climate change and disease result in mortality, shifting distributions, altered social practices and political outcomes that have long-term legacy effects. By comparing such disparate events we can better understand their relative effects and help scientists, land managers and politicians better appreciate and prioritize the biological/evolutionary impacts of climate change. We compare the evolutionary effects of bubonic plague, the Black Death, imposed on humans centuries ago, with those of climate change now imposed on pinyon trees inhabiting the American Southwest. Three findings emerged: First, using Crow’s “opportunity for selection,” we show that the maximum selection intensity on a foundation tree species by

climate change was 2.7 to 6.5 times greater than selection on humans caused by plague. Second, the magnitude of climate change selection represents one of the most potent selection pressures measured in nature and it occurred largely over a single year. Although evolutionary impacts of climate change are often considered to be long-term, these findings argue they can be as rapid as outbreaking diseases. Third, in both systems there are pronounced negative tradeoffs with long-term legacy effects. With humans, genes associated with enhanced immunity to plague are now associated with increased autoimmune diseases such as inflammatory bowel disease. With pinyons, increased drought tolerance is simultaneously associated with increased susceptibility to stem- and cone-boring moths that cause a 96-97% reduction in whole tree viable seed production. Such evolutionary tradeoffs may persist long after selection events have passed forever changing species and their associated communities. From an evolutionary perspective, our findings that the relative impacts of plague, the deadliest documented pandemic in human history, are far less than the impacts of climate change, argue the urgency of climate change mitigation. Importantly, land managers can use genetics to identify plant species and genotypes most likely to survive current and future climate conditions.

Morning-shifted water use coincides with amplified afternoon heat and dryness across western U.S. ecosystems

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Abstract: Vegetation responses to changing climate conditions play a crucial role in land-atmosphere feedbacks, but these interactions may unfold asymmetrically across the diurnal cycle – a dynamic with potential impacts on local and regional climate extremes. Under non-limiting soil moisture, ecosystems exhibit fairly symmetrical water use, following the solar cycle. However, with increasing soil and atmospheric drought, stomatal conductance and ecosystem water use often decline sharply in the afternoon, shifting water use earlier in the day. Although this behavior has been observed from leaf to ecosystem scales, regional patterns and resulting impacts on afternoon climate conditions remain poorly quantified due to a lack of spatially extensive, diurnally resolved measurements of evapotranspiration (ET), land surface temperature (LST), and corresponding meteorological variables.

Here, we leveraged five years of NASA ECOSTRESS observations (2018–2022) across the diurnal cycle at >1350 sites across the western U.S. to show that much of the region already exhibits morning-shifted ET, consistent with widespread water limitation. Further declines in climate water balance are associated with even earlier ET timing and both delayed and amplified afternoon LST, air temperature, and vapor pressure deficit (VPD). Projections under high-emission scenarios (1950–2099, RCP 8.5) suggest that ecosystem water use in the western US may shift 20 to 39 minutes earlier by the 2090s, disproportionately reducing

afternoon latent heat loss and moisture supply to the boundary layer. Correspondingly, afternoon increases in LST, air temperature, and VPD are projected to outpace morning increases by 0.6°C, 0.26°C and 0.07 kPa, respectively. These results suggest a form of temporal amplification, where the hottest, driest part of the day warms and dries faster, further reinforcing afternoon stomatal closure. As many plant communities approach critical temperature and hydraulic thresholds, accounting for these diurnal asymmetries and resulting amplified climate extremes is crucial for anticipating ecological vulnerability under future climate change.

