National Park Service
U.S. Department of the Interior

Rocky Mountain National Park
Continental Divide Research Learning Center

2017 Rocky Mountain National Park Research Conference

People and Stewardship: Using Research for Management



Welcome to Rocky Mountain National Park's 2017 Research Conference

Our theme this year is People and Stewardship: Using Research for Management.

People are the key to the long-term stewardship of the natural and cultural resources of Rocky Mountain National Park. Whether you are an interested citizen, community member, park visitor, citizen scientist, long term partner, new collaborator, research scientist, or a paid or volunteer member of the park staff, you are an important link in the stewardship of the park resources that we treasure.

The National Park Service faces large scale environmental and social changes that are increasingly challenging and complex. The work highlighted by this conference addresses key issues, including climate change, the spread of exotic plants, large scale restoration needs, environmental contaminants and disease, a need for greater relevancy to youth, and inadequate capacity to keep pace with growing visitation. The NPS Director's Order "Resource Stewardship for the 21st Century" directs park managers to steward resources for continuous change that is not yet fully understood. This challenge makes research, learning, and engagement at local to global scales more important than ever. The magnitude of issues and opportunities currently facing park managers is reflected in the breadth and depth of the Continental Divide Research Learning Center's research program – a program that would not be possible without a vast array of interested stakeholders.

We sincerely thank you for your interest. At this conference and afterward, we invite you to make new connections and gain new insights to help us collectively move forward in better understanding and caring for our shared natural and cultural resources.

--Therese Johnson, Director, Continental Divide Research Learning Center, Rocky Mountain National Park



We are pleased to announce our third research conference 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.

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.

We would like to thank the Rocky Mountain Conservancy for supporting the 2017 Research Conference.

2017 Research Conference Rocky Mountain National Park

Estes Park Municipal Building, 170 MacGregor Ave, Estes Park, CO 80517

Wednesday March 1st, 2017		
8:15 – 8:45 AM	Morning Mixer and Coffee — Lobby	
Room A: Welcome		
8:45 – 9:15 AM	Therese Johnson, John Mack, Darla Sidles	Conference Introduction and Awards Presentation
9:15 – 9:30 AM	Darla Sidles	What does UNESCO Man and the Biosphere Designation Mean?
9:30 – 10:00 AM	Tom Hobbs	Keynote Address – Human Values and Science Shape Wise Stewardship of Protected Areas: Case Examples from Scandinavia and North America
10:00 – 10:20 AM	Break	
Room A: Visitor Use		
10:20 – 10:40 AM	Steve Lawson	Overview and Trends of Visitor Use at RMNP
10:40 – 11:00 AM	Ruth Alexander	When Climbers Become Good Stewards: the History of Longs Peak
11:00 – 11:20 AM	Robin Graham	Peak Use: Visitor Use and Monitoring on High Elevation Peaks in RMNP
11:20 – 11:40 AM	Ashley D'Antonio	The Importance of Monitoring Resource Impacts from Emergent Activities: Lessons from Bouldering Use in the Bear Lake Road Corridor
11:40 AM – 12:00 PM	Kevin Sturmer and Michael Lukens	The Application of Visitor Use Research: Two Case Studies from RMNP
12:05 – 1:15 PM	Lunch	
1:20 – 2:20 PM	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, dessert and thoughtful discussions of Rocky's hot topics.	
2:20 – 2:40 PM	Break	
Room A: Youth Relevancy & Public Engagement		
2:40 – 3:00 PM	Greg Newman	Citizen Science Past, Present, and Future at RMNP
3:00 – 3:20 PM	Brett Butera	Integrating a Citizen Science Project into a High School Curriculum
3:20 – 3:40 PM	Dan Cribby	Plains to the Park: Integrating STEM Initiatives into National Parks
3:40 – 4:00 PM	Karen Barton	Colorado's Millennial Generation: Youth Perceptions and Experiences of Nature on Public Lands

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Wednesday March 1st, 2017		
These timeslots are not available during Award Presentation and Keynote Address, ROOM A		
10:00 – 10:20 AM	Break	
Room B: Ecosystem Restoration: Wetlands and Rivers		
10:20 – 10:40 AM	David Cooper	State of Knowledge of RMNP's Wetlands
10:40 – 11:00 AM	William Schweiger	Using Structural Equation Modeling to Link Human Activities to Wetland Ecological Integrity
11:00 – 11:20 AM	Edward Gage	Quantifying Montane Riparian Canopy Structure Using Terrestrial LiDAR Scanning
11:20 – 11:40 AM	Kristen Kaczynski	Large-scale Willow Restoration in Moraine Park
11:40 AM – 12:00 PM	Daniel Scott	Analyzing the Stability of Wood Jams in Rivers to Balance Ecological Health and Public Safety
12:05 – 1:15 PM	Lunch	
1:20 – 2:20 PM	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, dessert and thoughtful discussions of Rocky's hot topics.	
2:20 – 2:40 PM	Break	
Room B: Ecosystem Restoration: Grand Ditch Breach		
2:40 – 3:00 PM	Bryan Scott	Design and Construction of the Grand Ditch Breach Slope Stabilization (Zone 1A)
3:00 – 3:20 PM	Jeremy Sueltenfuss	The Restoration of Lulu City Wetland: Phase I Preliminary Results and Current Restoration Designs
3:20 – 3:40 PM	Matthew Sparacino	Monitoring the Effects of River Realignment on the Upper Colorado River, RMNP
3:40 – 4:00 PM	John Mack	Grand Ditch Breach Restoration: Using Science to inform Phase II

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Thursday March 2nd, 2017		
8:45 – 9:00 AM	Morning Mixer and Coffee — Lobby	
Room A: Archaeology / Climate Change		
9:00 – 9:20 AM	Robert Brunswig	Investigating 75,000 Years of Hunter-Gatherer and Animal-Herder Seasonal Migrations in Poland's High Tatras and Foothill Lowlands
9:20 – 9:40 AM	Jason LaBelle	The Archaeology and Paleoecology of the Ice Patches of RMNP
9:40 – 10:00 AM	Danielle Haskett	Benthic Invertebrate Response to Climate and Environmental Change in the Colorado Rocky Mountains during the Recent Past
10:00 – 10:20 AM	Jill Baron	Changing Trophic State of The Loch and Sky Pond in Loch Vale Watershed
10:20 – 10:40 AM	Claire Tortorelli	Vegetation Monitoring for Climate Change Effects in RMNP and other NPS Units
10:40 – 11:00 AM	Break	
Room A: Archaeology / Climate Change continued		
11:00 – 11:20 AM	Jason Sibold	Are Tree Species Migrating in Response to Recent (40 years) Warming in RMNP?
11:20 – 11:40 AM	Robert Andrus	Moisture Availability Limits Subalpine Tree Establishments
11:40 AM – 12:00 PM	Addressing Climate Change at RMNP, Panel Discussion with Paul McLaughlin, Danny Basch and Kyle Patterson	
12:05 – 1:15 PM	Lunch	
1:20 – 2:40 PM	Poster Session, Room B 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.	

Final conference session, Ecosystem Restoration: Vegetation, will be held in Room B.

2017 Research Conference Rocky Mountain National Park

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Thursday March 2nd, 2017		
8:45 – 9:00 AM	Morning Mixer and Coffee — Lobby	
Room B: Environmental Contaminants / Public Health		
9:00 – 9:20 AM	Katherine Benedict	Observations of Reactive Nitrogen in RMNP during the Front Range Air Pollution Photochemistry Éxperiment (FRAPPÉ)
9:20 – 9:40 AM	Barkley Sive	Impacts of Oil and Natural Gas Operations and Urban Emissions on Air Quality in RMNP during FRAPPÉ
9:40 – 10:00 AM	Robert Dean	Applying Low-Cost PCB Sensor Technology for Monitoring Electrochemical Changes in Alpine Lakes in RMNP
10:00 – 10:20 AM	Laura Scott	Detection of Ampicillin Resistant Bacteria in National Parks in the Contiguous United States
10:20 – 10:40 AM	Dan Salkeld	Ecology and Epidemiology of Rocky Mountain Wood Ticks and Colorado Tick Fever
10:40 – 11:00 AM	Break	
Room B: Wildlife		
11:00 – 11:20 AM	Nathan Galloway	Lessons Learned about Chronic Wasting Disease in Elk at RMNP
11:20 – 11:40 AM	Tyler Williams	Clark's Nutcracker Seed Use and Limber Pine Metapopulation Structure in RMNP: Predicting Future Trends
11:40 AM – 12:00 PM	Valerie Steen	Climate Change Impacts Assessment of Boreal Toad *(Anaxyrus boreas boreas)*
12:05 – 1:15 PM	Lunch	
1:20 – 2:40 PM	Poster Session, Room B 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.	
Room B: Ecosystem Restoration: Vegetation		
2:40 – 3:00 PM	Teal Potter	Is the Front Range Alpine Vulnerable to Invasion by Non-Native Plant Species?
3:00 – 3:20 PM	Ian Sexton	Evaluating Pile Burn Scar Restoration
3:20 – 3:40 PM	Cynthia Brown	Soil Amendments Can Encourage Establishment of Native Plants After Road Construction
3:40 – 4:00 PM	Scott Franklin	Clonal Plant Response to Disturbance in the Tatras, Central Europe

