National Park Service
U.S. Department of the Interior

Rocky Mountain National Park
Continental Divide Research Learning Center

2020 Rocky Mountain National Park Research Conference

Continual Change, Collaborative Stewardship

Photos: *Rydbergia* on tundra looking towards Forest Canyon, NPS/A Schonlau VIP (Cover); Bighorn rams on tundra, NPS/A Schonlau VIP (Welcome); Dr. David Cooper, courtesy of Dr. Cooper (Keynote); Aspen daisies on alpine tundra, NPS/H Ozolins (Conversation Café); Kawuneeche Valley in autumn, NPS/H Ozolins (Abstracts)

Welcome to Rocky Mountain National Park's 2020 Research Conference

Hosted by the Continental Divide Research Learning Center

This year's conference theme is: **Continual Change, Collaborative Stewardship**

The social and ecological landscape of Rocky Mountain National Park is complex and undergoing continual change. Issues such as increased visitation, climate change, alterations to natural disturbance regimes including fire and insect outbreaks, and competing priorities create unique challenges to protect natural and cultural resources while also providing opportunities for visitors to enjoy them. The expectation of continual change reinforces the need for perpetual collaboration to ensure stewardship of our national parks. Research scientists, citizen scientists, interested community members, park visitors, staff, and volunteers all play a vital role in the collaborative stewardship of Rocky Mountain National Park. Through collection of data and information on a variety of park resources we have created opportunities to confront some of the most critical challenges. During the 2020 Research Conference you will hear presentations on a multitude of topics and challenges including: park visitation patterns, wildlife population changes, cultural resources, vegetation dynamics and restoration, and many other management topics.

Thank you for participating in the 2020 Research Conference. We hope the information shared will provide you deeper appreciation and understanding so we can continue to effectively collaborate to protect our treasured National Parks.

Scott M. Esser—Director of the Continental Divide Research Learning Center,
Rocky Mountain National Park

The 2020 Rocky Mountain National Park Research Conference is made possible thanks to the support of the Rocky Mountain Conservancy.

We want to acknowledge efforts to undertake a Reduced Waste Initiative. Join us in making this effort a success by bringing a coffee mug and water bottle from home and using the recycling and compost bins throughout the building. By reducing waste, we uphold the National Park Service's mission to preserve unimpaired natural and cultural resources for the enjoyment, education, and inspiration of this and future generations.

2020 Rocky Mountain National Park Research Conference

Estes Valley Community Center, 660 Community Drive, Estes Park, CO 80517

Tuesday March 10, 2020		
8:00 – 8:30 AM	Morning Mixer and Coffee	
Welcome		
8:30 – 8:50 AM	Darla Sidles Koren Nydick	Conference Introduction and Awards Presentation
8:50 – 9:20 AM	David Cooper	**Keynote Address:** Connecting Science to Management through Collaboration at Rocky Mountain National Park
9:20 – 9:40 AM	Break	
Wildlife Challenges in a Changing World		
9:40 – 10:00 AM	Ashley Whipple	Assessing Habitat Quality using Stress Measurements in American Pika Populations
10:00 – 10:20 AM	Nathan Galloway	Changes in Chronic Wasting Disease Ecology in Elk at Rocky Mountain National Park
10:20 – 10:40 AM	Cameron Aldridge	Assessing the Population Viability and Reproductive Performance of White-tailed Ptarmigan in Colorado
10:40 – 11:00 AM	Amy Seglund	Southern White-tailed Ptarmigan Population Assessment and Conservation Considerations in Colorado
Landscape Dynamics: Evaluating Ecosystem Conditions		
11:10 – 11:30 AM	Tim Weinmann	Heterogeneity in Soils and Forest Stands may Explain a Complex Response to Nitrogen Addition in Old-growth Subalpine Forests
11:30 – 11:50 AM	Brett Butera	High School Students Engage in Citizen Science to Investigate how Tree Species are Responding to a Changing Mountain Climate
11:50 AM – 1:00 PM	Lunch	
1:00 – 1:20 PM	Mario Bretfeld	Long-term Understory Vegetation Dynamics of Mixed Aspen Forests in Rocky Mountain National Park
1:20 – 1:40 PM	Isabel Schroeter	Riparian Plant Physiology in the Context of Ecological Restoration in Rocky Mountain National Park
1:40 – 2:00 PM	Linda Zeigenfuss	Applying What We've Learned about Elk and Willow to Moose Herbivory in Wild Basin
2:00 – 2:20 PM	Break	
Recognizing the Past, Celebrating Cultures		
2:20 – 2:40 PM	Sean Larmore	Implementing a Multi-year Research Design: Old Data and New Survey to Test Precontact Hunter-Gatherer Settlement Models
2:40 – 3:00 PM	Janet Ore	Why Wild Basin Stayed Wild: A Landscape History of Rocky Mountain National Park's Least Developed Entrance
3:00 – 3:20 PM	Jason LaBelle	The Archaeology and Paleoecology of the Ice Patches of Rocky Mountain National Park
3:20 – 3:45 PM	**Panel:** Brooke Neely, Natasha Myhal, Kathy Brazelton, Kelly Dick, Hanley Frost Indigenous Connections at Rocky Mountain National Park	
3:45 – 4:00 PM	Break	
4:00 – 5:00 PM	**Poster Session** The poster session is an opportunity to read about a variety of research projects and activities in the park and engage in discussion directly with the presenter. Snacks will be provided.	

2020 Rocky Mountain National Park Research Conference

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Wednesday March 11, 2020		
8:00 – 8:30 AM	Morning Mixer and Coffee	
Monitoring Continual Change		
8:30 – 8:50 AM	Chris Ray	Trending Pikas: What One Population Might Say About its Neighbors
8:50 – 9:10 AM	Daniel McGrath	Deciphering the Mass Balance Regimes of Very Small Glaciers: A Case Study from Rocky Mountain National Park
9:10 – 9:30 AM	Chau Tran Marie Faust	National Ecological Observatory Network (NEON) Data Collection at Rocky Mountain National Park
9:30 – 9:50 AM	Jason Sibold	Is the Ongoing High-severity Spruce Beetle Outbreak a Result of Climate Change?
9:50 – 10:10 AM	Jill Baron	Nutrients and Warming Alter Mountain Lake Benthic Algal Structure and Function
10:10 – 10:30 AM	Break	
10:30 – 11:50 AM	**Conversation Café** The Conversation Café is a structured discussion time in which conference attendees rotate, at 30-minute intervals, among tables at which a specific topic is discussed. Please join us for coffee, treats, and thoughtful discussion of Rocky's hot topics.	
11:50 AM – 1:00 PM	Lunch	
Collaborating for Proactive Management		
1:00 – 1:20 PM	Brian Miller	Science for Stewarding Resources into an Uncertain Future: Integrating Climate Science, Scenario Planning, and National Park Service Planning
1:20 – 1:40 PM	Jim Cheatham	A Ten-Year Review of the Partnership to Reduce Nitrogen Deposition Impacts to Rocky Mountain National Park
1:40 – 2:00 PM	James Roberts	Changing Thermal Regimes of Lakes and Streams in Rocky Mountain National Park and Cutthroat Trout Conservation
2:00 – 2:20 PM	Ben Lawhon	Boulderers' Perceptions of Leave No Trace in Rocky Mountain National Park: Improving Resource Conditions and Visitor Experiences
2:20 – 2:40 AM	Noah Creany Shannon Wesstrom	The Effect of a Vehicle Diversion on Spatio-temporal Park Use: A Study in Rocky Mountain National Park
2:40 – 3:00 PM	Break	
3:00 – 3:20 AM	Anna Schoettle	Proactive Limber Pine Conservation Strategy for Rocky Mountain National Park
3:20 – 3:40 PM	Ian Sexton	Pile Burn Scar Restoration at Lily Lake: Tradeoffs between Non-native Abundance and Recruitment of Native Species
3:40 – 4:00 PM	Meghan Tait	Cross-boundary Stewardship for Wetland Integrity and Resilience in the Greater Rocky Mountain National Park Ecosystem
4:00 – 4:25 PM	**Panel:** Rocky Mountain National Park Management Team Challenges and Opportunities in Management Amid Change	
4:25 – 4:30 PM	Scott Esser	Conference wrap-up

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Posters	
Philipp Abel	Efficiency Analysis of National Park Management with Data Envelopment Analysis
Evelyn Bangs	Connecting Trends in Reactive Nitrogen at Rocky Mountain National Park to Observations of Reduced Nitrogen in the Front Range
Jill Baron	Marmots do not Drink Coffee: Human Urine Contributes Nitrogen to Loch Vale Watershed
Alex Brooks	The Role of Wide Valley Bottoms in Rocky Mountain National Park on Water Quality in Montane River Networks
Cynthia Brown	Effects of Nitrogen Availability on Cheatgrass *(Bromus tectorum L.)* and Seeded and Unseeded Native Plant Species
Robert Brunswig	Recent Advancements in Comparative Mountain Archaeology of Poland's Tatra and Colorado's Rocky Mountain National Parks: An International Sister-Park Collaboration
Caitlin Charlton	I Spy Something Green: Using Remote Sensing to Map and Monitor Changes in Mountain Lake Productivity
Dan Cribby	Plains to the Park: Integrating STEM Initiatives into National Parks
Keshia De Freece Lawrence	The Arctic Circle: Climate Change, International Law and Indigenous Heritage
James Doerner Robert Brunswig	Lawn Lake, a High Montane Hunting Camp in the Colorado Rocky Mountains: Insights into Early Holocene Late Paleoindian Hunter-Gatherer Adaptations and Paleo-landscapes
Geoff Elliot	Understanding Conservation Education's Impact on Youth: Rocky Mountain Conservancy's Corps Programs
Geoffrey Elliott	Kawuneeche Group Beaver Baseline
Scott Franklin	Clonal Plant Response to Disturbance in the Montane Spruce Forests of the Tatras (Slovakia)
Alison Haddad Marian Lea	Using NEON Data to Look at Ecological Trends around Rocky Mountain National Park
Audrey Harris	Gene Flow and Spatial Structure of Non-native Brook Trout in the Long Draw Area of the Upper Cache la Poudre River Basin
Spencer Holtz	Same Pika, Different Story: How New Genetic Analyses Offer a Different Perspective on Populations as they Respond to Climate Change
Lindsay Ringer	Altering Water and Nitrogen Availability after Roadside Disturbance to Favor Native Plant Species
Garrett Rue	Winter Limnology in Rocky Mountain National Park: Understanding Evolving Physical and Biogeochemical Controls on Aquatic Ecosystem Structure under Ice-cover
Sarah Schliemann Kooper Cline Kenneth Doyle	Soil Carbon Stability in Subalpine and Alpine Systems

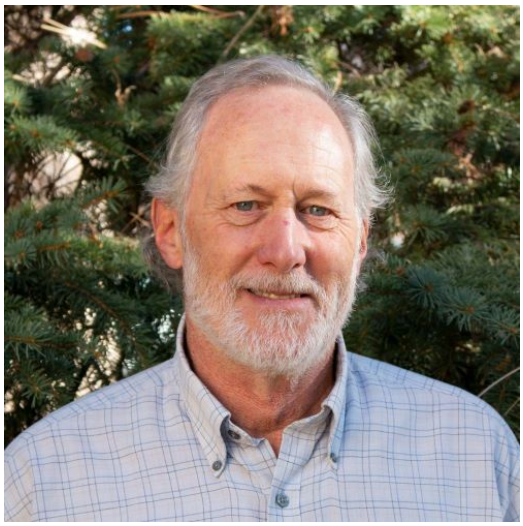
Brad Schrom Erica Garroutte Megan Mueller	Leveraging Citizen Science to Understand the Ecological Impacts of Climate Change and to Build Visitor Engagement in conservation in Rocky Mountain National Park
Laura Scott	Factors Related to the Presence and Abundance of Antibiotic Resistant Bacteria and Antibiotic Resistance Genes in Soil and Water
Barkley Sive	Decadal Trends and Variability in Intermountain West Surface Ozone near Oil and Gas Extraction Fields
Tim Weinmann	Applying Low-Cost PCB Sensor Technology for Monitoring Electrochemical Changes in Alpine Lakes in Rocky Mountain National Park from 2016 to 2019
Shawna Zimmerman	Environmental Gradients of Selection for an Alpine Obligate Bird, the White-tailed Ptarmigan *(Lagopus leucura)*

Keynote Address:

Connecting Science to Management through Collaboration at Rocky Mountain National Park

David J. Cooper

Department of Forest and Rangeland Stewardship, Colorado State University



Scientists play a vital role in expanding our understanding of nature, and the processes that shape and form landscapes and sustain biota in Rocky Mountain National Park (RMNP). My work in RMNP over the past 33 years has focused on wetland and riparian ecosystems and the hydrologic regime, biota and processes that support them. Many of the wetlands in RMNP are not pristine. They have been influenced by humans in many direct and indirect ways. Alterations in wetland hydrologic regime, biota, herbivory, and land-use are common. Climate change is a growing concern. Wetlands in certain areas were purposefully changed by past land uses. Some actions have pushed wetlands into alternative states that are now stable and may require significant management approaches to change. Collaboration with NPS staff is an effective way for scientists to collect data on natural and altered ecosystems and focus on important questions, problems and issues. It allows scientists to provide ideas that could be used by park staff to create novel and practicable solutions to complex natural history questions and problems.