Comparison of estimated plant water availability and vegetation health to inform forecast ensembles of a groundwater flow model

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Abstract: Managed in-channel water deliveries into the Colorado River in Mexico are, in part, intended to enhance habitat via vegetation restoration along the channel by either 1) increasing groundwater levels to within the root depth of vegetation or 2) creating the hydrological conditions necessary for new vegetation to develop, from seed collection to establishment. A comparison of plant water availability (estimated from water delivery volumes, groundwater-level and surface flow data) with estimated vegetation health (derived from satellite EVI2 data) over the same period is being used to identify spatial and temporal patterns and relationships within and between the hydrologic and vegetation data. These patterns and relationships will then be used to aid in parameterization and structuring of a groundwater-flow model (using MODFLOW and PESTPP-IES). This model may be used for creating forecast ensembles of various managed in-channel flow and irrigation regimes throughout the study area, which may prove useful for optimizing managed water deliveries and irrigation practices.

Integrating datasets for vegetation mapping and mortality controls

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Abstract: The use of multi-modal platforms for integrating remotely sensed datasets for forest health applications has shown dramatic improvements in recent years as regards spatial resolution and plant species identification. Here we examine the distinct and complementary

capabilities of (i) the National Ecological Observatory Network (NEON) Airborne Observation Platform (AOP) and its associated hyperspectral data and (ii) Landsat satellite data for comprehensive vegetation analysis at watershed scales exceeding 300 km². Of note, NEON AOP data excels at fine-scale plant species identification due to its unique combination of high spectral and spatial resolution, enabling the capture of subtle, species-specific biochemical signatures. In contrast, Landsat, with its unparalleled temporally extensive archive and consistent broad-scale coverage, is indispensable for monitoring landscape-level, long-term trends in vegetation health using established spectral indices and metrics, such as NDVI. Our results indicate geographically distinct regions of Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), lodgepole pine, and aspen (*Populus tremuloides*) mortality and vigor hypothesized to correspond to a variety of landscape characteristic including hillslope steepness, topographic wetness index, bedrock composition, aspect, and elevation among others. In the case of aspen, variations in ploidy type (diploid vs. triploid) that can similarly be mapped using remote proxies, exhibit strong gradients in both current and projected future increases in mortality largely governed by growth habit and landscape controls on water availability. The synergistic use of such multi-model platforms for characterizing tree species distributions at the watershed and basin scale and trajectories of landscape-controlled forest health provide rich datasets for ecologist, ecohydrologists, and forest managers throughout the Western US and beyond.

Cracking the nut: Forecasting and hindcasting multicentury records of piñon pine masting

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Abstract: Masting – the episodic and synchronous boom and bust of seed crops – is something of a botanical mystery. Traditional knowledge of seed gathering could be considered an ancient form of ecology, yet predicting when and where trees will bear fruit, flowers, and seeds remains a significant scientific challenge. While forecasting masting may seem obscure, a better understanding of this process could guide forest planning and management of wildlife habitat, tree regeneration, or traditional uses of seeds and nuts. In this talk, I expand upon a recently published forecast model of piñon pine cone production, exploring the spatiotemporal patterns of mast seeding across the range of this species. I downscale the native 4km spatial predictions to a 250-m hillslope resolution and incorporate species-specific measures of tree abundance to estimate mast availability across habitat types (woodlands, savannas, and shrublands). 21st century patterns of mast frequency and abundance are compared to the 20th century baseline to discern recent changes due to an ongoing megadrought. Last, I relate masting predictions to multicentury tree ring chronologies from across the southwest to explore the potential for reconstructing mast seed events, placing modern findings in a long-term context. The results indicate that forecasting masting is indeed possible, particularly at broader-regional scales. Yet predicting which tree produces how many seeds remains difficult to explain, likely due to individual-level variability in resources, competition, or vigor. Mast frequency and abundance has declined significantly with the onset of 21st century megadrought conditions, but these declines may not be unprecedented when viewed in a multicentury context. Adopting a forecasting framework into forest planning may improve management outcomes, but it also supports a predictive understanding of the natural world - providing key insights into the ecology and evolution of a botanical mystery.