Poster Presentations

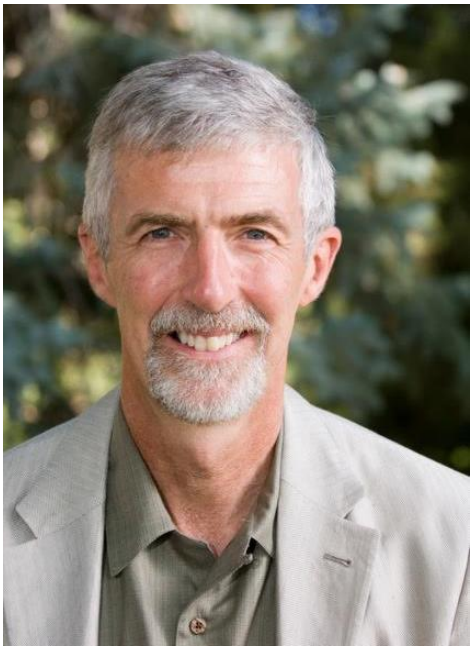
Presenter	Title
Colleen Flanagan Pritz	Mercury in Fishes from Yosemite (CA), Mount Rainier (WA), and Rocky Mountain (CO) National Parks: Potential Drivers and Ecological Risk
Kevin Gaalaas	Restoration of the Grand Ditch Breach in the Upper Kawuneeche Valley: Phase II
Kort Kirkeby	EPA National Wetlands Condition Assessment
Jay Merrill and Breanna Van	Wood Loads and Jam Spacing on the Upper Colorado River, Rocky Mountain National Park
Erin Pettigrew	Piscicide Effects on Macroinvertebrates in High Elevation Streams: An Initial Post-Treatment Evaluation
Hannah Podzorski	Expression of Geochemical Controls on Water Quality in Loch Vale, Rocky Mountain National Park
Muthu Sampath	Monitoring Algal Productivity to Inform Spatiotemporal Alpine Lake Dynamics in Rocky Mountain National Park
Sarah Schliemann	Controls on Soil Respiration in a High Elevation Alpine System
Tristan Weiss	Hydrologic and Fluvial Organic Carbon Source-Sink Dynamics of Mountain Meadows Across Land-Use/Land-Cover Change Gradients
Nate Williamson	Changes in a Mixed Conifer Stand Following Prescribed Fire and Mountain Pine Beetle Outbreak in Rocky Mountain National Park

Keynote Address

Human Values and Science Shape Wise Stewardship of Protected Areas: Case Examples from Scandinavia and North America

Dr. N. Thompson Hobbs

Colorado State University / Natural Resource Ecology Laboratory



A steward is someone who is responsible for taking care of something. Taking proper care of protected areas and other public lands is increasingly the responsibility of collaborations of stewards, notably citizens, managers, policy makers, and scientists. The need for diverse participation arises because most decisions that matter are shaped by facts and by values. In particular, there are few decisions about management of protected areas that don't involve conflicting goals. There are usually multiple alternatives for meeting those goals through management. Science can usefully inform the consequences of alternatives for management relative to goals, but human values must enter the conversation to identify goals and to resolve conflicts among them. To illustrate, I cite examples from my experience as a scientist working on the effects of lynx predation on harvest of reindeer by the Sámi people in Sweden, management of Brucellosis in Yellowstone, and elk management in Rocky Mountain National Park and the Estes Valley. Science played a vital role in informing management alternatives in all of these cases, but values expressed by stakeholders shaped the alternatives that were ultimately chosen. A key element of wise stewardship of protected areas is the need for citizens to learn about complex problems and their resolution, to understand how science works, and to demand decisions informed by facts.

Conversation Café



Join us for thoughtful discussions on some of Rocky Mountain National Parks' hot topics including:

Visitor Use

Climate Change

Wilderness

Relevancy

Ecological Services of the Park

Wildlife Management


Submitted Abstracts
(alphabetical order)

When Climbers Become Good Stewards: The History of Longs Peak

Ruth M. **Alexander** (Colorado State University), ruth.alexander@colostate.edu

I propose a presentation on the history of Longs Peak, the subject of a book I am now writing. My research on Longs shows, first, that this single alpine site is representative of historical tensions in national parks around the country. It stands for the challenges park managers have faced since the early twentieth century in trying to facilitate backcountry enjoyment while keeping humans and fragile environments from harm.

Second, my research on Longs Peak reveals something that environmental historians have ignored, that is, climbers' role as stakeholders with a vested interest in minimizing tensions between recreation and preservation and the likelihood of harm to humans. Certainly, Longs has often been overcrowded, and the hands, feet, debris, and excreta of visitors have damaged its natural resources. So too, many climbers have prepared inadequately for their ascent or made poor decisions about the risks they might face. Still, many climbers, especially those organized into groups such as the Colorado Mountain Club, the Rocky Mountain Conservancy, the Access Fund, and the Boulder Climbing Community have also attempted to work in partnership with RMNP to resolve emerging environmental and safety problems. While there is an extensive scholarly literature on the phenomenon of front and backcountry visitors "loving parks to death," scholars have not done enough to acknowledge the role played by an important cohort of visitors in looking for solutions to patterns of recreational and environmental harm. My presentation will highlight some of the most notable examples of climbers' efforts on Longs to minimize environmental and human danger, starting with the Colorado Mountain Club's educational efforts in the 1920s and 1930s, moving on to climbers' involvement in the park's efforts to development management plans capable of reducing accidents and mitigating environmental damage, especially since the 1970s. There is much at stake in recognizing backcountry visitors' role as active stakeholders. RMNP and all national parks are facing enormous pressures today from overcrowding, resource degradation, and climate change. My work asks how the historical engagement of climbers on Longs, and of backcountry visitors elsewhere, can be "scaled up" to contend with threats to parks that are now of unprecedented scope and scale.

Moisture Availability Limits Subalpine Tree Establishment

Robert A. **Andrus,** Brian J. Harvey and Thomas T. Veblen (University of Colorado–Boulder)
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Tree seedlings must establish (germinate and survive) in the forest understory to sustain future forests, particularly in the context of increasing tree mortality across the West. Periodic pulses of establishment (i.e., episodes) that contribute a majority of tree regeneration to forests likely occur when strong seed production years coincide with favorable climate conditions. Identifying the key climate factors that create favorable conditions for seedling establishment is therefore essential to understanding how climate change will affect the frequency of future establishment events. In subalpine forests in the Colorado Front Range, moisture deficits are projected to increase with warming temperatures. Moisture availability, therefore, is expected to be a limitation to seedling establishment at treeline and to seedling physiological processes. However, how this and other climate-related limitations have affected tree establishment in the recent past in the core elevation range of subalpine tree species is largely unknown. To determine the influence of the last 75 years climatic variation on seedling establishment, we compared interannual climate variability to germination dates for >500 Engelmann spruce (*Picea engelmannii*) and >500 subalpine fir (*Abies lasiocarpa*) seedlings (< 1m) collected across complex topographic-moisture gradients in the Colorado Front Range. Over the past 75 years, both species established episodically with strong synchrony across the landscape, suggesting an influence of broad-scale climate processes. Establishment episodes generally coincide with periods of above-average moisture availability during the year of germination, while years lacking seedling establishment were characterized by higher temperatures with greater moisture deficits. Additionally, we documented a decrease in the number of spruce establishment events during the past 30 years, which coincides with a multi-decadal trend of rising temperature and increased moisture deficits. Shifts in establishment patterns for two dominant and co-occurring species in Colorado's subalpine zone have important implications for the sustainability of future forests.