Key Messages:

- Many significant changes have occurred in RMNP riparian ecosystems in the past several decades.
- Scientists working collaboratively with park staff are trying to understand the cause of these changes and develop management approaches for restoring park ecosystems.

Conversation Café

Join us for thoughtful discussions on some of Rocky Mountain National Park's hot topics:

Visitor Use

Climate Change

Natural Fire and Community

Culture, History, and Relevancy

Wetland Restoration

Predators and Prey

Submitted Abstracts (alphabetical order by presenter)

The observations and opinions expressed in these presentations are those of the respective presenters and may not necessarily reflect the views or policies of Rocky Mountain National Park or the National Park Service.

Efficiency Analysis of National Park Management with Data Envelopment Analysis

Philipp Abel (Technische Universität München) philipp.abel@tum.de

The key role of national parks in environmental protection cannot be overemphasized. However, the management of national parks entails the use of scarce resources, most of which are provided via public sources. Besides the need for accountability or justification for resources invested by park management, there is an even greater need to evaluate the efficiency of national parks in order to seek for more acceptance amongst stakeholders with often conflicting resource allocation goals. With the aid of a Data Envelopment Analysis (DEA) and management data (1996- 2015) from the Bavarian Forest National Park, this study strives to answer the question; how can the efficiency of (German) national parks be measured? The results culminate in five model variants that can be largely described via two crosscutting model *efficiency trends* and as such provide an evidence-based approach for measuring the efficiency of national parks, which can be extended to other parks. The derivation of the model variables provides opportunities for future refinement of the approach, which could aid environmental and policy decision-making processes.

Assessing the Population Viability and Reproductive Performance of White-tailed Ptarmigan in Colorado

Cameron L. Aldridge (Colorado State University) cameron.aldridge@colostate.edu

Gregory T. Wann and Shelley L. Spear (Colorado State University), Sara J. Oyler-McCance (U.S. Geological Survey), and Clait E. Braun (Grouse Inc.)

Alpine-endemic species have been receiving increasing attention from ecologists over the past two decades due to concerns they may be adversely affected by warming temperatures and changes to snowpack. Rocky Mountain National Park (ROMO) has extensive alpine habitats where many alpine-endemic species reside, including white-tailed ptarmigan, the smallest grouse species in the world. We used a long-term (1966-2016) mark-recapture dataset available for white-tailed ptarmigan at ROMO and nearby Mt. Evans, along with a more contemporary radio-telemetry dataset (2013-2015) of marked females, to examine viability of birds in the ROMO and Mt. Evans study areas, and influences of reproductive timing relative to resource abundance on fecundity. As previously reported, the ROMO population has been declining since the 1970s while the Mt. Evans population has remained stable. However, results from our viability analysis indicate the reason for the decline at ROMO is likely due to poor reproductive performance, and not due to reductions in breeding-age survival, which have remained unchanged in the park. The ROMO population persists due to external recruitment from surrounding areas and is currently a sink with demographic rates that are insufficient to sustain the population. We found that chicks which hatched during periods of low food availability (as measured by NDVI and insect abundance) suffered the highest mortality rates, but the magnitude of the effect varied by site and year. These results indicate that phenological mismatches in a resident alpine ptarmigan may have strongly negative influences on reproductive rates. We encourage land stewards responsible for mountain habitats to maintain and build long-term monitoring programs to inform our knowledge of how changes in mountain habitats influence wildlife populations and the habitat they depend on.

Keywords: *Mark-recapture, Phenological Mismatch, Population Viability, Reproduction, Survival, White-tailed Ptarmigan*

Connecting Trends in Reactive Nitrogen at RMNP to Observations of Reduced Nitrogen in the Front Range

Evelyn J. Bangs (Colorado State University) ejb.bangs@beyondbb.com

Katherine B. Benedict and Jeffrey L. Collett (Colorado State University)

For the past ten years, monitoring of atmospheric concentrations and deposition of reactive nitrogen in Rocky Mountain National Park (RMNP) has attempted to close the gap on current understandings of the nitrogen budget for sensitive alpine ecosystems. These ecosystems have a low capacity to take up nitrogen and excess nitrogen deposition adversely affects plant and aquatic communities in these areas. Observations of wet deposition in RMNP show a transition from oxidized to reduced reactive nitrogen over the last decade. While reductions in anthropogenic emissions of nitrogen oxides (NO_x) have been mandated, no regulatory requirements limit emissions of ammonia, a dominant form of reduced nitrogen (NH_x). Further still, there is nearly no information regarding forms of reduced nitrogen such as organic nitrogen, and more specifically, amines. The main sources of NH_3 and amines in the region are agricultural operations, including confined animal feeding operations (CAFOs). In this study, measurements were made spring through fall at a site in RMNP (2009-2019) and at a network of sites across eastern Colorado (2010-2019). Observations of NH_3 concentrations closest to a CAFO were, on average, 20 times greater than those in the Pawnee Grasslands and as much as 100 times greater than concentrations measured in RMNP. This recent record indicated decreases in oxidized nitrogen species and no trends in reduced nitrogen concentrations in RMNP. Continued measurements of reduced nitrogen, particularly NH_3 and organic nitrogen, are necessary for evaluating simulations by chemical transport models, evaluating voluntary attempts by the Colorado agriculture community to reduce levels of NH_3 emissions reaching RMNP, and to gaining broader insight into the levels of reactive nitrogen being deposited in RMNP.

Keywords: *ammonia, nitrogen deposition, organic nitrogen, reduced nitrogen*

Key Messages:

- Organic nitrogen is not well understood and is not quantified in routine measurements like other species such as ammonia and nitric acid.
- Amines are important and relevant organic compounds in this area for understanding the nitrogen budget in sensitive ecosystems.

Nutrients and Warming Alter Mountain Lake Benthic Algal Structure and Function

Jill Baron (U.S. Geological Survey) jill.baron@colostate.edu

Isabella Oleksy (Carey Institute for Ecosystem Studies) and Whitney Beck (EPA)

Sediment core reconstructions from Loch Vale Watershed, RMNP, reveal unprecedented increases in algal production and shifts toward the dominance of mesotrophic algal groups (green algae) in historically unproductive mountain lakes. This shift in trophic state is likely due to multiple stressors like regional pollution, changing nutrient loads, and climate warming. To experimentally test the mechanism by which green algae are increasing, we used nutrient diffusing substrates to regulate nutrient concentrations in a 3-week experiment in Sky Pond, RMNP. We measured algal biomass and algal community composition in response to various levels of key nutrients, N and P. The greatest response to both N and P additions occurred in the green algal community, fueling increases in total algal biomass. Interestingly, in the control (no nutrient) treatments, diatoms outcompeted green algae and cyanobacteria, dominating the algal community. We paired this experiment with a laboratory incubation in which we manipulated both temperature and nutrients in a 3x4 factorial design. We found that N uptake increased with warming temperatures and that the magnitude of gross primary production was related to temperature, nutrient enrichment, and the community composition of the algal community. Taken together, these results help understand why green algae are increasing in Loch Vale, and point toward potential implications for ecosystem scale C cycling as these sensitive and dynamic lakes continue to change in response to global change.

Keywords: *algae, Loch Vale, nitrogen, phosphorus, warming*

Key Messages:

- Mountain lakes worldwide are seeing an increase in filamentous chlorophytes (green algae) in shallow, nearshore habitats of clear lakes with high water quality and low nutrient concentrations, and lakes of Loch Vale are no exception. Mountain lakes are "greening."
- Loch Vale lakes have had high nitrogen concentrations for years from atmospheric deposition. Nitrogen is a fertilizer. We are also measuring more phosphorus (another nutrient) and there is a 30-year trend in The Loch of increasing summer temperatures. Warming and nutrients favor algal growth leading to algal blooms.
- In our experiments, nutrients favored green algae over diatoms, and caused the greatest increase in biomass. Warmer temperatures affected ecosystem processes, stimulating microbial activity more than algal production.

Marmots Do Not Drink Coffee: Human Urine Contributes Nitrogen to Loch Vale Watershed

Jill Baron (U.S. Geological Survey) jill.baron@colostate.edu

Timothy Weinmann (U.S. Geological Survey), Caitlin Charlton (Colorado State University), Amanda Jayo (U.S. Geological Survey)

Loch Vale (The Loch) is among the most popular destinations in RMNP, and at least 29,908 people visited it and beyond between June 21 and September 19, 2019. With overall park attendance up nearly 42% since 2012, research into possible impacts of increased recreational use in the backcountry is more critical than ever. To that end we are asking whether human urine contributes significant amounts of nitrogen to The Loch and Sky Pond. Our research has three components: a comparison of the potential maximum contribution of human urine to Loch Vale with measured wet atmospheric nitrogen deposition; measurements of caffeine as a marker of human urine deposits in soils and lakes in summer 2019, since caffeine is a definitive marker of human waste; and a map of caffeine concentrations in soils in Loch Vale, depicting popular spots to urinate. There are no toilet facilities beyond the Glacier Gorge Parking Lot. Caffeine and mapping studies are in progress, but we calculated the maximum possible N inputs from urine using trail counter numbers for the Loch Vale trail in summer 2019 by making a number of assumptions, starting with the assumption that every visitor to Loch Vale voids in the watershed. The average bladder capacity is 0.5 L, and the average urea concentration is 4.65 g/L. There are 0.028 g N/mol urea. The maximum possible nitrogen contribution from urine in summer 2019 was, therefore, 0.10 kg N/ha, which is 12% of the 0.82 kg N/ha for summer months in wet atmospheric deposition (average summer N deposition 2000-2018). Work remains to be done, but human urine may be an important “new” source of nitrogen to an already nitrogen-saturated system.

Keywords: *Loch Vale, nitrogen, urine, visitor use*

Key Messages:

- As the numbers of visitors to Loch Vale watershed increase, so does the amount of human waste left behind. Unsightly and unpleasant, human waste also adds unwanted nutrients like nitrogen to sensitive high elevation lakes and soils. Nitrogen, a fertilizer, is harmful to protected and fragile ecosystems.
- We are calculating and quantifying the amount of nitrogen contributed to Loch Vale by hikers using trail counters, human physiological literature, and measures of caffeine in soils and in The Loch and Sky Pond.

Long-term Understory Vegetation Dynamics of Mixed Aspen Forests in Rocky Mountain National Park, USA

Mario Bretfeld (University of Wyoming) m.bretfeld@gmail.com

Scott B. Franklin (University of Northern Colorado) and Robert K. Peet (University of North Carolina, Chapel Hill)

Forests worldwide are subjected to increasing pressures from altered disturbance regimes, climate change, and their interactions. We resampled 89 vegetation plots that contained aspen (*Populus tremuloides*) in the original sampling in 1972/73 in Rocky Mountain National Park to assess changes in understory diversity, non-native species abundance, community composition, and elevation ranges. Analyses were performed at three spatial scales: landscape (all plots), ecotone (montane vs. subalpine), and seven forest "series" according to the classification presented in the original publication. Understory vegetation diversity did not significantly change at the landscape scale but increased in forests of the mesic montane series. Changes in diversity varied with elevation, with predominantly increases at lower elevations and decreases at higher elevations. Further, species turnover and upward shifts were more pronounced at lower elevations. The proportion of plots containing non-native species was similar between data sets, with 48% in 2012/13 and 46% in 1972/73. However, the number of non-native species per plot increased considerably, especially in lodgepole pine (*Pinus contorta*) forests. Significant shifts in understory community composition occurred in mesic montane forests and limber pine (*Pinus flexilis*) forests. Generally, higher floristic overlap was evident between forest types indicating homogenization between 1972/73 and 2012/13 understory plant communities. Although results indicate overall little change in understory communities between 1972/73 and 2012/13 in Rocky Mountain National Park, they also suggest that observed changes differ by elevation, possibly due to the interactions between elevation and changes in local climate. Our study underscores the importance of analyzing long-term vegetation dynamics at different spatial scales and provides data from direct observations to improve the predictive power of vegetation models.