Assessing the State and Trend of Pinyon-Juniper Woodlands in the Southwest

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Abstract: Interest in Pinyon-Juniper woodland dynamics has risen considerably over the past decade. Concerns with wildfire risk, habitat quality, water conservation and expansion into formerly treeless areas have prompted investigation into the current state and trend of Pinyon-Juniper woodland health. To address these needs, U.S. Forest Service Forest Inventory and Analysis data were used to characterize and quantify the resources of Pinyon-Juniper woodlands populated by common pinyon pine (*Pinus edulis*) across its range. We produced area estimates and spatial distribution of woodland age, community assemblage, reproductive potential, expansion/contraction history, and disturbance pattern and frequency in an effort to provide managers and policy makers with foundational information necessary for the management of the Pinyon-juniper woodland resource.

Assessing pollinator response to different grazing intensity from the Kaibab Plateau Bison Herd in Arizona

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Abstract: The diversity and abundance of pollinator communities on the North Rim of Grand Canyon are possibly influenced by the Kaibab Plateau Bison Herd (KPBH). This herd is composed of American bison (*bison bison bison*), a larger herbivore that serves as a keystone species, shaping the ecosystem by impacting the vegetation composition in this region. This effect on plant composition can have a direct impact on plant-dependent wildlife such as pollinators. Pollinators are essential ecosystem indicators of a healthy functioning ecosystem, and many flowering plants rely on pollinators for reproduction. This research aims to understand how both pollinators and the habitat are responding to bison grazing and behavior, as well as how policy can impact an ecosystem through wildlife management practices. A total of 24 sites were selected for assessment within the Kaibab National Forest (KNF) and Grand Canyon National Park (GCNP) jurisdictions. Twelve of these sites are bison exclosures (treatment sites), while the other twelve are non-exclosure (comparison sites). Field data was collected during the summer of 2024 and 2025 to assess pollinator resources, habitat conditions, and a flower visitation observation to analyze the presence of pollinators. Preliminary analysis indicates that exclosures have a lower density of flowering plants and forbs compared to the non-exclosure, which have a higher density of flowering plants and forbs. These results suggest that an area with a greater abundance of flowering plants attracts more pollinators. Additionally, the results show that the KNF has a higher forb cover compared to the GCNP, which has a higher flower diversity. Future research will examine how jurisdictional boundaries contribute to this ecological shift that may assist in developing new conservation action for both the KPBH and pollinators.

Recovery of *Pinus edulis* post-fire: biotic and abiotic drivers of tree seedlings establishment

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Abstract: Climate change and past land management are altering fire regimes across the western U.S., raising concerns about the resilience of dry, lower-elevation woodlands like piñon-juniper (PJ). Under novel post-fire climate conditions, piñon pine may fall outside its recruitment niche—the set of abiotic and biotic conditions required for germination, survival, and establishment—resulting in a lack of natural regeneration. Researchers have observed little natural tree recruitment several decades after wildfire, raising concerns about PJ woodlands transitioning to non-forested systems. To investigate biotic and abiotic drivers of piñon pine establishment, we examine natural tree recruitment in three 25+ year-old fires in western Colorado. Analysis shows that both piñon and juniper seedling establishment are negatively

associated with non-native plant cover and increasing distance to seed source. Additionally, piñon seedling presence is negatively associated with grass, shrub, and forb cover, and juniper seedling presence is negatively associated with grass cover. To better understand the limitations of PJ regeneration, we conducted a planting study investigating the role soil inoculation and different nurse objects have on seedling survival. We planted inoculated piñon seedlings (grown in a mixture of field soil from an unburned woodland and sterile potting mix) and non-inoculated seedlings (grown in sterile soil) into high-severity burned patches from a 3-year-old fire and a 27-year-old fire under varying nurse objects. After 1.5 years, overall survival is 38%, with no difference in survival between inoculated and non-inoculated seedlings ($p=0.458$) or between fire ages ($p=0.403$). However, seedlings have significantly higher survival when planted under Gambel oak, regardless of treatment or fire age ($p=0.0021$). Sequencing analysis of soil fungal communities reveals community-scale differences across fire ages and nurse object types. Understanding above- and belowground biotic interactions with seedlings can inform more effective land management strategies for post-fire restoration in PJ woodlands.