Keywords: *climate change, Engelmann spruce, subalpine fir, subalpine forest, Colorado Front Range*

Changing Trophic State of The Loch and Sky Pond in Loch Vale Watershed

Jill **Baron** (USGS) and Isabella Oleksy (Colorado State University)
Corresponding author: jill.baron@colostate.edu

Mountain lakes are changing rapidly from a triad of driving forces: non-native species, cultural eutrophication, and climate change. Some combination of these influences lake ecology in alpine Sky Pond, and subalpine The Loch in Loch Vale watershed, Rocky Mountain National Park. Using a range of different methods we ask: are increasing temperature and nutrients pushing Loch Vale lakes to a new trophic state? While we have monitored these lakes for water quality since 1982, limnological studies have been more sporadic. In response to atmospheric N deposition in the mid-20th century diatom assemblages reflected a shift in lake trophic state from ultra-oligotrophic to mesotrophic. In 2010 we noticed an increase in benthic primary productivity that has continued and possibly strengthened to the present, possibly indicating yet another shift toward eutrophication. In addition to sustained high atmospheric N deposition and lake nitrate concentrations, there has been a 30-year trend of increasing summer lake temperatures and a possible increase in phosphorus availability. It now appears both benthic and pelagic productivity are increasing. In August 2015 alpine water column chlorophyll *a* in alpine Sky Pond ranged 2.5-14.2 μg L^{-1}, > 2X higher than in the subalpine Loch (range 0.9-4.2 μg L^{-1}). Benthic chlorophyll a generally increased with temperature, with peak values of about 7.0 μg L^{-1} in Sky Pond, and about 5.0 in The Loch. Past measures of chlorophyll *a* concentrations in our lakes have been sporadic since 1984, but they suggest greater productivity since 2006.

Keywords: *Loch Vale watershed, algae, nitrogen, climate change, eutrophication*

Colorado's Millennial Generation: Youth Perceptions and Experiences of Nature on Public Lands

Karen S. **Barton** (University of Northern Colorado), karen.barton@unco.edu

This study uses survey and focus group methods to explore attitudes toward and experiences of nature among millennial-aged students in northern Colorado. First, results confirm that young people possess a strong interest in the outdoors yet time, transportation, and new technologies hamper their ability to visit public lands and outdoor spaces. Second, respondents experience nature in ways more mediated by new technologies such as cell phones and nature DVDs. Third, citizen science and active learning show promise as techniques for returning young people to the outdoors. The challenge lies in teaching young people to re-imagine the outdoors not as elsewhere or "out there" but as a backyard geographic space.

Keywords: *public lands*, *environmental geography*, *active learning*

Observations of Reactive Nitrogen in Rocky Mountain National Park during the Front Range Air Pollution and Photochemistry Experiment

Katherine B. **Benedict** (Colorado State University), Anthony J. Prenni (NPS Air Resources Division), Ashley Evanoski-Cole (Colorado State University), Amy P. Sullivan (Colorado State University), Emily V. Fischer (Colorado State University), Barkley Sive (NPS Air Resources Division), Yong Zhou (Colorado State University), Bret Schichtel (NPS Air Resources Division) and Jeffrey L. Collett, Jr. (Colorado State University)
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Ammonia emissions in northeastern Colorado impact sensitive ecosystems in Rocky Mountain National Park (RMNP). The spatial distribution of ammonia in the region and specific transport pathways are uncertain. It is important to understand the degree to which these different urban and agricultural sources impact RMNP, and how various meteorological conditions are associated with high-deposition periods in the park. Research in RMNP has been combined with measurements in the Front Range and eastern Plains of Colorado to better understand the movement of ammonia from source regions to the alpine ecosystems of RMNP. Results from ongoing measurements and special studies like the Front Range Air Pollution and Photochemistry Experiment (FRAPPÉ), which took place in July–August 2014, will be presented. During FRAPPÉ, measurements included high-time resolution sampling of ammonia, NO_y, alkylnitrates, and peroxyacetyl nitrate, as well as a suite of volatile organic compounds to characterize contributions to total reactive nitrogen in Rocky Mountain National Park from Front Range sources and long-range transport. Observations during this intensive study suggest impacts from agricultural and oil and gas regions as well as urban areas to the east. Ammonia concentrations exhibited a complex diurnal pattern, confirming the need for a multifaceted approach to better understanding their behavior. A more complete nitrogen deposition budget will be presented for RMNP.

Investigating 75,000 Years of Hunter-Gatherer and Animal-Herder Seasonal Migrations in Poland's High Tatras and Foothill Lowlands: Evolving Archaeology Field Studies in RMNP's sister-park, Tatra National Park Poland

Robert **Brunswig** (University of Northern Colorado), robert.brunswig@unco.edu

Nearly two decades of archaeological research in Rocky Mountain National Park and its neighboring region documented systematic patterns of economic and religious use of Colorado mountain interior valleys and high tundra extending back as early as 13 000 years. Over the past several years, the author has, in collaboration with Jagiellonian University's Institute of Archaeology (Krakow), been developing a field research program in RMNP's Polish sister-park, Tatra National Park Poland. This presentation details the proposed project, which draws on archaeological mountain landscape research methods pioneered in RMNP and links a two-decade foothills and low-mountain research program, the Dunajec Project, directed by Professor Pawel Valde-Nowak, with pending research in Tatra Park. Together, the author and Valde-Nowak anticipate the start of advanced field studies and archaeological landscape modeling of past seasonally migratory (transhuman) hunter-gatherer and pastoralist-early farming communities in Poland's western Carpathian Mountains within the next two years.

Keywords: *archaeology, sister-park, Tatra National Park Poland, international collaboration*

Integrating a Citizen Science Project into a High School Science Curriculum

Brett **Butera** (Denver Public Schools), brett_butera@dpsk12.org

Citizen science is a research tool that can provide insightful data to inform management decisions while also enhancing ecological awareness and fostering the development of environmental stewardship among participants. A group of Denver area high school students and their teachers are participating in a forest-monitoring citizen science project. These citizen scientists aim to track change over time in RMNP subalpine forests to help RMNP managers better understand how trees species are migrating across the landscape to track suitable habitat in a changing mountain climate. This presentation describes the educational resources that have been developed to teach students the prerequisite background knowledge and skills that are necessary to conduct a forest-monitoring citizen science project.

Keywords: *citizen science, high school students, forest monitoring, tree species migration, educational resources*

State of Knowledge of Rocky Mountain National Park's Wetlands

David J. **Cooper** (Colorado State University), david.cooper@colostate.edu

Wetlands occur at all elevations in Rocky Mountain National Park (RMNP), and include willow dominated floodplains of the Colorado River, sedge dominated fens in the subalpine zone, and snowmelt dominated meadows and marshes on Trail Ridge. In their natural state, all RMNP wetlands share the characteristic of having seasonally or perennially saturated soils in most or all years. The wide range of environments where wetlands occur in RMNP supports tremendous biodiversity that contributes significantly to RMNP's overall ecological functioning and the important ecological services provided. Over the past 150 years, modifications to the region by humans have changed stream and ground water hydrologic regimes, and altered vegetation and ungulate grazing regimes. The park still supports high biodiversity, but several factors should be addressed to learn more about and restore the ecological condition of the park's wetlands. These include (1) restoration of hydrologic regimes disturbed by the Grand Ditch water diversion, as well as drains and ditches that still exist in the lower valleys, (2) rebalancing the intensity of browsing by large ungulates on riparian willows so that beavers can be restored to the multitude of valleys where they are now functionally extirpated, (3) addressing the significant population of moose that is having a major effect on riparian vegetation, and (4) continue to understand the potential effect of climate change on snowpack, ground water recharge, and stream flows that could influence all of the park's wetlands. RMNP has been a leader in the study and management of wetlands, and was one of the first parks in the west to implement a significant wetland restoration project, Big Meadows in 1989. Continued collaboration between RMNP staff and the scientific community is vital to learn more about the park and to collect the most rigorous data sets for use in resource management and restoration.

The Importance of Monitoring Resource Impacts from Emergent Activities: Lessons from Bouldering Use in the Bear Lake Road Corridor

Ashley **D'Antonio** (Oregon State University), Christopher Monz (Utah State University), Abigail Kidd (Utah State University) and Robin Graham (Utah State University)
Corresponding author: ashley.d'antonio@oregonstate.edu

Visitor activities in parks and protected areas can cause resource impacts, such as vegetation and soil damage, at varying levels and extents. Certain recreational activities—those that, by their nature, require off-trail access like fly fishing, rock climbing, and bouldering—often create a series of associated informal trails and visitor-created sites. Rocky Mountain National Park (ROMO), particularly the Bear Lake Road Corridor, is a popular destination for such activities. The formation of resource impacts can negatively influence both the ecology of the area and the recreational experience of visitors. In 2015, spatial data on the degree and extent of resource impacts was collected in ROMO in the Bear Lake Corridor at destinations where off-trail activities were occurring at high levels. This study focused on the bouldering areas near Emerald Lake and around Lake Haiyaha in Upper and Lower Chaos Canyons. A node and linkage system of resource impacts, organized around bouldering locations, was observed at both the Emerald Lake and Lake Haiyaha areas. Resource impacts were moderate to severe, with the Emerald Lake bouldering areas containing highly impacted sites and the Lake Haiyaha area containing a significant network of informal trails. Most importantly, many of the resource impacts discovered in 2015 have formed since an intensive survey of resource impacts was conducted in the Bear Lake Road Corridor in 2008/2009. This suggests that rapid ecological change can occur in sensitive locations as a result of new and emergent recreation use and emphasizes the need for continued monitoring.