Keywords: *aspen, climate change, elevation, forest ecology, invasive species, mountain pine beetle, understory, vegetation community dynamics*

Key Messages:

- At the landscape scale, forests containing aspen in RMNP have exhibited no change in understory plant species diversity over the past 40 years.
- Observed diversity changes at local scales varied with elevation, with predominantly increases at lower elevations and decreases at higher elevations.
- The number of non-native species per plot increased considerably, especially in lodgepole pine forests.

The Role of Wide Valley Bottoms in Rocky Mountain National Park on Water Quality in Montane River Networks

Alex Brooks (Colorado State University) alex.brooks@colostate.edu

Tristan Weiss, Ellen Wohl, and Tim Covino (Colorado State University)

Across the United States, as much as 90% of natural riparian floodplains are functionally extinct as human alterations have altered natural flood regimes and eliminated dynamics that sustain their ecologic and hydrologic integrity. These losses are magnified in mountainous regions where extensive riparian zones are rare and only occur intermittently in wide, low gradient alluvial valley bottoms. In Rocky Mountain National Park, many of these valley bottoms were once complex mosaics characterized by wetlands, multi-thread channels, ponds, and diverse vegetation but are now simplified grasslands with single-thread incised channels. We sought to understand the role that complex and simplified floodplains have on mountain river networks. We present findings from several years of work that characterize seasonal patterns in the storage and release of water within valley bottoms and assess the timing and aquatic implications of hydrologic connectivity between the stream and floodplain habitats. Finally, we explored how the degree of connectivity between these streams and their floodplains affects the ability of river networks to regulate important water quality parameters. Better understanding these dynamics can help guide restoration strategies and management policy in mountain riparian ecosystems and help predict how proposed riparian wetland restoration will impact the broader river network.

Keywords: *riparian wetlands, river-floodplain connectivity, water quality*

Effects of Nitrogen Availability on Cheatgrass (*Bromus tectorum* L.) and Seeded and Unseeded Native Plant Species

Cynthia (Cini) Brown (Colorado State University) cynthia.s.brown@colostate.edu

Ian Sexton and Lindsay Ringer (Colorado State University), Christopher Davis (National Park Service)

The current rate of atmospheric nitrogen (N) deposition in Rocky Mountain National Park (RMNP) is nearly 20 times greater than pre-industrial rates and is projected to double in the next century. Exotic plant species abundance in RMNP is positively associated with increased N availability and decreased overstory cover. Past herbicide treatments to control cheatgrass (*Bromus tectorum* L.) in RMNP reduced its cover and increased cover of bare ground. Immobilization of available soil N by adding sucrose, a form of readily available carbon, to the soil reduced cheatgrass cover and stimulated perennial plant growth in old-fields and restoration sites in RMNP in previous studies. We tested the effects of increased and decreased plant available soil N (reduced [1,600 kg C/ha/y as sucrose], ambient [nothing added], two times ambient and ten times ambient [3.2 and 28.8 kg N/ha/y as ammonium nitrate) and seeding of native perennial grasses (bottlebrush squirreltail [*Elymus elymoides* (Raf.)Swezey] and Canada wildrye [*Elymus canadensis* L.] at 200 seeds/m^2 or unseeded) on establishment and growth of seeded and unseeded native plant species and reinvasion of cheatgrass into herbicide-treated forest, shrubland, and grassland sites. In 2017, cheatgrass cover was higher in grasslands than forests, but did not differ between other vegetation types. Although N applied at ten times the current rate of atmospheric deposition increased ammonium in forest soils and nitrate in forest and shrubland soils, it did not affect cover for any functional group in 2017. Sucrose addition decreased cheatgrass cover in 2014, but this effect disappeared by 2017, when we detected no effect of sucrose on vegetation or plant available N. Results may alleviate some concern about predicted increases in N deposition favoring cheatgrass invasion, but this project was a pilot study and future work should include greater replication to increase statistical power.

Keywords: *atmospheric nitrogen deposition, Bromus tectorum, cheatgrass, downy brome, invasion, restoration*

Recent Advancements in Comparative Mountain Archaeology of Poland's Tatra and Colorado's Rocky Mountain National Parks: An International Sister-Park Collaboration

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Pawel Valde-Nowak (Jagiellonian University, Poland)

Past seasonal and annual habitations of mountain environments by human ancestors date over 100,000 years in Europe and Asia and more than 13,000 years in the Americas. Sustained and expanding mountain archaeology projects have grown substantially in both Old World and New World regions over the past three decades. Two such regions are Colorado's Rocky Mountains and Poland's Western Carpathian Mountains where long-term (three decades+) archaeology projects have been conducted in Rocky Mountain National Park (University of Northern Colorado, USA) and in the Tara Mountain region's mid-elevation mountains and foothills (Jagiellonian University, Poland), downslope and north of Tatra National Park (Poland). In 2010 after a formal sister-park agreement (2007) between RMNP and Tatra National Park, efforts were begun to establish a collaborative archaeology research program involving the two parks, the University of Northern Colorado and Jagiellonian University (Krakow). Development of the archaeology program involved several years (2010-2016) of teaching, research, and project planning visits to Jagiellonian University's Institute of Archaeology by this paper's lead author and organizational meetings with Tatra Park research staff. Tatra Park's first ever archaeology research permit was granted to the project co-directors in 2017, followed by a short exploratory summer field survey. New more extensive Tatra Park surveys are planned for summer 2020. This paper describes background, methods, and early results of the Tatra project, which builds on the investigators' mutual and complementary experience in the two sister-parks of in Poland's Tatra (Western Carpathian) mountains and Colorado's Southern Rockies.

Keywords: *late ice age/early Holocene hunter-gatherers, mountain archaeology, Rocky Mountain National Park, sister-parks, Tatra National Park*

Key Messages:

- National parks throughout the world have common elements of environmental contexts and paleoclimate histories, which have similarly affected prehistoric and historic human populations over many millennia.
- Comparative study of those shared aspects not only enriches an understanding of human heritage in general but reveals the deep foundations of cultural adaptations in mountain-based national parks on the international stage.

High School Students Engage in Citizen Science to Investigate How Trees Species are Responding to a Changing Mountain Climate

Brett Butera (Denver Public Schools) brettbutera@gmail.com; brett_butera@dpsk12.org

This presentation will describe how Denver AP environmental science students, their teachers, and RMNP ecologists are collaborating in an ongoing project that uses citizen science as a tool for place-based field learning. In this project, student citizen scientists collect data in Rocky Mountain National Park (RMNP) and analyze the data to monitor changes in ecological structure of subalpine forest communities over time. The data will help RMNP scientists better understand how trees species are adapting to a changing mountain climate. This presentation will briefly explain a scaffolded sequence of lessons that collectively form an authentic scientific inquiry. Through these lessons, and a field trip to RMNP, students learn about the ecosystems that compose Rocky Mountain forest communities and how to collect and analyze data to track change over time in these ecosystems. The presentation will focus largely on how this project documents change in RMNP subalpine forests, but more specifically on what students learn about these changes. It is critical to observe and document change in the ecological structure of the forest, but it is imperative to use these data to inform students and foster environmental stewardship and conservation-mindedness. This presentation will emphasize student observations of forest change and their insights pertaining to the ecological and environmental drivers of these changes; as well as other relevant student take-aways.

Keywords: *documenting change, citizen science, ecological structure, forest monitoring, high school students, scientific inquiry, student observations & insights, subalpine forest*

Key Messages:

- This project teaches students the process of science through authentic inquiry-based field data collection and analysis.
- This project provides students access to experiences they may otherwise have never had.
- This project inspires students to be stewards of our environment.

I Spy Something Green: Using Remote Sensing to Map and Monitor Changes in Mountain Lake Productivity

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Jill Baron, Timothy Weinmann, and Amanda Jayo (U.S. Geological Survey); Anastasia Kunz, Sarah Wingard, Genevieve Clow, and Natalie Schmer (Colorado State University)

Mountain lake greening has been observed across Rocky Mountain National Park, but quantitative data on greening over time is lacking due the difficulty of reaching many mountain lakes routinely for adequate sampling. Remote sensing provides promise to monitor changes in mountain lake productivity with satellite imagery at the landscape level and build a widespread database of change over time. Recent remote sensing work in the Loch Vale Watershed in The Loch and Sky Pond paired LANDSAT 8 OLI and Sentinel-2 MSI images and field chlorophyll-a data from May to September from 2015 to 2018 to create indices for evaluating pelagic productivity. The two highest indices using this data are 6.922 - 5.758 * (ln(Blue) / ln(Red)) from Landsat 8 (ρ = -0.585) and Red Edge 1/Red from Sentinel-2 imagery (ρ = -0.548). More extensive chlorophyll-a data were collected from The Loch and Sky Pond during Summer 2019 to correspond with Sentinel-2 fly overs, to create more robust indices for chlorophyll-a. While these current indices are focused on pelagic productivity, research and observations indicate that many mountain lakes are experiencing an increase in benthic algal productivity, particularly shallow lakes like The Loch. Research efforts beginning Summer 2020 are aimed at teasing apart benthic and pelagic productivity. Seasonal benthic algal cover will be mapped out in The Loch and used to get quantitative estimates for seasonal productivity. These data will be incorporated into the satellite derived indices to create the most robust model possible to be used across lakes in Rocky Mountain National Park. Although work is needed for a satellite imagery-based model to be applicable to such mountain lake systems, current and proposed research efforts show promising results to develop one of the first remote sensing tools for monitoring and assessing mountain lake productivity.

Keywords: *algae, chlorophyll-a, Landsat 8 OLI, Loch Vale, remote sensing, Sentinel-2 MSI*

Key Messages:

- Mountain lake greening is becoming an increasingly common phenomenon.
- We are working on one of the first remote sensing tools for monitoring productivity in small mountain lakes.

A Ten-Year Review of the Partnership to Reduce Nitrogen Deposition Impacts to Rocky Mountain National Park

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NPS Project Team (in place of co-authors): Darla Sidles, Koren Nydick, Jim Bromberg (Rocky Mountain National Park); Debbie Miller (Intermountain Region); Carol McCoy, Kirsten King, John Vimont, Jim Cheatham, Kristi Morris, Bret Schichtel, Kristi Gebhart (NPS Air Resources Division)

Based on research at Rocky Mountain National Park (RMNP) showing that nitrogen deposition was causing ecological impacts, a resource management goal was established. For 15 years, the NPS, State of Colorado, and EPA have collaborated with Colorado agricultural to reduce excess atmospheric nitrogen deposition causing ecological impacts in RMNP. Leadership and scientific contributions by the agencies, including researchers, RMNP, and Air Resources Division staff, have made significant progress toward understanding nitrogen deposition in RMNP and laying the groundwork for needed emission reductions from the agricultural sector. Studies show that ammonia emissions from Colorado agricultural production and nitrogen oxide emissions from fossil fuel use are significant contributors to the excess nitrogen deposition in the park. With most sources of nitrogen oxide emissions regulated, this initiative has connected agencies with agriculture in an unconventional partnership to secure voluntary reductions and improved management of ammonia emissions from the agricultural sector in northeastern Colorado. Building the partnership required overcoming scientific and data challenges to agree on a path forward that balances the cost and benefit to both industry and agencies. Obstacles have been overcome through relationships and mutual understanding achieved by regular communication, perseverance, and staying current with research and science communication. While greater park protection from this partnership is not certain, future success is more likely with continued collaboration and ongoing research.