A New Monitoring Program for Adaptive Management of Prescribed fire and Natural Ignitions Managed for Objectives Other than Full Suppression (OTFS) in Northern Arizona

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Abstract: Prescribed fire and natural ignitions managed for objectives other than full suppression (OTFS) are increasingly being implemented on dry forest landscapes in the Western U.S. as tools for restoration and fuels reduction. In particular, the pace of this work has increased dramatically in northern Arizona forests over the last decade plus. Given the resources devoted to this work across the Four Forest Initiative (4FRI) landscape there is a pressing need to understand the effectiveness of these fire-based treatments on fuels reduction, ecological effectiveness for moving towards desired conditions, and overall wildfire risk reduction. In 2024, the U.S. Forest Service and The Nature Conservancy partnered to develop and implement a monitoring program across the 4FRI footprint aimed at quantifying the effects of prescribed fire and OTFS fires on fuels and forest structure. This monitoring program aims to find innovative and efficient techniques for monitoring fire effects but also incorporates long standing protocols fire effects monitoring protocols and methodologies. Pre- and post-fire ground-based fuels and vegetation information is being combined with *in situ* fire behavior data to better understand fire effects as well as how fuels profiles change over time as more frequent fire is applied to the landscape. In the first full year of implementing the monitoring program we have planned and begun to install and measure pre- and post-treatment plots covering approximately 15,000 ha (37,000 acres) of prescribed fire and OTFS fire. This spatially and temporally robust dataset will provide much needed information for adaptive management of implementing fire-based restoration and fuels reduction treatments and will allow fire managers to better plan the frequency and placement of fire across large dry forest landscapes based on fuels trajectories over time.

A Cool Mix: Causal Inference, Adaptive Management and Environmental Flows

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Abstract: Uncertainty in the expected responses of aquatic ecosystems can be a barrier to environmental flow implementation. Robust assessments of flows when flows are implemented can reduce this uncertainty and inform future flow implementation. True control river segments are usually not available, necessitating before-after designs that can lead to erroneous inference if replication is low, important environmental drivers cannot be controlled, or experimental flows are not prescribed randomly. Model-based approaches provide an alternative to design-based approaches to analysis. Specifically, models that consider both controlled and uncontrolled factors can be used to forecast responses under both the observed conditions and the expected conditions in the absence of flows (i.e., a counterfactual).

Here we assess the impacts of “cool mix” flows released from Lake Powell through Glen Canyon Dam into the Grand Canyon segment of the Colorado River during 2024 using casual modeling. Cool mix flows involved releasing a portion of the daily flow through river outlet works located 100 feet deeper in the reservoir than the hydropower generating tubes from which water is typically released. Cool mix was designed to minimize spawning and somatic growth of Smallmouth Bass (*Micropterus dolomieu*: SMB). SMB were first observed reproducing below Glen Canyon Dam in 2022 coincident with the lowest reservoir elevations and warmest release temperatures in five decades. Cool mix was also expected to lead to increases in phosphorous and dissolved oxygen in addition to cooling water temperatures and to increase the somatic growth of Rainbow Trout (*Oncorhynchus mykiss*) and decrease the growth of Humpback Chub (*Gila cypha*). Observed water quality, SMB population dynamics, and somatic growth for all species was consistent with forecasts; however, the precision of causal inferences differed among metrics substantially suggesting some impacts were more certain than others.