Keywords: *resource impacts*, *monitoring*, *bouldering*

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

Robert N. **Dean** (Auburn University) and Isabella A. Oleksy and Daniel W. Bowker (Colorado State University)
Corresponding author: deanron@auburn.edu

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 natural resources. Printed circuit board (PCB) technology is a mature technology used in almost every electronic device. It is excellent 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 being applied to many environmental and agricultural applications, including soil moisture content measurement, pollution detection, drought monitoring in estuaries, and saltwater intrusion detection in coastal areas. For this study, PCB sensor technology is being investigated for monitoring electrochemical changes at four alpine lake ecosystems in the Loch Vale Drainage at Rocky Mountain National Park resulting from precipitation changes over five years. The lakes are The Loch, Sky Pond, Andrews Tarn and Lake of Glass. Water samples were collected in August 2016 and tested in the laboratory with a specially designed PCB sensor suite to determine a baseline for the five-year study. This presentation will discuss the application, the sensor suite developed for this application, and the results of the baseline testing.

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

Plains to the Park: Integrating STEM Initiatives into National Parks

Dan **Cribby** and David Kline (Westview Middle School),
Scott Esser (Rocky Mountain National Park), Melinda Merrill (Estes Park Environmental Center)
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Plains to the Park is a park-based 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 NP and the Estes Park Environmental Center. Since the summer 2014, students, teachers and park staff have participated in a two-week STEM Academy at Westview Middle School and within Rocky Mountain NP. Students and teachers worked with CDRLC staff and volunteers to learn scientific methods and collect data in Horseshoe Park to answer the questions “Who lives in this place?” and “How is that changing over time?” For two weeks each July, 14 middle school citizen scientists used standardized protocols as they conducted research on wildlife populations. Students learned scientific field skills and gained experience using trail cameras, GPS units, and field guides. In addition to citizen scientist crews, students work as film-makers to document the experience and findings.

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

Mercury in Fishes from Yosemite (CA), Mount Rainier (WA), and Rocky Mountain (CO) National Parks: Potential Drivers and Ecological Risk

Colleen **Flanagan Pritz** (NPS Air Resources Division), Collin Eagles-Smith (USGS), James Willacker (USGS), M.A. Lutz (USGS), M.T. Tate (USGS)
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The National Park Service (NPS) safeguards over 400 special places for the protection of unique natural resources and scenic beauty. Although celebrated as some of the most pristine ecosystems, recent studies have documented the presence of mercury in fish from NPS units across the western U.S., including Mount Rainier (MORA; WA), Rocky Mountain (ROMO; CO), and Yosemite (YOSE; CA) national parks. Even protected areas, such as national parks, are subjected to mercury (Hg) contamination because it is delivered through atmospheric deposition, often after long-range transport. Total mercury (THg) was measured in 1,176 fish comprising six species that were collected from 2003–2012 across 50 subalpine lakes and rivers at MORA, ROMO, and YOSE. Across all sites, fish muscle mercury concentrations ranged from approximately 3.0 to 1,865 ng/g wet weight (ww), with a mean of 100.5 ng/g ww. We applied a mixed-effect model to control for species and length and compare year-specific, size-standardized THg muscle concentrations (ng/g ww). Results indicate that THg concentrations in fish varied substantially among and within parks, suggesting that landscape factors may be particularly important determinants of Hg risk in the parks. THg concentrations in fish also varied significantly among years. Mean catchment parameters thought to influence fish THg concentrations were calculated for each basin and landscape models were utilized to determine drivers in fish Hg concentrations. The most parsimonious model explaining least-squares mean fish THg concentrations in MORA, ROMO, and YOSE contained soil Hg, evergreen forest, basin area, and basin-averaged Hg deposition (μg Hg/m^2). The models' significance is driven by soil Hg and evergreen forested area, suggesting that landscape variables are ultimately more important in determining fish THg concentrations than wet deposition of mercury.

Keywords: *subalpine lakes*, *mercury*, *fish*, *drivers*, *soil*, *forest*, *deposition*

Clonal Plant Response to Disturbance in the Tatras, Central Europe

Scott B. **Franklin** (University of Northern Colorado), Jozef Šibík (Slovak Academy of Sciences) and Paweł Olejniczak (Polish Academy of Sciences)
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We examined clonal plant response to disturbance in the Tatras Mountains, Slovakian-Polish border, at both the community and population levels. We hypothesized that communities in canopy gaps had greater dominance and foraging of clonal species than those in large windthrows and greater diversity due to the greater heterogeneity of the canopy gap communities (such environmental heterogeneity should favor clonal plants over non-clonal plants). We collected 10 plots (10X10 m) of data from four disturbance site types (DR = windthrow and not salvaged; DS = windthrow salvaged; NF = Forest without gap; NG = forest with canopy gap) in both Slovakia and Poland. Data included cover of all species, heterogeneity data and clonal connectedness data (through dye experiments on three species). Mean and maximum number of ramets and distance between ramets for *Calamagrostis villosa*, *Vaccinium myrtillus*, and *Rubus idaeus* suggest little difference among treatments. Based on the variance to mean ratio as a measure of heterogeneity, windthrow sites that were not salvaged had the greatest heterogeneity and all other sites had similar heterogeneity. Further, heterogeneity was driven by litter and woody debris as live grass and herbaceous vegetation heterogeneity were similar among sites; however, both herbaceous and grass heterogeneity were noticeably less in forests without gaps, suggesting that treatment had the lowest heterogeneity. Based on these data, forest sites without gaps seem to have a greater number of *Calamagrostis* ramets with shorter distances between ramets, while all other treatments had greater maximum distances among ramets, suggesting a greater amount of long-distance foraging by *Calamagrostis* individuals in treatments with more heterogeneity. This trend also appears true for *Rubus*, at least for disturbed treatments (i.e., windthrow), supporting our hypothesis. Preliminary data also support fewer species found in the least heterogeneous treatment (i.e., forests without gaps).

Keywords: *disturbance, clonal plants, windthrow, High Tatras Mountains, forest, Slovakia, Sister Park*

Restoration of the Grand Ditch Breach in the Upper Kawuneeche Valley: Phase II

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The Grand Ditch, a trans-basin water diversion canal, breached its bank on May 30, 2003, causing extensive alterations to the upper Kawuneeche Valley area in Rocky Mountain National Park (RMNP), Colorado. The breach caused a mud- and rock-slide into Lulu Creek and the headwaters of the Colorado River, damaging upland, stream, riparian, and wetland habitat over an approximately 2.4-kilometer distance and 9-hectare area. In accordance with the Record of Decision, a tie-back anchoring system has been installed to stabilize the slope in Zone 1A including soil-nail anchors, steel mesh, and a reinforced earth cap to reduce raveling of slope face materials. In 2017 and 2018, the Environmental Impact Statement Alternative D, the NPS Preferred Alternative, will be implemented for the restoration of ecological processes. Restoration will emphasize the removal of debris deposits in the alluvial fan area and Lulu City wetland. Actions will stabilize slopes and banks throughout the upper portions of the restoration area. Hydrology through the Lulu City wetland will be restored in the historical central channel, relying on the historical channel to transport river flow. Small-scale motorized equipment will be employed for stabilization and revegetation activities, including excavation of large debris deposits and reconfiguration of the Colorado River through the Lulu City wetland.

Restoration activities will be conducted primarily in the summer, June through September. Mechanized equipment will be flown in and out using helicopters. Restoration activities may include streamflow diversions to adequately dewater areas to allow restoration actions, including mitigation measures to minimize impact on water quality, wetlands, and aquatic species. Restoration will include planting of sedge divisions from salvaged sod, seeding upland areas and tall willow planting in compliance with the park's Vegetation Restoration Management Plan; exotic plant species will be treated in compliance with the park's Exotic Plant Management Plan.