The Effect of a Vehicle Diversion on Spatio-temporal Park Use: A Study in Rocky Mountain National Park, Colorado, USA

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In 2017, Rocky Mountain National Park (RMNP) received more than 1 million vehicles entering from the two entrances nearest to Estes Park, CO: Beaver Meadows and Fall River. These traffic totals represented a 141% increase in vehicles within RMNP since 2013. Further, this increase in volume presents a challenge for managers and park infrastructure to accommodate increased traffic while providing quality visitor experiences and protecting the Park's natural resources. In response to these record levels of visitation, traffic along the Bear Lake Road corridor was temporarily diverted to other areas of the park during peak use times in the summer months. Using spatial data collected from visitor vehicle trips from a quasi-experimental study design conducted in the summer of 2017, we provide insights into visitor traffic patterns during diversion and non-diversion scenarios using two analysis methods. First, the Distributed Flow Lines tool in ArcGIS provides a visual summary of travel patterns during the diverted and non-diverted states. Second, using the GPS spatial-data an Activity-Based Traffic model was developed to understand the vehicle travel patterns and destination characteristics within and outside of the Bear Lake Corridor. Results suggest that for visitors to RMNP with intentions of using the Bear Lake Road corridor, no replacement is within the Park for the activities and experiences found along that corridor. With this information managers can understand patterns and preferences of visitor movement within the Park to inform traffic planning and the potential ecological impacts from displacement and changes in visitor use levels.

Keywords: *activity-based modeling, distributed flow lines, smart lines, traffic simulation*

Key Messages:

- Visitors to RMNP, for whom the Bear Lake Corridor is the primary destination, find substituting this experience in other areas of the park to be difficult.
- Voluntary GPS tracking is an effective way to understand visitor patterns of use and traffic flows within the Park.
- The vehicle diversion within the Bear Lake Corridor increases traffic to other areas of the Park.

Plains to the Park: Integrating STEM Initiatives into National Parks

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Plains to the Park is a STEM (Science, Technology, Engineering, Mathematics) project hosted by Westview Middle School in partnership with the Continental Divide Research and Learning Center (CDRLC) of Rocky Mountain National Park (RMNP), and the City of Longmont – Button Rock Preserve. Since the summer of 2014, students, teachers, and park staff have participated in a two-week STEM Academy at Westview Middle School and within RMNP or the City of Longmont's Button Rock Preserve. Students and teachers worked with CDRLC staff and volunteers to learn scientific methods and collect data in Horseshoe Park and Button Rock Preserve to answer the questions "Who lives in this place?" and "How is that changing over time?" For two weeks each June, 20 middle school citizen scientists learn and practice standardized protocols as they collect data about wildlife populations. Students learned scientific field skills and gained experience using trail cameras, GPS units, and field guides. During the school year, monthly field days occur to check and maintain equipment. Plains to the Park aims to help youth build understanding of ecological and environmental issues at formative age. How do we value and care for public lands? How do we meet the needs of a growing human population? How is that growing population impacting public lands? How do we address the challenges of a changing world? These students see interactions between science and stewardship of public lands firsthand. Our goal is that this program provides a model of engagement for citizen scientists of all ages, fostering a next generation of informed park stewards and scientists who will continue to protect public lands into the future. Through the 5-plus years of Plains to the Park, we have fortunate to have the opportunity to collaborate with many groups, including RMNP, City of Longmont, Estes Park Environmental Center, University of Colorado, Longmont Times Call, U.S. Forest Service, St Vrain Schools, Globe Program, and more. Plains to the Park students have collected data related to important ecological issues. All data are being made available to the public, thanks to our partnership with the Estes Park Environmental Center. This program brings youth to the park, which provides unique insights on how they connect to the park and use technology to engage and share that message with others.

Keywords: *camera traps, mountain lions, STEM, youth engagement*

The Arctic Circle: Climate Change, International Law and Indigenous Heritage

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Global climate change is the most pressing environmental issue in modern history. Similar to other environmental world wonders, the Arctic Circle is under an immediate threat—the threat of extinction. The threat of extinction includes the multifaceted biomes and ecosystems living within the North Pole, and the indigenous communities in the Arctic region. As the new record for global warming is being observed regularly, the Arctic ice sheet melting will continue in upcoming years. The Arctic environment, Arctic societies, and Arctic politics will all endure the stress of these climatic and human-made effects. This study identifies the Arctic Council and Indigenous Arctic communities as the most influential actors in Arctic governance. This study will analyze and critique the contribution of this intergovernmental panel to the region's overall environmental security. Qualitative content analysis of the twelve declarations of the Arctic Council not only reveal the council's perceived achievements in the field of climate change, but also pushes the international discussion towards constructing methods of remedy for environmental conflicts at all levels. Further, an approach employed by this international environmental law study is citizen science and climate change-related field research. The quantitative content being analyzed within this thesis is the findings from a one-month long multidisciplinary research effort with the international non-profit organization Earthwatch, and the independent non-profit research station, the Churchill Northern Studies Centre. The scope of this thesis is that these findings will be used in international legal discourse for the construction of a culturally appropriate international environmental doctrine for the North.

Keywords: *Arctic, Arctic Circle, Arctic Council, citizen science, climate change, environmental law, environmental security, governance, Indigenous, international law, sustainability*

Key Messages:

- Stewardship and citizen science initiatives are the gateway to a health relationship between policymakers, scientists and citizens.
- Permafrost and glacier studies are much closer to human lives globally, then perceived especially in the face of climate change.
- Indigenous heritage and knowledge play a crucial role in positive, progressive environmental governance and stewardship techniques.

Lawn Lake, a High Montane Hunting Camp in the Colorado Rocky Mountains: Insights into Early Holocene Late Paleoindian Hunter-Gatherer Adaptations and Paleo-landscapes

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The Lawn Lake archaeological site is a stratified hunting camp on a glacial lake outlet river terrace in Rocky Mountain National Park's upper subalpine forest zone. Its cultural deposits and associated surface artifacts represent 9,000 years of use by Native American hunter-gatherers as a game animal and local plant processing base camp for subalpine forest and nearby alpine tundra summer grazing areas. The site's deepest occupation levels contain artifacts and hearth features whose radiocarbon chronology, dating 8,900-7,900 cal BP, places it among the region's earliest human (Paleoindian) high montane (3,353 m. a.s.l.) hunting camps used to support systematic exploitation of summer migratory subalpine forest and tundra game animals and plant foods in the Southern Rocky Mountains. Local and park paleoenvironmental studies provide background evidence of Lawn Lake's long-term prehistoric environments, contributing to an understanding of Late Paleoindian high-altitude hunter-gatherer adaptations and their associated paleo-landscapes. The site's archaeological evidence viewed through decades of mountain research in the park and its region, scientifically portrays an early hunting-gathering camp operating within a well-documented annual migratory transhumance system between interior mountain valleys to high altitude mountain landscapes in summer and persisting from Early Holocene through historic times.

Keywords: *Early Holocene, Late Paleoindian, paleoenvironmental, Rocky Mountain National Park, seasonal mountain transhumance*

Understanding Conservation Education's Impact on Youth: Rocky Mountain Conservancy's Corps Programs

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This project evaluates the programmatic impact of Rocky Mountain Conservancy Corps programs on conservation behaviors in youth. The project developed and utilized evaluative tools for an existing program, the Rocky Mountain Conservancy – Conservation Corps, and a new program, the Conservancy – High School Leadership Corps. The Rocky Mountain Conservancy – Conservation Corps was established in 2003 and provides college-aged youth with an eleven-week internship completing conservation projects on public lands in Colorado during the summer months. Youth are also engaged in educational activities related to the cultural and natural resources in Northern Colorado and trainings related to outdoor, leadership, and communication skills. In 2017, the program supported thirty-six college-aged youth across six separate crews. The program has been loosely evaluated over the years, but evaluations have served primarily as a reflective tool for participants. The Rocky Mountain Conservancy – High School Leadership Corps was created in 2017 to help the Conservancy better serve high school youth in Colorado. It was developed through research into conservation psychology to better understand how to impart a conservation ethic on youth. During the first two seasons, the program has provided thirty high school students with a twelve-day immersive service-learning experience in Rocky Mountain National Park. Program impacts were evaluated using the same tools as the Conservation Corps to understand impacts of similar programs on differing age groups and over different time scales. Additionally, the Conservancy conducts post-program evaluations for both Corps programs to better understand the long-term impact on participants. These surveys use the same questions and tools to allow for a longitudinal understanding.

Keywords: *conservation behaviors, conservation corps, conservation psychology, public land, stewardship, youth development*

Key Messages:

- How service learning motivates change in conservation-psychology.
- The role of community in fostering conservation-based behaviors.

Kawuneeche Group Beaver Baseline

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The Kawuneeche Group is a team of local professional and citizen scientists working with Colorado State University (www.citsci.org) on a "beaver baseline" for the North Fork Colorado River (NFCR) and tributaries in the Kawuneeche Valley (KV). Working under Rocky Mountain National Park (RMNP) Research Permit (www.kawuneechegroup.com), we aim to validate findings from the Beaver Restoration Assessment Tool (BRAT, see Upper Colorado River Watershed Group www.ucrwg.org), with monitoring results presented on open-source platforms. Preliminary findings include:

- Strong community connection to the KV and great interest in RMNP resource stewardship.
- Volunteers eager to participate in scientific research with a cause using simple tools like photo-monitoring, a graduated PVC "willow rod," and kick-net sampling of aquatic macroinvertebrates.
- The KV watershed baseline can be definitively extended back in time by repeating photographs available through local Grand Lake Area Historical Society (rePhoto Kawuneeche on www.citsci.org), substantiated by community members including retired rangers, active and retired volunteers, and other outdoor enthusiasts.
- Willow remains plentiful on the KV floor, but mostly overgrazed and lacking longer green canes needed for beaver structural bioengineering (Kawuneeche Willow Blitz 1 on www.citsci.org).
- Cellphone-grade GPS is suitable for most observations and can be enhanced with sub-meter GPS or pinning sites on Google Earth©.
- Aquatic macroinvertebrates indicate moderate stream health (www.kawuneechegroup.com). This activity is a volunteer magnet for youth of all ages.

The KV offers an ideal baseline to better understand past watershed conditions, including well-documented abundance of beaver ponds now essentially absent, present conditions as a significantly modified watershed, and opportunities for future beaver restoration = promoting natural beaver recruitment and beaver bioengineering (see for instance Enos Mills 1913). KV watershed restoration would improve Hydrogeomorphic functions in turn would improve water quality in the lower NFCR and impaired waters further downstream while mitigating climate change.

Keywords: *aquatic macroinvertebrates, beaver bioengineering, climate change, hydrogeomorphic functions, Kawuneeche Valley, North Fork Colorado River, repeat photography, watershed restoration*

Clonal Plant Response to Disturbance in the Montane Spruce Forests of the Tatras (Slovakia)

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We examined clonal plant response to disturbance in the Tatras Mountains, Slovakia, at both the community and population levels. We hypothesized that communities in canopy gaps had greater dominance of clonal species than those in large wind throws and greater diversity, due to the greater heterogeneity of the canopy gap communities (environmental heterogeneity should favor clonal plants). We collected 10 plots (10X10 m) of data from four disturbance site types (DR = wind throw and not salvaged; DS = wind throw salvaged; NF = Forest without gap; NG = forest with canopy gap) in both Slovakia and Poland (total of 80 plots). The data included species cover, spatial diversity (heterogeneity) indexes and clonal connectedness data (through dye experiments on three species). Based on the variance to mean ratio as a measure of heterogeneity, wind throw sites that were not salvaged exhibited the greatest environmental heterogeneity while all other sites were more uniform. Further, diversity was driven by litter and woody debris as grass and herbaceous vegetation heterogeneity were similar among sites; however, both herbaceous and grass diversity were noticeably lowest in forests without gaps and this habitat had the lowest heterogeneity. Forests sites had the greatest richness while forest gaps and regenerating wind throw sites had the greatest diversity. Nearly all species had some aspect of clonality (86%), but only those species with roots with adventitious buds had significantly more cover in wind throw sites; rhizome species also tended toward more cover in gap and salvaged sites. All dye parameters differed between treatments for *Rubus* and were generally higher is wind throw plots. For *Calamagrostis*, only mean length differed between treatments and was highest in wind throw sites, suggesting consistency in both species. The data confirm disturbance favors in some types of clonal plants.