Arbuscular Mycorrhizal (AM) Fungi within Traditional vs. Non-Traditional Maize Fields

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Abstract: Our research compares the structure and function of arbuscular mycorrhizal (AM) fungal associations in maize using soils from traditional and non-traditional agriculture and adjacent native habitats. Arbuscular mycorrhizal fungi provide soil resources to plants, improving their growth and protecting them from disease, but their abundance and diversity can be reduced with traditional agriculture. We are comparing six different agroecosystems on the Colorado Plateau using a greenhouse experiment in which an indicator plant, sorghum, is grown in soil collected from the six sites. We are conducting a Microbial Growth Response (MGR) experiment to measure the symbiotic function of the AM fungi at each site using live-inoculated and sterile-inoculated treatments. We will also use DNA sequencing to analyze the species composition of AM fungi to see if certain taxa shift in abundance depending on agricultural practices. We hypothesize that AM fungi from low-input agricultural systems will be more beneficial to sorghum, as measured by plant biomass, compared to the soil from the high-input agricultural systems. We also expect to see differences in AM species composition between high and low-input maize fields. We are researching traditional (low-input) farmers maize fields to determine if they have more beneficial microbial communities compared to the high-input (non-traditional) maize fields. This would improve drought tolerance, plant nutrition, plant tolerance to heat, soil microbes, and overall crop performance.

Using dynamic programming with deep reinforcement learning to inform hatchery supplementation strategies for Rio Grande Silvery Minnow

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Abstract: Managing endangered species is challenging, as decisions can increase extinction risk or be overly expensive, depleting resources and reducing support for future management. To address this, detailed consideration of population and environmental dynamics, as well as uncertainty in field observations, is essential for identifying cost-effective management solutions. Stochastic dynamic programming is an approach for identifying cost-effective management when there are recurring management decisions. However, incorporating such complexity in endangered species management is often computationally infeasible. Recent advances in deep reinforcement learning (DRL) offer a promising alternative. Here, we

demonstrate the application of a DRL algorithm paired with an integrated population model to optimize hatchery supplementation strategies for the federally endangered Rio Grande silvery minnow (RGSM). The population dynamics of RGSM are characterized by a highly flow-dependent life history, coupled with extensive river fragmentation, necessitating the supplementation of hatchery-reared fish. While captive breeding programs are an important conservation tool to decrease extinction risk, they can also have unintended negative effects. Our approach identifies optimal annual decisions related to how many RGSM to produce in spring under uncertain flow conditions and how many to stock in fall, in order to maximize both genetic and demographic objectives. We compare the derived strategies to the current supplementation strategy to highlight the potential improvements enabled by DRL, and its applicability in a real-world conservation problem.

Drivers of extreme carbon sources and sinks across diverse ecosystems in the western USA

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Abstract: Increasing climate variability is impacting the carbon cycle in unprecedented ways, demanding an understanding of the conditions leading to extreme carbon flux states. Spatiotemporal variation in drivers of carbon fluxes is poorly characterized; therefore, we sought to determine the strength and influential timescales of key environmental drivers governing unusually high daily gross primary production (GPP) or ecosystem respiration (R_{eco}) fluxes across diverse ecosystems in the western USA. We obtained CO_2 flux data for 14 AmeriFlux eddy covariance flux tower sites (11-22 years/site) across the western USA to understand the drivers of extreme CO_2 sinks (extreme GPP) and sources (extreme R_{eco}). We computed environmental covariates across multiple timescales (day, week, month, year), including temperature, vapor pressure deficit (VPD), short-wave radiation, soil moisture, and precipitation, along with site-level characteristics (e.g., mean annual precipitation [MAP] and temperature [MAT]). To account for seasonality, we defined extreme sink and source states as those GPP and R_{eco} values exceeding a site-level 95th quantile spline regression. We then used random forest classification models to evaluate the importance of different covariates for classifying between extreme and “nominal” fluxes. Previous month precipitation quantity and variability were important predictors of extreme sinks and sources. These covariates improved classification accuracy by 13.7% and 14%, respectively, and their effect was shown to be most influential in water-limited sites. A 9% improvement was observed between increasing temperature and its influence on extreme sources. At the month-long timescale for temperature, a shift to negative effects in sites with high MAT suggest important interactions between temperature effects across different timescales at warmer sites. This study lends insight into how precipitation conditions and temperature interactions across timescales differentially influence extreme carbon flux states along gradients of water availability and temperature in the arid and semi-arid ecosystems of the western USA.