Quantifying Montane Riparian Canopy Structure Using Terrestrial Lidar Scanning

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Many critical ecological functions directly relate to the canopy structure of riparian willow communities in Rocky Mountain National Park (ROMO). Canopy structure and height is a key determinant of habitat suitability for beaver, birds, and other taxa, and while structure differs among willow species, with plant age, and along hydrologic gradients, ungulate herbivory is a key determinant of structure in many ROMO riparian areas. Ongoing monitoring as part of ROMO's elk-vegetation management plan assesses canopy structure, but methods are time consuming and difficult to effectively scale up to larger areas. This study is using terrestrial lidar scanning (TLS) to extract key canopy characteristics. TLS produces highly accurate and detailed 3-dimensional point clouds that are being used to quantify structural attributes including willow canopy height and volume. These data compliment manual methods for characterizing willow structure and provide an important tool for calibrating assessments of riparian structure using aerial lidar data.

Lessons Learned About Chronic Wasting Disease in Elk at Rocky Mountain National Park

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Two key studies at Rocky Mountain National Park, Colorado, (ROMO) have begun to describe 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 the early 1980s. By the early 2000s, ~50% of female elk found dead tested positive for CWD. The first study evaluated rectal biopsy as an antemortem CWD diagnostic test and estimated CWD prevalence. Rectal biopsy, while useful to investigate disease ecology and estimate prevalence, is not reliable for early detection of CWD. Immunohistochemistry of rectal biopsy yielded a test sensitivity of ~70–85% depending on the stage of disease, prion genotype, and number of follicles observed. After including CWD-positive animals that died with disease within 24 months after misdiagnosis, we found a disease prevalence of ~13% (8-19%; n=136) in 2008. Additionally, we estimated that the population growth rate in female elk was flat to declining (λ=~1.0) and that CWD can exceed natural rates of mortality, reduce adult female survival, and decrease population growth of elk.

The intent of the second study was to more closely investigate disease dynamics in ROMO elk. Preliminary results support findings 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 the park and now exhibit much lower densities within the park. The effects of this on CWD prevalence are unclear; movement may spatially dilute disease across the landscape or may effectively reduce disease transmission pressure. We have a preliminary estimate of prevalence for 2012–2016 of ~8.5% (4.6-13.3%; n=138).

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

Peak Use: Visitor Use and Monitoring on High Elevation Peaks in Rocky Mountain National Park

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Reaching the summit of high elevation mountain peaks is a highly sought-after visitor experience in Rocky Mountain National Park, with total ascents of iconic Longs Peak nearing 10,000 yearly. With high visitor use levels comes the potential for degradation of ecological conditions, as well as decreases in the quality of the visitor experience. Of particular concern as visitor use increases, are threats to visitor safety associated with crowding on narrow, exposed sections of trail.

We will discuss research conducted at Longs Peak in July 2015 and Twin Sisters in July of 2016. These two assessments of high elevation peaks used automated trail counters and cameras as well as GPS tracking methods to better understand visitor use levels and behaviors. Results from 2015 collected on Longs Peak indicate that certain locations on the hiking route, including the Keyhole, Trough, and Homestretch, are experiencing relatively high densities of visitor use that roughly correspond with potential areas of safety concerns and potential visitor experience issues. Results from 2016 collected on Twin Sisters reveal that many extremely steep informal trails have been created by visitors attempting to navigate around the 2013 landslide that washed out portions of the Twin Sisters trail. Higher visitor use densities are also occurring in this area, creating potentially unsafe situations associated with steep slopes and eroded sections of trail. Data suggest that thresholds of crowding may be important for management, especially on the Keyhole Route. Other management implications include improvements to visitor enumeration and use planning, and visitor management in the context of landscape-scale natural disturbances such as landslides.

Keywords: *visitor use, management, GPS tracking, mountain summits*

Benthic Invertebrate Response to Climate and Environmental Change in the Colorado Rocky Mountains during the Recent Past

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A paired study of high elevation lakes in glaciated and unglaciated catchments in Rocky Mountain National Park is being conducted to: 1) elucidate the degree to which glacial meltwater input is dampening the effect of elevated summer temperatures on the chironomid communities present; and 2) document the magnitude and rate of climate change as evidenced by variations in larval chironomid assemblages during the late 20th and early 21st centuries. Five pairs of short cores collected from alpine and subalpine lakes have been dated using 210Pb and analyzed for sub-fossil chironomid remains and sediment geochemistry, including total N, total C, δ13C and δ15N. In addition, the analysis of the δ15N and δ18O of water, snow and ice samples collected at the study lakes as well as from inflowing streams will be used to help characterize the relative contribution of glacier and year-of-snow melt to each lake basin. Comparing the chironomid assemblages found in lakes in glaciated catchments to those in lakes in unglaciated catchments, with variations in elevation, geology, and vegetation controlled for, will enable an assessment of the relative role that meltwater plays in shaping chironomid communities in alpine lakes in RMNP.

Keywords: *climate change, paleolimnology, paleoecology, biogeography*

Large-scale Willow Restoration in Moraine Park

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The Fern Lake Fire in the fall of 2012 had a dramatic effect on riparian willows in Moraine Park. Our previous research found that 91% of the over 1,400 randomly sampled individuals exhibited 100% canopy loss. Forty-five percent of sampled willows resprouted from the base. However, resprouting willows had high intensity browsing in both summer and winter. Burned and resprouting willows inside exclosures had a greater chance of survival. The fire also affected willow seed production in Moraine Park and resulted in extremely low seed rain density. To assist the post-fire recovery of the willow stands, we initiated a large-scale active restoration in the summer of 2015. A crew from Colorado State University, working with Rocky Mountain National Park staff, planted over 7,500 willow stakes within five exclosures, focusing on areas where the historical depth to groundwater in mid-August had been less than 90 cm. We monitored 751 randomly selected willow stakes across all exclosures in fall 2015, and spring and fall 2016. We assessed stakes for survival, presence or absence of *Cytospora*, counted the number of shoots, and measured plant heights and longest shoots. By fall 2016, willow survival was 61% and varied by exclosure. *Cytospora* infection affected 17% of willow stakes. Live stakes ranged in height from 49 to 147 cm and mean height increased from 51 cm in 2015 to 62 cm in 2016. The number of new shoots per stake nearly tripled between 2015 and 2016, with stakes averaging 4.4 shoots in 2015 and 11.7 shoots in 2016. Overall, our monitoring has demonstrated that over two growing seasons the willows that have survived are thriving.

EPA National Wetlands Condition Assessment

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Wetlands are a vital component of our nation's waters, providing a wide array of benefits that contribute to the overall health and integrity of aquatic ecosystems and the well-being of the public. Although the important benefits of wetlands are understood, very little is known about their actual ecological health. The U.S. Environmental Protection Agency's (EPA's) National Wetland Condition Assessment (NWCA) is a statistical survey that begins to address some of the gaps in our understanding of wetland health by providing information on the ecological condition of the nation's wetlands and stressors most commonly associated with poor wetland conditions. The NWCA examines the chemical, physical, and biological integrity of wetlands through a set of commonly used and widely accepted indicators. PG Environmental is the prime U.S. EPA contractor that was tasked to sample 364 NWCA sites across the country in 2016. The 2016 sampling included two reference condition wetlands within Rocky Mountain National Park.

Keywords: *wetlands, national assessment, EPA, NWCA, reference wetlands*

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

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Over the past five years, the Center for Mountain and Plains Archaeology at Colorado State University examined 39 ice patches in the Arapaho-Roosevelt National Forest (n=15) and Rocky Mountain National Park (n=24) of the Colorado Front Range, USA. Culturally associated ice patches have proven rare, although many 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 our on-going 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: *ecology, archaeology, glacier, ice patch, Native American, climate change*

Overview and Trends of Visitor Use at RMNP

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Visitation to Rocky Mountain National Park (RMNP) has grown dramatically in recent years, increasing from fewer than three million visits in 2010 to well over four and a half million visits in 2016. This increase in visitation has led to a number of park management issues associated with resource protection, visitor experiences, transportation systems, visitor safety and law enforcement, and park operations and administration. To better understand the scope of information available to address these issues, RSG conducted a literature review of visitor use-related social science studies and compiled visitor use-related data for RMNP. This presentation provides 1) background on the breadth and content of visitor use-related social science studies conducted in RMNP and the potential for studies to inform park management decisions, and 2) an overview of the trends in visitor use at RMNP and in the RMNP region. Reviewed social science studies focus on visitor characteristics, visitor use patterns, recreation ecology, and transportation. Compiled data characterize visitation to the park as a whole and specific regions within the park, transportation system use, trail use, and socioeconomic factors. This talk will set the stage for the presentations that follow which include: the history of climbers and stewardship on Longs Peak, visitor monitoring on high elevation peaks, monitoring visitor use impacts, and the application of visitor use research two case studies from RMNP.