Keywords: *clonal, disturbance, forest, High Tatras Mountains, sister park, Slovakia, wind throw*

Changes in Chronic Wasting Disease Ecology in Elk at Rocky Mountain National Park

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We conducted two key studies at Rocky Mountain National Park, Colorado, to investigate the population-level effects of chronic wasting disease (CWD) in elk with historically high densities (up to 110 elk/km^2 on portions of the winter range). CWD was first detected in this population in 1981 and by the early 2000's half of the adult elk found dead tested positive for CWD. We estimated disease prevalence of ~13% (8-19%; n=136) in adult females in 2008. Additionally, we estimated that the population growth rate in female elk was flat (λ~1.0) and that CWD can reduce adult female survival and decrease population growth rate of elk (Monello et al. 2014). In a subsequent study, we investigated disease dynamics in the elk population and monitored changes in disease transmission pressure associated with locally specific reduced elk density and increased elk dispersion. We have a preliminary estimate of prevalence for 2012-2016 of ~8.5% (4.6-13.3%; n=138). Results corroborate that CWD reduces adult female elk survival and this increased mortality decreases the population growth rate. Concurrent with our study, elk are re-distributing to lower elevations outside of the park, where CWD prevalence has always been lower, resulting in much lower densities within the park. The effects on CWD prevalence are unclear; movement may simply spatially dilute disease across the landscape or lower densities may reduce disease transmission.

Keywords: *cervus elaphus nelsoni, chronic wasting disease, elk, mortality, prion, survival*

Key Messages:

- Chronic wasting disease decreases elk survival.
- Chronic wasting disease can reach levels high enough to harm elk population growth.
- Chronic wasting disease is dynamic but slow, with major changes over extended time scales.

Using NEON Data to Look at Ecological Trends around Rocky Mountain National Park

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In a rapidly changing world, understanding our ecosystems and how they respond to those changes is increasingly important. The National Ecological Observatory Network (NEON) project was designed around that goal, and is collecting a wide range of ecological data products over 30 years across the United States, including just outside of Rocky Mountain National Park. This poster looks at initial trends from NEON data collected since 2017 near Rocky Mountain National Park. Specifically, I look at how plant species diversity and woody species regeneration vary by aspect and location, how litterfall and fine woody debris changes by season, and the abundance and presence of mosquitoes. While this poster looks only at initial trends, the 30 year NEON project presents a unique opportunity to look at large-scale, long term ecological trends; some inter-annual variation present in these initial trends poses interesting questions that may eventually be answered by analyzing long-term data sets.

Keywords: *NEON, public data, plant diversity, mosquito abundance*

Key Messages:

- A wide potential exists for NEON data use.

Gene Flow and Spatial Structure of Non-native Brook Trout in the Long Draw Area of the Upper Cache La Poudre River Basin

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The greenback cutthroat trout (*Oncorhynchus clarkii stomias*; GBCT) is federally listed as threatened and designated as the state fish of Colorado. We aim to use non-native brook trout (*Salvelinus fontinalis*) as a surrogate of GBCT to quantify gene flow across the landscape and identify potential barriers to movement in the Long Draw area. Currently, US Forest Service, Rocky Mountain National Park, US Fish and Wildlife Service, and Colorado Parks and Wildlife are working collaboratively to restore greenback cutthroat trout to a 60-km section of continuous stream network in the Long Draw region. A successful implementation of the Long Draw project will result in a fivefold increase of GBCT occupied habitat within its native range. The GBCT reclamation project involves major steps, including removing non-native brook trout that currently dominate the area and physically isolating the area from (re-) invasion by non-native trout. During summer and fall of 2018 and 2019, tissue samples were collected from 23 stream segments in the upper Poudre River basin located in Rocky Mountain National Park and Arapaho-Roosevelt National Forests. A subsample of 796 individuals are currently undergoing genetic analysis. We will genotype brook trout using 12 microsatellite loci, examine spatial population structure, and identify genetically similar clusters of sites. Our research on brook trout gene flow and movement will provide key scientific support for the reclamation of greenback cutthroat trout in the Long Draw area by informing strategic steps for removing brook trout and identifying potentially important habitat locations (e.g., source-sink dynamics) for GBCT, and will have broader implications for future conservation of native cutthroat trout and water management in the face of climate change.

Keywords: *collaborative management, conservation genetics, fish movement, greenback cutthroat trout, non-native trout*

Key Messages:

- The Greenback Cutthroat Trout Restoration Project is a highly collaborative effort to restore GBCT to the Long Draw area. This project is critical to the recovery of the subspecies.
- We aim to use non-native brook trout to investigate gene flow across the landscape and identify potential barriers to movement in the Long Draw area.
- Our research on brook trout gene flow and movement will provide key scientific support for the reclamation of greenback cutthroat trout in the Long Draw area.

Same Pika, Different Story: How New Genetic Analyses Offer a Different Perspective on Populations as They Respond to Climate Change

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How species will respond to the shifting climate is poorly understood and will become increasingly important as the climate changes further, particularly in alpine areas that will experience some of the most dramatic changes in temperature and precipitation. To track responses to climate, the National Park System has identified "sentinel" species such as the American pika *(Ochotona princeps)*. Pikas typically occur in alpine habitats and are "cold adapted" to survive long winters without hibernating. These adaptations make it easy for pikas to overheat in the summer, which is when juveniles must disperse to find their own territories. Warmer summers might reduce the chances of successful dispersal, reducing gene flow and local genetic diversity. Previous studies of genetic diversity in pikas have focused on measures like microsatellites that give inflated estimates. Our study used a novel genetic analysis based on SNPs (Single Nucleotide Polymorphisms) from RADseq (Restriction site Associated DNA sequencing) to analyze the genetic composition of pikas in three habitat patches just south of Rocky Mountain National Park. Although these patches were 1-3 km apart, we found little genetic differentiation among the pikas living there, suggesting high levels of dispersal under current climatic conditions. However, one component of genetic diversity—heterozygosity—was much lower than reported in a recent study of pikas in the park. Heterozygosity based on SNPs and RADseq was only half the value reported in a 2018 study based on microsatellites. These results should be considered when defining populations for conservation, estimating the functional diversity of a population, and evaluating the effects of climate change on species in the park.

Keywords: *heterozygosity, Ochotona princeps, population structure, restriction site associated DNA sequencing, single nucleotide polymorphisms*

Key Messages:

- Common measures of genetics may give inflated estimates of diversity compared to functional diversity.
- Pika in the Rockies are still able to disperse well under current climatic conditions.

The Archaeology and Paleoecology of the Ice Patches of Rocky Mountain National Park

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Over the past four field seasons, the Center for Mountain and Plains Archaeology examined 30 ice patches in Rocky Mountain National Park of the Colorado Front Range, USA. Culturally associated ice patches have proven rare (*n*=1, possibly 2), although nearly half of the locales yielded biological materials including trees buried in ice as well as fragmentary faunal remains of bighorn sheep, elk, deer, and/or bison. The dearth of ice patch archaeological sites is surprising given that this portion of the Colorado Front Range is one of the most intensively surveyed alpine areas in North America, with abundant evidence for prehistoric Native American use dating back to the late Pleistocene. This presentation summarizes the results of a four-year ice patch survey program in ROMO, presenting new radiocarbon dates obtained from biological materials, and proposing several scenarios that might help explain the lack of cultural association with ROMO ice patches.

Keywords: *archaeology, climate change, ecology, glacier, ice patch, Native American*

Key Messages:

- Ice patches are melting in RMNP, and that many of them contain ancient ecological information.
- Bison has been found in several RMNP ice patches, documenting use of the alpine ecosystem by bison in the last 3000 years.
- Cultural use of ice patches appears rare, but humans intensively used other aspects of the alpine ecosystem of RMNP for at least 10,000 years.

Implementing a Multi-Year Research Design: Old Data and New Survey to Test Hunter-Gatherer Settlement Models

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This presentation introduces a multi-year collaborative effort to modernize existing Park cultural resource data for effective long-term management and research efforts. The Park recognizes a need to develop a comprehensive database of existing cultural resources that have been documented since the pioneering efforts of Jack Moomaw and Mary Yelm, the first woman to receive a master's degree in anthropology. Past cultural resource documentation in the Park culminated in the efforts of the Systemwide Archeological Inventory Program that took place from 1998 to 2002. From these efforts and others, the Park is aware that over a thousand archeological sites are located within the park but lacks a comprehensive database from which to effectively manage potential impacts from visitor experience and climate change, among others. The suite of archeological sites also provides robust data to develop and address research questions specific to how humans have traveled and used high altitude resources. Using least-cost path analysis and patch ecology, the second component to this research is to "connect the dots" and use existing archeological site location data and new survey efforts to develop and test models to evaluate where and why archeological sites occur on the landscape. Were campsites positioned on the landscape to facilitate travel through rugged topography or to effectively position themselves on the landscape to harvest plant, animal, or other resources? Or is the relationship much more complex? In an effort to address these questions, the research design funded by the Rocky Mountain Conservancy will be introduced.

Keywords: *cultural resources, database, hunter-gatherers, research design*

Boulderers' Perceptions of Leave No Trace in Rocky Mountain National Park: Improving Resource Conditions and Visitor Experiences

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Participation in bouldering has increased substantially over the past two decades. Of the 7.5 million estimated rock climbers in 2013, nearly two-thirds were considered to be boulderers and/or indoor gym climbers. As bouldering continues to gain in popularity and participation, more climbing opportunities are being discovered outdoors within both public and private lands. Rocky Mountain National Park (RMNP), for example, has been a popular climbing destination since the 1800s and is often considered a mecca for boulderers around the world (NPS, 2001). Park managers have documented the increase of bouldering and have raised questions regarding the potential for associated environmental and social resource impacts. While the RMNP management plan allows for all modes of climbing (see NPS, 2001), no estimate of baseline conditions exists (e.g., how much bouldering exists in the park, potential user group conflicts, ecological damage related to bouldering activity). Moreover, there is little to no understanding of the environmental and social practices of boulderers, and their attitudes toward such practices.

Keywords: *Leave No Trace, bouldering, outdoor ethics, rock climbing*

Key Message:

- Boulderers' attitudes generally align with Leave No Trace recommended practices, although attitudes are less congruent with practices that are perceived as limiting to safety, access, and maintaining bouldering opportunities in the park.

Deciphering the Mass Balance Regimes of Very Small Glaciers: A Case Study from Rocky Mountain National Park

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Very small glaciers (<0.5 km^2) account for ~60–80% of all glaciers in mid- and low-latitude mountain ranges and are predicted to experience rapid wastage in the coming decades due to their short response times and narrow elevation ranges. However, secondary mass balance processes (e.g., topographic shading and snow redistribution by wind and avalanches) can effectively decouple these glaciers from regional climate forcings, challenging an ability to predict their response. Previous studies have found widely varying sensitivities to late 20th and early 21st century warming, emphasizing the need for further research. We examine volume and area changes for 11 glaciers along a 50 km stretch of Colorado's Front Range. We found significant interannual variability in glacier area, with ± 50 % of normalized area changes in sequential years, but limited net change since the 1960s. In contrast, geodetic differencing of photogrammetric-derived topographic maps from the early 1960s and 2016 DEMs derived from commercial stereo-image pairs revealed widely varying sensitivities, with average glacier-wide elevation changes ranging between –23 m and +1 m. We attribute this variable response to the unique morphological settings of these glaciers, which produces uneven winter mass balances. For instance, seasonal LiDAR and ground-penetrating radar surveys revealed that Andrews and Tyndall glaciers in Rocky Mountain National Park accumulated 6–14 m of seasonal snow depth, which represents a nearly ten-fold increase relative to nearby non-drifted locations. Given the importance of wind redistribution of snow to the viability of these glaciers, we employed a high-resolution, spatially distributed physically-based snow modeling system (SnowModel) to simulate these spatial patterns and assess the sensitivity of this process to future climate forcings.

Keywords: *climate, glaciers, lidar, seasonal snow*

Key Messages:

- The mass balance of very small glaciers is complicated, as secondary processes can play an outsized role.
- Over decadal timescales, glaciers along the Front Range show varied sensitivities to observed warming; some thinned by >20 m, while others have remained in near balance.