Biocrust mosses and cyanobacteria show distinct carbon uptake responses to variations in precipitation amount and frequency

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Abstract: Biological soil crusts (biocrusts), photosynthetic communities of mosses, lichens, and cyanobacteria, cover much of the Colorado Plateau and play foundational roles in stabilizing soil, cycling nutrients, and exchanging carbon with the atmosphere. These communities are particularly sensitive to changes in precipitation, a key driver of biocrust activity. While the "pulse-reserve" paradigm has been widely applied to dryland plants to understand responses to precipitation variability, its application to biocrusts remains limited. To address this gap, we conducted two complementary experiments evaluating carbon flux in moss- and cyanobacteria-dominated biocrusts under different watering regimes. In the first experiment, we applied a gradient of water amounts to test how carbon exchange responded to individual precipitation events. In the second, we simulated climate change scenarios by varying pulse size and frequency over a three-month period. Our results revealed distinct carbon uptake strategies: moss-dominated crusts showed higher carbon uptake under larger, less frequent watering events, indicating a strategy that favors infrequent but substantial moisture pulses. In contrast, cyanobacteria-dominated crusts maintained consistent carbon uptake regardless of pulse size or frequency, suggesting greater tolerance to variable conditions. These findings highlight the different strategies that biocrust may use to cope with variable precipitation and emphasize the importance of biocrust type when predicting responses to changing precipitation patterns. For land managers, this suggests that moss-dominated crusts may be more vulnerable to shifts toward smaller, more frequent rainfall events, while cyanobacteria-dominated crusts may be more resilient but offer different ecological functions.

Population genomics of *Quercus emoryi*: Disentangling fragmentation, genetic connectivity, hybridization and climate resilience

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Quercus emoryi (Emory oak) is a drought-tolerant, culturally significant tree native to the oak woodlands of the southwestern U.S. and Mexico. Once sustained by Indigenous land stewardship, its genetic and demographic stability may now be jeopardized by post-colonial disruptions, habitat fragmentation, and climate change. Therefore, understanding how

landscape change and post-colonial disruption have affected genetic connectivity in *Quercus emoryi* is essential for guiding its conservation and restoration. We hypothesize that changes in land use and climate in the past 150 years have reduced gene flow, genetic diversity, and the number of parental plants contributing to new seedlings. We are developing a population genomic framework using historical and modern cohorts of *Q. emoryi* sampled from across its southwestern U.S. range. Our full dataset will include genetic data from up to 60 populations, including trees over 150 years old and younger, more modern individuals. It has been difficult to sample many older trees at the randomly selected sample sites; thus, it is crucial to conduct preliminary analyses to determine optimal sampling strategies. We used preliminary genetic analyses of our species and publicly available genetic datasets from related oak species in the National Center for Biotechnology Information (NCBI) as a simulation framework to test bioinformatic pipelines, optimize SNP filtering, and evaluate our ability to detect population structure and gene flow across fragmented landscapes. Using PCA, F-statistics, and relatedness measures, we were able to test patterns of differentiation and admixture, using analyses with different sample sizes to optimize that our genetic assay density and sampling strategy are to resolve fine-scale connectivity. These preliminary results validate our analytical approach and provide confidence that our future genetic dataset will be capable of detecting genetic signals of fragmentation, inbreeding, and demographic shifts. By piloting our pipeline on simulated oak data, we are building the foundation for interpreting post-colonial changes in *Q. emoryi*'s genetic landscape and informing its ecological restoration.