Keywords: *Visitor Use; Social Science; Transportation*

The Application of Visitor Use Research: A Case Study on Preventative Search and Rescue efforts in Rocky Mountain National Park

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Longs Peak, an iconic 14 thousand foot peak in Colorado, attracts tens of thousands of visitors each year that attempt to climb to its summit. These visitors vary in skill and outdoor recreation background and a small percentage of these visitors end up needing NPS assistance in the form of a search and rescue (SAR). In this presentation I will discuss how data collected on SAR incidents and overall visitor use on the peak spurred the creation of a preventative search and rescue (PSAR) program. Components of this discussion will focus on PSAR efforts to include formal PSAR presentations, the use of digital media, and educational foot patrols on the mountain. In addition, preliminary data on the progress of the project will be presented.

Keywords: *Longs Peak, Mountaineering, Climbing, Search and Rescue*

Grand Ditch Breach Restoration: Using Science to Inform Phase II

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On May 30, 2003, the Grand Ditch, a trans-basin, water-diversion canal in the northwest corner of Rocky Mountain National Park (RMNP) breached its bank. The breach saturated an adjacent hillslope which gave way, sending an estimated 47,000 cubic yards of sediment and debris into Lulu Creek and the headwaters of the Colorado River. Damage to 22-acres of upland, stream, riparian, and wetland habitat occurred over a distance of 1.5 miles. Over 20,000 trees were lost and approximately 50 different plant species were impacted.
Starting directly after the breach, RMNP partnered with local researchers and agencies to study the ecosystem components impacted by the breach. Colorado State University, the NPS Rocky Mountain Network Inventory and Monitoring Program, and the NPS Water Resources Division were key partners in the effort. The goal was to study and understand the ecosystem and then use science to design the best restoration possible. Furthermore, RMNP used an adaptive management based implementation strategy by breaking the restoration project into phases. This allowed the restoration treatments to be monitored and allowed for changes to be made if restoration goals were not met. Phase I of this strategy began in 2015. It included the restoration of a small segment of the Colorado River in the Lulu City wetland. Phase II of the ecological restoration includes the removal and redistribution of sediment and wood from Lulu Creek, the Colorado River, and Lulu City wetland, and is scheduled to begin during the summer of 2017.

Key words: *restoration, adaptive management, partnerships*

Wood Loads and Jam Spacing on the Upper Colorado River Rocky Mountain National Park

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Large wood in rivers and streams, as individual pieces and as aggregations in jams, creates important geomorphic complexity by altering channel form, substrate, hydraulics, and channel floodplain connectivity. A 2003 debris flow that initiated at Grand Ditch on the west side of Rocky Mountain National Park resulted in the mortality of approximately 20,000 trees along the Upper Colorado River corridor. In addition, a mountain pine beetle kill outbreak (peak in 2004–2006) introduced more trees into the system. We test the hypotheses that: 1) wood jams are more widely spaced downstream, 2) wood recruitment is greater, and 3) overall wood volume contributing to geomorphically effective jams is lower on the Upper Colorado River and Lulu Creek tributary relative to reference reaches. Instream wood was mapped and wood dimensions were measured along Lulu Creek and the Upper Colorado River in summer 2016. A total of 407 pieces greater than 1m in length and 10 cm in diameter, including 23 jams, were measured during initial field data collection. Preliminary results indicate that fewer jams exist along the Upper Colorado and Lulu Creek relative to least-altered reference reaches. We suspect that the high frequency of both natural and anthropogenic mass movements destroys jams, disperses wood along the length of the river corridor and renders it geomorphically ineffective. Additional research using remote imagery will assess changes in greenness index to quantify the wood loading from peak beetle kill die-off relative to wood recruitment resulting from the 2003 debris flow. Results of this analysis may be useful for restoration on the Upper Colorado River that may include artificial jams to reduce water velocity, enhance sediment and nutrient deposition, and create aquatic habitat.

Keywords: l*arge wood, jams, geomorphic complexity, Colorado River*

Citizen Science Past, Present, and Future at Rocky Mountain National Park

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We evaluated past and current citizen science projects at RMNP and assessed their applicability to identified park needs. We see a mismatch in current project data collection and data needs, but also some excellent examples matching projects with known data needs. For example, a stated need is the "Potential effects of limber pine loss in the park." The 2016 Limber Pine Population Protection and Cone Collection Study is well suited to provide the baseline data necessary to address this need. However, 67% (10/15) of the data needs identified do not align with current citizen science offerings. Some of these data needs may make excellent citizen science projects while others may not. We provide a few different rubrics that can be used at RMNP for assessing the applicability and approachability of park needs and how well citizen science might be suited to them. These rubrics include factors such as the simplicity of data collection protocols, resource availability and requirements, topics covered, Park Significance Statements, Fundamental Resources and Values (FRVs), and data needs. When looking at topics having dedicated management plans in place at RMNP, we see that 64% (7/11) have related citizen science projects that might be leveraged to help address these topics. Of the six topics not having past or current related citizen science projects, we see four (e.g., commercial horse use, bark beetles, trails, and wilderness/backcountry) as topics that might be well suited for future citizen science projects. We conclude by offering recommendations for park staff to assess citizen science projects and envisioning a future of citizen science at RMNP.

Keywords: *citizen science, place, conservation decision-making, meta-analysis*

Piscicide Effects on Macroinvertebrates in High Elevation Streams: An Initial Post-Treatment Evaluation

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By the early 1900s, native subspecies of cutthroat trout, *Oncorhynchus clarkii,* specifically greenback cutthroat trout (i.e., the state fish of Colorado), were at risk of extinction owing to habitat loss, unregulated fishing, and introduction of nonnative salmonids. Identifying, maintaining, and establishing genetically pure populations became and continues to be the primary management strategy for conservation of these subspecies. The elimination of competing nonnative salmonids such as brook trout has been accomplished through use of piscicides, namely rotenone. Furthermore, high elevation lakes and streams hold the best chance for establishing populations due to sufficient barriers which prevent fish movement, minimize human modifications (e.g., dams, developments), and reduce human intervention (i.e., bucket biology).

While rotenone treatments have been used for more than 70 years to eradicate nonnative fishes, the impacts of this piscicide on aquatic macro-invertebrates and amphibians is not fully understood and the duration of negative effects is vastly debated. Understanding the indirect effects of piscicides on aquatic macroinvertebrates (i.e., important fish forage items) is essential for ensuring healthy fish populations and significant for overall biodiversity and ecosystem processes of lakes and streams.

We developed a robust sampling design to test for short-term and long-term piscicide treatment effects on aquatic macroinvertebrates of mountain lakes and streams. Since 2014, we have collected pre-treatment samples from sites in Rocky Mountain National Park (ROMO; Mirror Lake and Cascade Creek) and Arapaho National Forest (ANF) including Herman Gulch. While no treatments have occurred in ROMO, the ANF streams were treated with rotenone in fall of 2015 and 2016. Here, we present initial results of the immediate post-treatment effects of piscicide on the ANF streams. Given similarities of the ANF streams to Cascade Creek, we will use these preliminary results to predict potential effects on the structure and function of aquatic macroinvertebrate communities within ROMO.

Keywords: *rotenone, greenback cutthroat trout, indirect effects, trout reclamation*

Expression of Geochemical Controls on Water Quality in Loch Vale, Rocky Mountain National Park

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Hydrologic processes in high alpine regions are dominated by snowmelt, making these systems highly susceptible to changes in the timing and magnitude of precipitation. Loch Vale, a high-elevation catchment in Rocky Mountains National Park, is one of such regions where changes in snowpack have large effects on water quality. The U.S. Geological Survey has studied this undeveloped watershed since the early 1980s. Using several decades of data collected at Loch Vale, the relationship between the concentration of rock weathering products and discharge at the site was examined to provide insight into the interactions between water availability and solute dynamics. Annual-scale concentration-discharge (C-Q) relationships showed hysteresis, which depended on the timing of peak discharge. Before peak discharge the concentration of weathering products was higher than after peak discharge. The observed pattern was consistent with accumulation of solutes in pore water followed by "flushing out" due to snowmelt. This study then compared C-Q relationships among years to see how these patterns changed over a longer time scale. Temporal trends in solute concentrations and flux were analyzed in the context of changing weathering rates associated with temperature increases and precipitation trends. Increased weathering reactions due to warmer temperatures would produce greater flow-normalized fluxes as more rock is exposed to weathering. Long-term changes in solute flux were also examined in the context of climate trends.

Keywords: *geochemistry, stream discharge, concentration-discharge relationships, water quality, Loch Vale, Rocky Mountain National Park*

Is the Front Range Alpine Vulnerable to Invasion by Non-Native Plant Species?