Science for Stewarding Resources into an Uncertain Future: Integrating Climate Science, Scenario Planning, and National Park Service Planning

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A major challenge facing resource managers today is not knowing exactly when, where, or how climate change effects will unfold. To plan for this uncertain future, managers have begun to use a tool known as scenario planning. This structured process describes 3-5 storylines that capture a wide range of plausible future climate conditions, explores ecological, cultural, and structural vulnerabilities in each of these scenarios, and then develops strategies to achieve goals across or within scenarios. Scenario planning has been used in the National Park Service (NPS) for over a decade, but it is not always clear how best to apply the outcomes of scenario planning exercises. We report on recent efforts to make scenario planning more relevant and usable to NPS resource managers by integrating it into an NPS Resource Stewardship Strategy (RSS) – a long-range and adaptive planning tool for a national park unit to achieve its desired natural and cultural resource conditions. We describe and reflect on lessons learned from recent climate change scenario planning projects at several NPS units (i.e., Knife River Indian Villages National Historic Site, Badlands NP, Devils Tower National Monument, and Wind Cave NP) and look ahead to potential applications at Rocky Mountain National Park.

Keywords: *climate adaptation, climate change, resource management, Resource Stewardship Strategy, scenario planning*

Key Messages:

- Scenario planning is an effective tool for grappling with the uncertainty associated with future climate change and its impacts on resources
- Coupling qualitative scenario planning with quantitative modeling tools can yield additional insights.
- Developing processes for integrating climate change scenario planning with existing resource management planning processes (e.g., NPS RSS) can provide considerable added value.

Indigenous Connections at Rocky Mountain National Park (Panel)

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The University of Colorado's Center of the American West (CAW) and the Center for Native American and Indigenous Studies (CNAIS), Rocky Mountain National Park (RMNP) and representatives from the Arapaho Tribe of the Wind River Reservation in Wyoming, the Cheyenne and Arapaho Tribes in Oklahoma, the Northern Cheyenne Tribe in Montana, the Southern Ute Indian Tribe in Colorado, the Ute Indian Tribe of Uintah and Ouray in Utah, and the Ute Mountain Ute Tribe in Colorado, are carrying out a project that *seeks to improve the educational and interpretive programs at Rocky Mountain National Park in ways that are more inclusive of tribal nations*. In September 2017 and January 2018, we held two workshops that brought together tribal representatives, CU faculty and students, and NPS personnel. The group discussed how the park can better share information with their 4.5 million annual visitors about the tribal nations with connections to this region. Building on the success of these workshops, we secured funding for the next phase of the project in 2018-2019. We are currently gathering content from existing research on each tribe's connections to the RMNP region that will contribute to the creation of new park exhibits and programs. In this presentation, we will explain the origins and progression of this multi-year project as well as our plans for the future. We will highlight the opportunities and challenges of building this sort of collaborative project, which involves tribal representatives, university faculty and students, and park and regional NPS personnel. Further, we will discuss examples of the content and interpretive products we are developing.

Keywords: *education*, *history*, *interpretation*, *partnerships*, *tribal nations*

Key Messages:

- The value of collaboration over just consultation with tribal partners.
- The possibilities of expanding visitor awareness of Native peoples AND improving the connections Native people have to the park region
- The opportunities and challenges of collaborating between NPS, a university, and tribal nations.

Why Wild Basin Stayed Wild: A Landscape History of Rocky Mountain National Park's Least Developed Entrance

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Visitors enamored with Rocky Mountain National Park's most iconic tourist sites often overlook the beauties that lie in the park's southeast corner. Only one constrained route, the Wild Basin Corridor, funnels adventure seekers into Wild Basin's spectacular alpine backcountry. The Wild Basin Road defines the corridor's length as it follows the North St. Vrain Creek that flows down through a forested canyon to the wet meadow at the park's entrance. The only logical route to the trails into Wild Basin's highcountry is a narrow, graveled road inhospitable to large recreational vehicles. In winter, auto traffic stops at a gate half-way into the drainage. Devoid of campgrounds and pavement, of travel trailers and visitor centers, Wild Basin Corridor is a park landscape that retains its essential vernacular form—the unplanned, local, organic creation outside of government bureaucracy. Although most park entrances underwent modernizations in the New Deal and Mission 66 eras, Wild Basin Corridor hung onto its primitive characteristics and its pre-park form. In the 1970s, when parks entered the Environmental Age and policy shifted to wilderness and natural resource protection, Wild Basin Corridor already existed in a state of rudimentary development. In an ironic twist, the pre-dominance of private property along its length kept the Wild Basin landscape wild. Because of Wild Basin Corridor's history, this paper will argue that it is an important cultural landscape representing a vanishing pre-park era within Rocky Mountain National Park.

Keywords: *cultural landscape, cultural resource management, vernacular landscape, Wild Basin*

Key Messages:

- The cultural landscape of the Wild Basin Corridor is historically significant because it continues to exhibit its vernacular origins.

Trending Pikas: What One Population Might Say about Its Neighbors

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Many species are facing local extinctions due to changes in climate. For example, the currently broad distribution of the American pika has been forecast to shrink significantly over the next few decades. A recent forecast for Rocky Mountain National Park (RMNP) suggests that pikas might be lost from the park during this century due to effects of climate on pika survival and movement. Pikas might die during cold winters if there is too little snowfall to insulate them from sub-freezing temperatures, and populations lost over winter might not be recolonized if summers are too warm for juveniles to disperse across south-facing and lower-elevation habitats. To evaluate this forecast, we used data from the Niwot Ridge Long-Term Ecological Research site (NWT), about 30 km south of RMNP. NWT pikas were captured, weighed, and classified as adults or juveniles each summer during 1981-1990, 2004, 2006, 2008 and 2009-2019. Trends in the number of adult and juvenile pikas captured were estimated using mixed-effect models, allowing for effects of year and climate, including a metric of "extended summer" that combines information on the initiation date, length and warmth of the growing season. We also estimated pika birth dates using a growth curve developed for the NWT population because earlier births might cause us to mistake juveniles for adults during the trapping season. We found a strong decline in the number of juveniles captured per adult captured during 1981-2019, especially in years with extended summer, which suggests a strong reduction in recruitment and reduced potential for population growth. This decline was not explained by a trend toward earlier pika births. Dramatic and climate-related changes in pika recruitment adjacent to the park suggest that parallel changes might be underway in RMNP.

Keywords: *American pika, climate change, demographic trend, dispersal, growth curve, juvenile recruitment, Long-Term Ecological Research Network, Ochotona princeps, Rocky Mountain National Park*

Altering Water and Nitrogen Availability after Roadside Disturbance to Favor Native Plant Species

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Disturbances such as road construction cause increased light and soil nutrients and decreased soil structure and ecosystem function, which can favor establishment of invasive plants. In Fall 2013, soil amendments were applied to roadsides in Rocky Mountain National Park to encourage establishment of native perennial species by manipulating water and N availability. The treatments applied alone and in pairwise combinations were an incorporation of yard-waste compost (C:N, 10:1) or super absorbent polyacrylamide gel (C:N, 4:1), and/or application of pine-duff wood mulch blanket (C:N, 57:1). We expected compost to increase soil water content and N, polymer to change the timing of water and N availability, and mulch to increase soil water and reduce N. Ten native perennial grass and forb species were hydro-seeded with tackifier above the incorporated amendments and below the mulch blanket. Plant density, cover, mineral nutrients, soil moisture, soil C:N, and rainfall were measured in 2014 and 2015. In the greenhouse, we tested responses of two pairs of native and non-native grasses to identical amendment application methods as in the field. We measured biomass, plant height, seedling density, and soil water content during 9 weeks of growth. The amendments changed water and nutrient availability and therefore, native perennial and non-native species establishment. Generally, mulch reduced plant size ($p=0.001$) but increased native grass biomass relative to non-natives ($p=0.002$). In the field, compost/polymer increased N availability and non-native density to 12 plants/m^2 ($p=0.02$, 2015), while mulch immobilized N and reduced non-native density to 2 plants/m^2. Mulch, mulch/compost, and mulch/polymer increased soil moisture after rainfall ($p=0.0007$) and after irrigation ($p=0.0001$). Seeded perennial species' density was highest in mulch/compost treatments in 2014 ($p=0.029$) and mulch/polymer treatments in 2015 ($p=0.003$). Land managers can select soil amendments to decrease soil N availability and increase soil water content to favor native perennial species over non-natives.

Keywords: *disturbance, ecosystem function, plant competition, succession*

Changing Thermal Regimes of Lakes and Streams in Rocky Mountain National Park and Cutthroat Trout Conservation

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Mountain streams and lakes are warming with changing climate conditions. These changes in thermal conditions are poised to have implications for coldwater fishes found in these high elevation systems. Rocky Mountain National Park (RMNP) is home to a stronghold of native Cutthroat Trout (*Oncorhynchus clarkii*) populations. However, shifts in thermal conditions are a concern threatening the security of these populations. To effectively plan conservation efforts, it is important to understand and incorporate the threats of changing biotic conditions, which include rising temperatures, changing hydroclimate, and new disturbance regimes. We created a database of historical and newly collected stream and lake temperature records. The database was used to inform a Bayesian Network model predictive of Cutthroat Trout habitat suitability. This model considers among other factors, hydro-thermal conditions and habitat type. Preliminary results suggest lakes are warming faster than streams and that warming in some extremely cold high elevation streams improves thermal habitat suitability for Cutthroat Trout. The probability of Cutthroat Trout persistence in any habitat is also a function of multiple interacting factors including temperature, habitat size, and presence of non-native fishes. These results are spatially explicit and were used to map the probability of persistence for Cutthroat Trout populations within RMNP. Maps of Cutthroat Trout habitat suitability should provide useful information that allows conservation planning to include information about current and future habitat conditions to ensure the long-term efficacy of management actions.

Keywords: *climate change, conservation planning, cutthroat trout, native fish*

Winter Limnology in Rocky Mountain National Park: Understanding Evolving Physical and Biogeochemical Controls on Aquatic Ecosystem Structure under Ice-Cover

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In mountainous regions such as Colorado's Front Range, changes in hydroclimatology and enhanced exogenous input of nitrogen from atmospheric deposition are driving changes in lake ecosystems. Although summer is an important period when primary production dominates lake ecosystem structure and function, less is known about how these trophodynamics change during the longer period of winter ice-cover. Ongoing research of Bear Lake, located in the sub-alpine transition zone of Rocky Mountain National Park, has shown that depth profiles of dissolved oxygen change in the lake due to variation of snow cover on the ice. Preferential deposition of snow on the east side of the lake driven by wind creates a shallower depth to the oxycline by limiting light penetration through the snow and ice to support photoautotrophs compared to the snow-free west side of the lake. However, concentrations of dissolved organic carbon (DOC) appear consistent across these surface cover conditions and increase slightly by depth. Under the competing role of snow cover influencing primary production near the surface in producing oxygen against heterotrophic processes consuming it at depth, we hypothesize that the developing strata create a redox gradient where dissolved organic matter (DOM) accumulates in a reduced state below the oxycline to act essentially as a battery to store chemical energy. Favoring heterotrophic activity, this further promotes the assimilation of nutrients into the DOM pool and an evolving reservoir of labile carbon to prime the aquatic ecosystem during lake turnover in the spring. We present data collected from Bear Lake throughout the winter of 2018 to better elucidate these shifts in aquatic ecosystem function against physical and chemical gradients. These findings both advance an understanding of oligotrophic, mountain lake sensitivity to change and predict response to future pressure, and also identify key biogeochemical processes that may seasonally control foodweb structure.

Keywords: *biogeochemistry, lakes, seasonality, trophodynamics*

Soil Carbon Stability in Subalpine and Alpine Systems

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Tundra systems have historically been sinks for soil carbon as the diminished temperature suppressed microbial activity. With warming temperatures, these systems could transition from sinks to sources of carbon. This ongoing project is focused on the stability of soil organic matter and soil carbon in subalpine and alpine systems. In June of 2015, six study sites were established in Rocky Mountain National Park. Two sites were located in subalpine conifer forest near treeline (elevation ~11,500 feet). The remaining four sites were located in alpine tundra (elevation ~12,000 feet) and represented wet meadow, fellfield, and dry meadow communities. Soil respiration, soil temperature, and soil moisture were measured twice monthly throughout the snow-free periods of 2015-2019 using a LI-COR LI-8100A automated CO_2 flux system and digital probes. Soil samples were collected monthly using a 1-inch diameter corer to a depth of 15 cm. In the lab, soil organic matter was measured using loss on ignition. Although soil organic matter content was lower in one of the plots, soil respiration (organic matter decomposition) was similar across all plots. If conditions were becoming more favorable for decomposition, we would expect that soil respiration rates would be higher at sites with elevated levels of soil organic matter. Across all plots, soil respiration was significantly related to soil moisture and the interaction between soil moisture and soil temperature ($p < 0.05$), but it was unrelated to soil temperature on its own ($p > 0.05$). These findings suggest that, in the alpine tundra, an increase in annual temperature associated with global climate change may not have a dramatic effect on the carbon storage capacity of soils in which soil moisture remains low.