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Non-native plant invasions are a threat to ecosystems because of their ability to alter nutrient cycling and outcompete native plant species which provide important ecosystem services and aesthetic landscapes for recreation. Observations of non-native plants in the Rocky Mountain alpine are still rare, providing an opportunity to identify species of concern and study factors that could promote alpine invasions before invasions occur. Alpine ecosystems are thought to be resistant to invasion because non-native species at low elevations are not necessarily adapted to cold alpine temperatures and short growing seasons. However, climate, resource availability, and human activities are changing at high elevations in the Rocky Mountains, which may allow upslope range expansion. To assess the spatial distribution of invasive species across an elevation gradient and test key hypotheses about the feasibility of invasives moving upslope, we conducted a non-native species survey along five Front Range roads that extend into the alpine zone, and experimentally tested how temperature and resource availability could influence upward expansion of invasive cheatgrass (*Bromus tectorum*). First, the survey data allowed us to determine local upper elevation limits and distributions of non-native species in the Front Range. Second, we conducted growth chamber experiments with cheatgrass, an invasive species of local and regional concern. We tested how temperature and resource limitation affect cheatgrass germination, growth, and reproduction. We found that cold (current) growing season temperatures and spring freezing temperatures negatively affect growth and reproduction. Alpine soil also inhibited growth and reproduction compared to plants grown in subalpine soil. A nitrogen addition treatment (which simulated atmospheric nitrogen deposition) enhanced growth and reproduction of cheatgrass grown in the subalpine soil but not alpine soil. These results reveal that multiple factors in concert may influence upward range expansion of cheatgrass on the Rocky Mountain Front Range.

Keywords: *alpine, cheatgrass, invasive plants, non-native plants, nitrogen deposition, resource limitation, temperature*

Soil Amendments Can Encourage Establishment of Native Plants After Road Construction

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Disturbances such as road construction cause increased light and soil nutrients, which can foster establishment of invasive plants. In the revegetation process after construction of Bear Lake Road in Rocky Mountain National Park, we studied using soil amendments to give seeded, native perennial species an advantage over non-natives. The amendments were expected to: 1) increase soil moisture and reduce plant-available nitrogen (synthetic polymer incorporation); 2) increase soil moisture and decrease soil nitrogen (wood mulch blanket); and 3) decrease bulk density and increase slowly available nitrogen (yard-waste compost incorporation). Amendments were applied alone and in pairwise combinations to roadside slopes concurrent with hydro-seeding of native perennial grasses and forbs. We also conducted a paired greenhouse study with native and non-native grasses.

Mulch alone and combined with compost or polymer increased soil moisture after rainfall in the field ($p = 0.0007$) and after irrigation in the greenhouse ($p = 0.0001$). In the field, plant-available nitrogen was lower in soils of the mulch and mulch+ polymer treatments than in the compost treatment ($p = 0.0002$). Seeded species densities were highest in the mulch+compost treatment ($p = 0.03$, 2014) and mulch+polymer treatment ($p = 0.003$, 2015). Mulch decreased non-native density compared to the compost+polymer treatment ($p = 0.02$). In the greenhouse, mulch increased native grass growth relative to non-native grasses ($p = 0.002$) and decreased biomass across all species ($p=0.001$). Non-native growth was lower than natives in control ($p = 0.001$), polymer, and mulch soil treatments. In contrast, compost incorporation, which increased nitrogen availability in the field, greatly increased growth of all species in the greenhouse ($p < 0.0001$). These results demonstrate that mulch blanket alone or in combination with other amendments can favor native perennial species establishment and growth without stimulating non-native species by increasing soil moisture and decreasing soil nitrogen.

Keywords: *disturbance, revegetation, invasive plants, soil amendments, native plants*

Ecology and Epidemiology of Rocky Mountain Wood Ticks and Colorado Tick Fever

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Colorado tick fever is caused by a virus transmitted by the Rocky Mountain wood tick (*Dermacentor andersoni*, hereafter 'wood ticks'). The ecology of the wood tick and the virus in RMNP were well-described in the late 1970s and early 1980s, but research has been sparse since then. A recent publication suggested that wood ticks in northern Colorado are associated with sagebrush habitat and occur at 7200–7900 ft elevations, with near-zero abundance lower than 6,900 ft and higher than 8,200 ft. However, our preliminary research in Rocky Mountain National Park and northern Colorado in spring 2016 demonstrated that the wood tick's habitat distribution has been underestimated: we have located ticks at higher elevations (9100-9400 ft, Lawn Lake Trail, Deer Mountain, Hidden Valley) and in a broader range of habitat types (e.g., lodge pole pine forest, aspen woodland). Consequently, current ideas of risk maps for Colorado Tick Fever Virus are misleading.

Keywords: *infectious disease, zoonotic pathogen, tick ecology*

Monitoring Algal Productivity to Inform Spatiotemporal Alpine Lake Dynamics in Rocky Mountain National Park

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Colorado's northern Front Range alpine lakes provide critical habitats for animal and plant species. Since the 1960s, these lakes have experienced an increase in nitrogen and phosphorus depositions resulting in increased algal productivity. In the early 2000s, algal biomass has continued to increase despite relatively constant nutrient deposition. Excessive algal productivity negatively affects water quality through eutrophication and the creation of anoxic events. We assessed the accuracy of Landsat 8 Operational Land Imager (OLI) in estimating chlorophyll-a levels compared to field measurements. The top performing model over the study period included pixels averaged near the collection point and predicted chlorophyll-a averaged by depth (RMSE = 3.1). Combination of the SWIR-2 Landsat 8 OLI band and the ratio of NIR/RED Landsat 8 OLI bands as predictor variables had the highest correlation to field measurements. Incorporating satellite data provided a comprehensive analysis that has potential to supplement field data collection methods. Although the use of Landsat 8 OLI data in modeling did produce coarse approximations of chlorophyll-a, it is still valuable to researchers for understanding general spatiotemporal trends. Overall, the model produced helps to give an indication of chlorophyll-a levels in all study area lakes and a tool to examine lakes in space and time on a larger scale than has been possible with field measurements.

Keywords: c*hlorophyll-a, eutrophication, Landsat, water quality, Random Forests*

Controls on Soil Respiration in a High Elevation Alpine System

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Plants and soil have a dynamic relationship in which each partner influences the characteristics of the other. In particular, soil organic matter impacts many important aspects of soil quality including soil structure, soil water-holding capacity, and nutrient availability. These factors can, in turn, influence the type of vegetation that can grow in an area. Organic matter is removed from the soil primarily through microbial decomposition, the rate of which can be investigated through the measurement of soil respiration. The respiration rate depends on soil moisture and soil temperature, among other parameters. To investigate the relative influences of soil moisture and soil temperature on soil respiration, 12 study sites were established in June 2015 in Rocky Mountain National Park. Sites were distributed across three plots with distinct vegetation and soil regimes: 1) Conifer forest at the upper limit of the tree line, 2) Tundra characterized by shallow soil and minimal vegetation, 3) Tundra characterized by organic-rich, deep soil and abundant vegetation. Soil respiration, soil temperature, and soil moisture were measured weekly throughout the snow-free period of 2015 and 2016. Soil temperature was positively correlated with soil respiration across the study sites. Soil CO_2 flux was also significantly related to the interaction of soil moisture*plot and soil temperature*soil moisture (positive relation). Soil respiration rates were significantly different from one another in all plots and were highest in the forest plot and much lower in the two tundra plots. These data suggest that as the alpine climate warms, an increase in soil temperature and a longer snow-free period may result in an overall increase in the rate of soil respiration, which could alter the soil carbon pool and could impact the overlying vegetation community.

Keywords: *soil respiration, climate change, soil organic matter*

Using Structural Equation Modeling to Link Human Activities to Wetland Ecological Integrity

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The integrity of wetlands is of global concern. A common approach to evaluating ecological integrity involves bioassessment procedures that quantify the degree to which communities deviate from historical norms. While helpful, bioassessment provides little information about how altered conditions connect to community response. More detailed information is needed for conservation and restoration. Here we illustrate an approach to addressing this challenge using structural equation modeling (SEM) and long-term monitoring data from Rocky Mountain National Park (ROMO). Wetlands in ROMO are threatened by a complex history of anthropogenic disturbance including direct alteration of hydrologic regimes; elimination of elk, wolves, and grizzly bears; reintroduction of elk (absent their primary predators); and the extirpation of beaver. More recently, nonnative moose were introduced to the region and have expanded into the park. Bioassessment suggests that up to half of the park's wetlands are not in reference condition. We develop and evaluate a general hypothesis about how human alterations influence integrity and then a specific model using ROMO wetlands. Bioassessment reveals three bioindicators that appear to be highly sensitive to human disturbance (HD): (1) conservatism, (2) degree of invasion, and (3) cover of native forbs. SEM analyses suggest several ways human activities have impacted wetland integrity. First, degradation is highest where the combined effects of all types of direct HD have been the greatest (i.e., there is a general, overall effect). Second, specific HDs appear to create a "mixed-bag" of complex indirect effects, including reduced invasion and increased conservatism, but also reduced native forb cover. Some of these effects are associated with alterations to hydrologic regimes, while others are associated with altered shrub production. Third, landscape features created by historical beaver activity continue to influence wetland integrity years after beavers have abandoned sites via persistent landforms and reduced biomass of tall shrubs. Our model provides a system-level perspective on integrity and provides a context for future evaluations and investigations. It also suggests scientifically supported natural resource management strategies that can assist in the National Park Service mission of maintaining or, when indicated, restoring ecological integrity "unimpaired for future generations."