Keywords: *carbon, global change, soil, tundra*

Key Messages:

- Alpine tundra soils have historically been a carbon sink.
- Climate change may cause tundra soils to transition from a sink to a source of carbon as microbes decompose stored carbon.
- Changes in soil carbon will affect the flora and in turn, the fauna in the park.

Proactive Limber Pine Conservation Strategy for Rocky Mountain National Park

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Limber pine (*Pinus flexilis*) is declining throughout most of its range due to the interacting impacts of the non-native pathogen that causes the lethal disease white pine blister rust (WPBR), mountain pine beetle (MPB), dwarf mistletoe, and climate change. In 2010, WPBR was confirmed in the Rocky Mountain National Park (RMNP) and new infections continue to be found and threaten limber pine. WPBR is expected, if left unmanaged, to increase in incidence and severity, leading to long-term negative impacts on biodiversity, ecosystem processes, and park resources. RMNP and USDA Forest Service established the collaborative Limber Pine Conservation Program in 2008 to build the science foundation to facilitate efficient and effective conservation of limber pine. In 2015 the park adopted the developed Limber Pine Conservation Strategy (Schoettle et al. 2019). The purpose of the strategy is to guide management to conserve limber pine resilience, ecosystem function, and overall biodiversity in the park. Regeneration dynamics and genetic resistance to WPBR are key factors that will determine the species trajectory in the future. Therefore the Strategy promotes: (1) ex situ and in situ conservation, (2) increasing population size and sustain genetic diversity, (3) locating treatments to maintain durability of qualitative WPBR resistance, (4) discovering and deploying local quantitative WPBR-resistant sources, (5) monitoring pines and rust (Cleaver et al. 2017), and (6) coordinating management actions within and among agencies. This presentation will provide a synthesis of the research that continues to be conducted under the Limber Pine Conservation Strategy and a discussion of its implications for management and the collaborative stewardship approach.

Key Words: *climate change, conservation, five-needle white pines, invasives, white pine blister rust, wilderness*

Riparian Plant Physiology in the Context of Ecological Restoration in Rocky Mountain National Park

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Physiological thresholds and resource use strategies of dominant plant species are an important but little explored aspect of montane riparian systems that may determine constraints on ecosystem recovery. Over the course of summer 2019, I took a plant physiological approach to investigate water-limitation in montane riparian plant species in Rocky Mountain National Park (RMNP) to evaluate a central research question: does water-limitation affect the degree to which species can recover? Seventeen long-term monitoring sites were surveyed for plant community composition, hydrologic condition, disturbance, plant water potential, and stomatal conductance. Sites spanned a gradient of ecological and hydrologic condition. Focal species of interest – willows (*Salix* spp.) – demonstrated relatively hydrated stem water potentials across sites and increased stomatal regulation in degraded sites, in line with classic drought avoidant, isohydric behavior. Increased stomatal regulation at drier degraded sites may constrain biomass production and ultimately ecosystem recovery towards tall dense willow-dominated riparian plant communities. Combined analysis of plant physiological data and long-term trends of species turnover provide for a novel approach to inform riparian management – including possible beaver dam analog restoration approaches on the landscape.

Keywords: *physiology, plant ecology, restoration, riparian*

Leveraging Citizen Science to Understand the Ecological Impacts of Climate Change and to Build Visitor Engagement in Conservation at Rocky Mountain National Park

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Given the complexity of the ecological impact climate change is having on wildlife and important ecosystems, a growing need is to engage citizen scientists in the collection of the landscape-scale, high frequency data needed to understand and inform conservation action. For nine years, the Front Range Pika Project has engaged citizen scientists from Colorado in the collection of data on the presence and habitat characteristics of the American pika across the Southern Rocky Mountains. Because American pikas are sensitive to increasing temperatures and variation in snowpack, studying the biophysical drivers of pika persistence can help improve understanding of the ecological impact climate change may be having on wildlife, alpine ecosystems, and natural resources. In 2018, the Front Range Pika Project expanded into Rocky Mountain National Park to support the Park Service efforts to monitor pika populations and to help assess the biophysical variables that explain pika persistence across the Park. We aim to provide data needed to predict and track American pika response to climate change and inform conservation. Through the active engagement of Coloradoans in citizen science, the project has gained valuable insights into the potential impacts of climate change on pika and effective ways to actively engage the public in climate change mitigation.

Keywords: *alpine, citizen science, climate, pika*

Key Messages:

- Citizen science can serve as tool for understanding landscape-scale patterns of climate.
- Citizen science generated data provides information on ecological impacts of climate on pikas and alpine ecosystems across RMNP.
- Citizen science is a powerful tool for increasing engagement of public in citizen science mitigation and management.

Factors Related to the Presence and Abundance of Antibiotic Resistant Bacteria and Antibiotic Resistance Genes in Soil and Water

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Infections caused by antibiotic resistant bacteria (ARB) are an imminent public health threat. While the incidence of resistant infections in healthcare settings in the United States has been decreasing since 2011, the incidence of resistant infections overall has increased. Previous studies have demonstrated that ARB and antibiotic resistance genes (ARGs) can be detected in soil and water environments. The objective of this study is to characterize anthropogenic and ecological factors that relate the presence and abundance of ARB and ARGs. Rocky Mountain National Park was used as a model environment due to its reliable gradient of human presence and other ecological variables. Soil and water samples were collected (n=450) across the park and analyzed for ARB and six ARGs. Increased human presence is associated with increased abundance of doxycycline (p=0.001) and levofloxacin ($p<0.0001$) resistant bacteria in water and vancomycin resistant bacteria (p=0.007) in soil. Linear regression models indicated that human presence, proximity to human waste, elevation, season, water flow, and other variables are significant contributors to the variability in the abundance of ARB, but other predictive factors are currently neglected. These data imply the mechanisms of dissemination and movement of ARB and ARGs in natural environments are driven by more complex forces than human contamination alone. Characterization of these mechanisms will allow for robust risk assessments to be developed to protect human and animal health from the antibiotic resistance threat.

Key Messages:

- Anthropogenic forces are primary drivers of the presence and abundance of antibiotic resistant bacteria in the environment, but the mechanism of dissemination is highly complex.
- Microbial stewardship is paramount to the protection of both the natural environment and public health of humans and animals within it.

Southern White-Tailed Ptarmigan *(Lagopus leucura altipetens)* Population Assessment and Conservation Considerations in Colorado

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The southern white-tailed ptarmigan (*Lagopus leucura altipetens)* is an alpine endemic grouse currently proposed for listing under the Endangered Species Act. It inhabits naturally fragmented mountainous habitats in Colorado that have been, and are currently impacted, by anthropogenic threats that predominantly include climate change, sheep grazing, hunting, mining, and recreation. With a listing decision pending, Colorado Parks and Wildlife evaluated the status of the southern white-tailed ptarmigan from 2013-2017 using metrics to determine trends in abundance, survival, and reproductive success. Incorporating the spatial and temporal variation in the demographic and abundance rates measured at six study sites, an Integrated Population Model was developed to assess populations at multiple spatial scales from the community level to statewide with a subsequent Population Viability Model produced to evaluate extinction probabilities into the future. Although we found that white-tailed ptarmigan have low reproductive success with high annual variability in brood productivity predominantly driven by predation and to a lesser extent by weather, overall indication from our work showed a resilient species with stable populations and low extinction probabilities. We recommend that a long-term monitoring plan be implemented to continue to assess changes in white-tailed ptarmigan distribution as environmental changes become more pronounced. It is also imperative for agencies to coordinate on the development of management practices to address increased recreation in the alpine, use adaptive management to deal with domestic grazing as the state warms and climate conditions change, and continue the cleanup and closure of historic mine sites. Finally, effective methods to assess hunting pressure of white-tailed ptarmigan at localized areas that may be over exploited as a consequence of easy access and proximity to human population centers should be considered.

Key Messages:

- Indications from our work found that white-tailed ptarmigan are well distributed in the state with overall stable populations.
- We recommend that resource managers continue to monitor the species into the future as environmental conditions change.
- Increased recreation in the alpine will need to be managed to avoid negative impacts to the species within localized areas.

Pile Burn Scar Restoration at Lily Lake: Tradeoffs between Non-Native Abundance and Recruitment of Native Species

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Invasive species are of worldwide concern due to their impacts on native ecosystems. There is potential to exacerbate the threat of invasion through typical fuel management practices on public land. Fuel reduction has been employed as a restoration method that has been shown to decrease fire severity and increase resilience. Burning fuel piles is a common practice to remove unmarketable wood from the landscape following fuel reduction and other forest management activities. These fires alter soil chemistry, destroy soil microbial communities, and alter plant communities. These changes can create conditions favorable to invasion by non-native plants. Restoration has been recommended as a method to minimize the impacts of invasive species. In 2014, Rocky Mountain National Park collaborated with students from the Public Lands History Center at CSU to restore more than 300 pile burn scars at Lily Lake. We monitored plant cover of 26 scars at this site during the summers of 2013-2017 to determine the effect of restoration on pile burn scars. After three years, restoration had a significant impact on what grew within scars. In 2017, restored scars had 8.6 times more cover of seeded species and less than a third of the non-native plant cover found in unrestored scars. Restoration also reduced growth of native species that were not seeded resulting in unrestored scars having 65% more cover of unseeded native species compared to restored scars at the end of the study. Seed additions in 2017 revealed that restoration decreased biomass of seedlings in their first year of growth by 93.6 %. This finding is likely due to competition with established grasses and illustrates the importance of considering effects of restoration on both native and non-native species.

Keywords: *competition, fuel reduction, invasive species, public land*

Is the Ongoing High-severity Spruce Beetle Outbreak a Result of Climate Change?

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Rocky Mountain National Park is currently experiencing an extensive, high-severity spruce beetle (*Dendroctonus rufipennis*) outbreak, which is killing most canopy trees. Whereas spruce beetles are native to the Rocky Mountains, and outbreaks are a central part of the disturbance ecology of spruce-dominated (*Picea engelmannii*) forest systems, it is not clear if the severity of the current outbreak in RMNP is similar to historical outbreaks or is a result of climate change. Spruce beetle outbreaks are associated with drought and warmer temperatures, which stress spruce trees and decrease their ability to resist attack and facilitate spruce beetle population development. Previous research in northwest Colorado has shown that spruce beetle outbreaks in that region are infrequent high-severity events, which are similar in severity to the ongoing outbreak in RMNP. In contrast, recent research in southwest Colorado indicates that historical outbreaks there were relatively frequent low-severity events. However, southwest Colorado is currently experiencing a high-severity outbreak, and the shift in outbreak severity is linked to climate change. Specifically, the ongoing high-severity outbreak in the southwest is associated with a shift to warmer temperatures and frequent high-severity drought. The goal of this research was to identify if the severity of the current outbreak in RMNP represents a shift in severity or if past outbreaks were similar high-severity events. To accomplish this, I used existing tree core samples, which were originally collected to reconstruct fire history in RMNP, to identify the characteristics of past spruce beetle outbreaks with a specific focus on the severity of past outbreaks.

Decadal Trends and Variability in Intermountain West Surface Ozone near Oil and Gas Extraction Fields

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Decadal trends in the annual fourth-highest daily maximum 8-hour average (A4DM8HA) ozone (O_3) were studied over 2005 – 2015 at 13 rural/remote sites in the U.S. Intermountain West to investigate the impact of oil and natural gas (O&NG) emissions on decadal O_3 levels. No trends were observed in A4DM8HA O_3 at two reference sites, which are located upwind of and thus minimally influenced by emissions from O&NG production regions. Trends, or a lack thereof, varied widely at 11 sites in/near O&NG basins resulting from different controlling factors rather than a simplistic, uniform one. A lack of trend was observed at 8 sites, including Rocky Mountain National Park (ROMO), and was likely caused by the increasing O&NG emissions and decreasing emissions from other activities. ROMO is located to the west of the Denver-Julesburg Basin and experienced northwesterly and southeasterly wind most frequently over 2005 – 2015, with higher O_3 (>60 ppbv) from the east and southeast. Natural gas production in Weld County increased by nearly a factor of 3 from 2009 to 2015, which coincided with use of horizontal drilling starting in 2009. Additionally, NOx emission reductions of ~37% from the urban area of Denver offset the effect of increased NOx emissions from O&NG extraction. The decadal (2005 – 2015) mean of the A4DM8HA O_3 reached or exceeded 70 ppbv, the current National Ambient Air Quality Standard, at three sites in the Intermountain West, including ROMO (75.1 ppbv). Decreasing trends were observed at three sites and were attributed to decreases in natural gas production, emission reductions in coal-fired electricity generation, and increasingly frequent precipitation weather. Our findings suggest that emissions from O&NG extraction played a significant role in shaping long-term trends in surface O_3 near/within O&NG regions and warrants consideration in the design of efficient O_3 mitigation strategies for the Intermountain West.

Keywords: *air quality, Intermountain West, oil and natural gas, ozone*

Key Messages:

- Emissions from oil and gas extraction operations have altered the decadal trends in the Intermountain West surface ozone levels.
- The long-term ozone trend at Rocky Mountain National Park exhibits no trend because of increasing emissions from oil and gas extraction operations that have countered emission reductions from other sectors.

Cross-boundary Stewardship for Wetland Integrity and Resilience in the Greater Rocky Mountain National Park Ecosystem

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Long-term monitoring by the Rocky Mountain Inventory and Monitoring Network has found that approximately half of the wetlands in Rocky Mountain National Park (ROMO) are not in reference condition due to anthropogenic disturbances. These disturbances often occur beyond park boundaries such as alterations to hydrologic regimes or introduction of species. ROMO, like most protected areas, is part of a larger ecological system in which interactions with surrounding lands are critical for sustaining the species and ecological flows present within them. Therefore, more effective stewardship of wetlands within ROMO is likely to be achieved through collaborative efforts that account for wetland sustainability while acknowledging the differing missions and goals of land management entities that share responsibility for those wetlands. Through semi-structured interviews with federal and state agency officials, nonprofit organizations, and municipalities, and an analysis of these organizations' wetland policies and goals, we explored ways to facilitate collaborative wetland stewardship in the greater ROMO ecosystem. The findings of this research illustrate awareness of the issue and willingness to participate in collaborative management. Participants identified growing concerns about effects of population growth and climate change on limited water resources, increasing the need for collaborative efforts. Despite a desire and urgency to participate in collaboration, we identified many barriers to working across jurisdictional boundaries that differ between entity type. Based on this research, we provide recommendations on how to address these challenges, while taking advantage of collaborative opportunities through shared goals and objectives among organizations to facilitate cross-boundary stewardship for wetland integrity and resilience in the greater ROMO ecosystem.

Key Messages:

- Wetland stewardship professionals recognize that disturbances to the ecosystems they manage often occur beyond the boundaries of their jurisdiction.
- Working with others to manage these disturbances, however, poses many challenges.

National Ecological Observatory Network (NEON) Data Collection at Rocky Mountain National Park

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Change is inevitable in today's environment and the National Ecological Observatory Network (NEON) is in place to record this ecological change and provide the data free for public use for the next thirty years. NEON is a research facility that collects environmental data from 81 terrestrial and aquatic field sites across the United States for thirty years. The Rocky Mountain National Park (RMNP) hosts one of NEON's terrestrial field sites and uses tower and soil-based instruments, airborne remote sensing technology, and technicians to collect an array of ecological data. At 2743m, the RMNP tower is at the second highest elevation in the observatory, representing an important ecological data point. In this talk we will discuss the wide range of data that NEON collects. We will also discuss how to use NEON data to examine changes within and between our natural communities with a focus on RMNP tree health data collected as part of the NEON vegetation structure protocol. Using NEON data we can not only determine how natural communities are changing, but also develop strategies for stewardship.

Keywords: *NEON, public data, vegetation structure, lodgepole pine, aspen*

Applying Low-Cost PCB Sensor Technology for Monitoring Electrochemical Changes in Alpine Lakes in Rocky Mountain National Park from 2016 to 2019

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Rocky Mountain National Park has many beautiful and fragile alpine lakes. Low-cost sensors could greatly assist in monitoring the status and improving the management of these valuable natural resources. Printed circuit board (PCB) technology is a mature, low-cost technology used in almost every electronic device. PCB technology is also an excellent technology for realizing low-cost environmental sensors by using the standard materials and manufacturing processes to implement a circuit board that electromagnetically interacts with its surrounding environment, thereby affecting the measurable electrical properties of the circuit board. This sensor technology is useful for environmental and agricultural applications including soil moisture content measurement, pollution detection (water and soil), drought condition monitoring in estuaries, and saltwater intrusion detection in coastal areas. For this study, PCB sensor technology is being investigated for monitoring electrochemical property changes at four alpine lake ecosystems in the Loch Vale Drainage at Rocky Mountain National Park resulting from precipitation and atmospheric deposition rate variations over five years. These alpine lakes are The Loch, Lake of Glass, Sky Pond, and Andrews Tarn. To date, water samples were collected from these ecosystems in August of 2016, 2017, 2018, and 2019, and then taken into the laboratory and tested with a specially designed PCB sensor suite to evaluate if small changes in the electrochemistry of the lakes from year to year could be observed using this sensor technology. We observed a peak in the electrical conductivity in 2018, which may have correlated to ash residue entering the watershed from the rampant western forest fires that year. This presentation will discuss the application, the sensor suite developed for this application, and the results from testing over the previous four years with respect to annual precipitation rates and other environmental variables during this time period.

Keywords: *environmental sensing, low-cost PCB sensor, RMNP alpine lakes*

Heterogeneity in Soils and Forest Stands May Explain a Complex Response to Nitrogen Addition in Old-Growth Subalpine Forests

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Excess reactive nitrogen (Nr) in the environment from fossil fuel burning and agricultural emissions impacts ecosystems in Rocky Mountain National Park. To understand how Nr impacts subalpine forests and forest soils, we initiated a N fertilizer application experiment in Loch Vale watershed which ran from 1996-2017. We found that annual additions of 25 kg/ha Nr produced no overall difference in soil nitrogen or carbon between three treatment and three control plots. This counterintuitive result contrasts with observed increases in soil organic C and N following Nr addition to forests in other experiments. Plot-level variability in the results present a more nuanced picture, and we found the response of the system depends on additional factors besides Nr application. We modelled the mediating influence of forest stand characteristics, soil moisture, and C and N content of fine roots, soils, and soil solution, to determine how plot-level variability in soil C and N arises. Our results show that interplay with N limitation may influence the effects of Nr on coniferous systems. Where the control plots were more N limited, soil C was 137% of average, and root N was 89% of average. These results suggest that where N is more limiting, plants produce less labile organic materials that resist decomposition and increase soil C storage.

Keywords: *carbon, forest soils, nitrogen, subalpine forest*

Key Messages:

- Air pollution impacts on Rocky Mountain ecosystems may vary depending on characteristics of the landscape.

Assessing Habitat Quality Using Stress Measurements in American Pika Populations

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Climate vulnerability predictions for the American pika (*Ochotona princeps*) forecast that under high greenhouse gas emission scenarios, pika will be extirpated from Rocky Mountain National Park by 2100. Surveys within the park, however, have shown evidence that current pika occupancy and distribution are relatively high. The currently broad distribution of pika within the park provides an opportunity to test the pika forecast by looking for early evidence of population stress. Some pika habitats were predicted to support pika for several decades into the future, while others were predicted to lose pika much sooner. Animals who utilize poor habitats may be most susceptible to new threats and be the first to show population decline because poor habitat quality could be a source of chronic stress. Acute stress can be a beneficial response in mammals to allow for actions like fight or flight, but chronic stress is associated with lower reproduction and higher mortality. During the spring and fall of 2018 we evaluated physiological stress within pika populations occupying different types of habitat. By using non-invasive methods to collect fecal samples from pika in the field, we were able to measure glucocorticoid metabolites (a type of stress hormone) in individuals. We chose habitats with and without subsurface ice to determine whether pika near ice features in the park are less stressed, as suggested by previous studies elsewhere. We found that stress was higher at lower elevations and in habitats without subsurface ice, but this effect was evident only for samples collected in the spring. Results support the further use of stress metrics to evaluate predictions of pika on the cusp of decline in the park, as well as inform managers which populations are most vulnerable to changes in climate today.

Keywords: *American pika, climate vulnerability predictions, glucocorticoid metabolite, habitat quality, Ochotona princeps, physiological stress, Rocky Mountain National Park, subsurface ice*

Key Messages:

- Individuals within a population respond similarly to stressors.
- Stress is highest in the alpine spring.
- Stress is lower in populations living in habitats that contain subsurface ice.

Applying What We've Learned about Elk and Willow to Moose Herbivory in Wild Basin

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Research on ungulate use in Rocky Mountain National Park (RMNP) has often been prompted by change. Change in a species' population within the park such as for bighorn sheep (*Ovis canadensis*), or changes in vegetation communities such as for elk (*Cervus elaphus*). As a result, much ungulate herbivory research has focused on willow and aspen communities on the Park's east side elk winter range, alpine willow, and more recently on the Kawuneeche Valley. Areas that were perceived as having "healthy" vegetation and few ungulates often received less attention due to the need to focus resources on locations where critical declines in habitat condition were occurring. The Wild Basin willow area was perceived as having a healthy willow community resulting from an active beaver community and minimal ungulate browsing and was, therefore, not included in research into willow habitat decline. Over the past decade, however, moose (*Alces alces*) have begun to move into drainages on the east side of RMNP. The potential for ungulate-induced changes on one of the few remaining high condition willow wetlands in RMNP prompted a 2017 pilot study to gather baseline information on willow status and ungulate impacts in Wild Basin. We used data from over two decades of collaborative research studies on ungulate herbivory by NPS, USGS, Colorado State University, and other academic institutions to put current conditions in Wild Basin in context. This pilot study points to increasing browse pressure on willow, likely from both moose and elk, in Wild Basin. To develop a strategy to protect this remaining "healthy" riparian willow wetland on the east side of the Park, there is a need to determine seasonal habitat and willow use by elk and moose, current status of beaver in this system, and assessment of changes in willow cover over time.

Keywords: *Alces alces, Cervus elaphus, elk, herbivory moose, Salix spp., willow*

Key Messages:

- Wild Basin is one of the last remaining high condition willow wetlands on the Parks' east side.
- Although willows are generally in good condition in Wild Basin, nearly half of willows surveyed showed signs of moderate to intense browsing or appeared to be transitioning from light to moderate browsing to more intense browsing.
- More needs to be learned about seasonal willow utilization by elk and moose and how this use is apportioned to determine best approaches to maintain this wetland in good condition.

Environmental Gradients of Selection for an Alpine Obligate Bird, the White-Tailed Ptarmigan (*Lagopus leucura*)

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The warming climate will expose alpine species that are adapted to thrive in a highly seasonal, harsh environment to novel environmental conditions. A species can shift their distribution, acclimate, or adapt genetically in response to a new climate. Alpine species have little suitable habitat to shift their distribution, and the limits of acclimation will likely be tested by climate change in the long-term. Adaptive genetic variation may provide the raw ingredients for species to adapt to this changing environment. Here, we build on previous work characterizing range-wide divergence to link potentially adaptive genetic variation in an alpine-obligate species, the white-tailed ptarmigan (*Lagopus leucura*), to local environmental condition across the species distribution (Alaska to New Mexico). We detected associations between patterns genome-wide divergence and multiple environmental gradients, suggesting the ptarmigan populations may be locally adapted to the latitude and elevation, plant community composition, local climate, and to the local phenology. Overall, our results suggest there may be groups within the species' range with genetic variation that may be essential for adapting to a changing climate.

Keywords: *environmental variation, genetics, genomics, range-wide, subspecies, white-tailed ptarmigan*

Key Messages:

- White-tailed ptarmigan genetic variation is associated with environmental differences across the species range.
- The association between genetic and environmental variation suggests local adaptation to vegetation composition, elevation, phenology, and/or climate.
- Potential local adaptation could impact conservation actions and species persistence in a changing climate.

For more information about the research conference or conducting research in Rocky Mountain National Park, please visit:

http://www.nps.gov/rlc/continentaldivide/index.htm

or email: romo_research@nps.gov