Keywords: *beaver, ecological integrity, human disturbance, SEM, ungulates, wetlands*

Design and Construction of the Grand Ditch Breach Slope Stabilization (Zone 1A)

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The Grand Ditch, a trans-basin water diversion canal, breached its bank on May 30, 2003, causing extensive impacts to the upper Kawuneeche Valley area in Rocky Mountain National Park (RMNP), Colorado. Erosion of the steep hillside immediately below the Grand Ditch resulted in instability of this slope. RMNP and its contractors, in cooperation with the operator of the Grand Ditch, evaluated alternatives for slope stabilization, investigated local subsurface conditions, planned the stabilization design and implementation, and constructed a tie-back anchoring system to stabilize the slope. The project team evaluated potential slope stabilization alternatives and chose reinforced soil slope (RSS) stabilization for the upper portion of the slope. The RSS was designed to be founded on existing soil and rock or on steel micropiles, depending on the depth of the bedrock. Below the RSS section, soil nails and steel mesh were designed to stabilize the slope.

After the initial design, geotechnical and geophysical investigations were completed to evaluate assumptions and modify the design as necessary. Based on these investigations, the limits of the micropile section were established, with the majority of the RSS founded on existing soil and rock. The depth and spatial density of the soil nails were established, with shallower and more widely spaced soil nails used on the lower portion of the slope. During the summer of 2016, RMNP and its contractor substantially completed construction of the slope stabilization in accordance with the design drawings. Testing during construction indicated a small portion of the slope where additional soil nails were required to meet the necessary design strength. The design was modified and the additional soil nails were installed. With slope stabilization complete, RMNP will implement restoration of ecological processes in the lower reaches of the impacted areas in the future.

Analyzing the Stability of Wood Jams in Rivers to Balance Ecological Health and Public Safety

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Accumulations of wood in rivers (wood jams) provide essential habitat for insects and fish, improve water quality, and increase the complexity of river channels, improving ecological health. However, wood jams also have the potential to pose a hazard to infrastructure and people. That potential depends on the nature of the infrastructure and human activity, but also largely on wood jam stability. Although river management increasingly includes efforts to retain and even place wood jams in rivers to improve river health, we must do so in a way that minimizes hazard. We are developing an effective strategy to determine the stability of wood jams in rivers to guide wood management. We are nearing completion of a set of guidelines that will utilize reproducible measurements, collaborative data gathering, and adaptive, context-aware statistical modeling to produce easily understandable predictions of whether wood jams are stable for given design flows. These guidelines include an assessment of wood jam location in relation to human activity in and around rivers; evaluations of ecological benefit, wood jam stability, and infrastructure hazard using field and remotely sensed data; and suggestions to manage wood jams given their potential hazard and ecological benefit. Wood jams are intrinsically complex and vary greatly among regions with differing hydrology and tree species compositions. To accommodate this variability, we use a statistical, internet-based stability analysis model that can be improved using new data submitted by managers and researchers. This model will communicate to users its applicability to their management scenario by evaluating the similarity between their sites and those used to build the model. Here, we focus on current findings regarding the factors that control wood jam stability and the framework we are developing to facilitate better informed wood jam management in rivers.

Keywords: *wood jam, stability, river, management, hazard, guidelines, ecological health, infrastructure safety, statistical model*

Detection of Ampicillin Resistant Bacteria in National Parks in the Contiguous United States

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Antibiotic resistant bacteria have previously been identified in environmental substrates such as soil, water, and wildlife. Environmental contamination by antibiotic resistant bacteria poses a serious risk to human health. In order to quantify potential human health risk, environmental assessments must first be conducted. This study sought to determine if antibiotic resistant bacteria could be found in soil and water in national parks across the contiguous United States. Soil and water were collected from multiple areas within 10 national parks and analyzed for ampicillin resistance. All parks yielded positive results and several human interaction variables were identified as important risk factors for the presence of antibiotic resistant bacteria in environmental samples. Risk factors were assessed to determine associations with presence of ampicillin resistant bacteria. Human density and latitude were determined to be important predictors of the presence of ampicillin resistant bacteria. Further assessments should be conducted to understand the extensiveness of environmental contamination. This study demonstrates a need to integrate public health practices with environmental conservation strategies within the national park system.

Keywords: *antimicrobial-resistance, microbiology, public health*

Evaluating Pile Burn Scar Restoration

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Invasive species threaten the natural resources national parks strive to preserve. The disturbance caused by common management practices on public lands can promote invasion of non-native plants. For example, foresters reduce hazardous fuels and manage forest structure by removing dead trees, piling the woody material, and burning it during the winter. This practice can destroy native plants and seeds and cause other changes under burn piles that favor invasive, non-native plants. Restoration has been suggested as a means to mitigate these impacts. The effect of restoring burn pile scars was studied at Lily Lake in Rocky Mountain National Park. While preliminary results showed that restoration increased the cover of native graminoids (grasses and grass-like plants) (mean % cover ± standard error for restored and unrestored, respectively: 11.19 ± 1.68 and 3.60 ± 0.70, $p = 0.003$) and native shrubs (5.05 ± 0.99 and 1.53 ± 0.70, $p = 0.002$), we were unable to detect a significant effect of restoration on non-native graminoids (0.94 ± 0.59 and 0.85 ± 0.52, $p = 0.91$) or non-native forbs (1.14 ± 0.52 and 4.24 ± 1.40, $p = 0.152$). Non-native graminoid cover was very low for all plots and likely indicates low invasion pressure. Non-native forb cover tended to be lower near the edge of scars, but high variation in control plots and the small number of samples in this study make it difficult to detect this effect statistically. Restoration is likely an important part of integrated pest management in pile burn scars. Coupling the benefits of increased native plant cover through restoration with other treatments such as herbicide application will enable managers to achieve greater success than reliance on a single means of control.

Keywords: *restoration, pile burning, invasive species, public land, fuel reduction*

Are Tree Species Migrating in Response to Recent (40 Years) Warming in Rocky Mountain National Park?

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Recent and projected climate change will create many challenges for species and ecosystems. For tree species, one of the primary challenges will be to follow suitable climate conditions for survival. Because temperatures cool rapidly with increasing elevation, species will need to migrate upslope a relatively short distance in order to track shifting climate. Nonetheless, the projected rate of warming is generally expected to challenge species' capabilities to track climate change over the next century. To gain insight into the ability of tree species to track climate changes in Rocky Mountain National Park (RMNP), we investigated the response of species to warming that has occurred in the park over the last 40 years. Specifically, we relocated and resampled approximately 300 forest plots on the east side of RMNP where forest characteristics, including species composition, were originally measured in the early 1970s by Robert K. Peet. By relocating and remeasuring these plots, we were able to test for changes in species distributions that might be associated with recent warming trends. We found that forest conditions and species distributions are changing but not in a clear, consistent response to warming. Ecological disturbance, topography, and the ecology of individual species are interacting with warming to create a complex landscape mosaic of system and species responses to climate change. In the context of ecosystem management, this research suggests that ecosystem adaptation to climate change will be contingent on a number of factors that will stress site specific management plans and adaptive management practices.

Keywords: *tree migration, global change, species distribution*

Impacts of Oil and Natural Gas Operations and Urban Emissions on Air Quality in Rocky Mountain National Park during FRAPPÉ

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The Front Range Air Pollution and Photochemistry Éxperiment (FRAPPÉ) occurred during July and August 2014. This study focused on characterizing and understanding summer air quality in the Northern Front Range Metropolitan Area (NFRMA) with an emphasis on ozone and its precursors. Exceedances of the National Ambient Air Quality Standard for ozone occur regularly in the NFRMA during the summer and impact air quality in Rocky Mountain National Park ROMO. As part of FRAPPÉ, the National Park Service supplemented long-term monitoring at its Longs Peak site (~9000 ft.) with enhanced trace gas and aerosol measurements; ozone and meteorological measurements were also deployed at a high altitude site off of Trail Ridge Road (~11,600 ft.). Additionally, whole air samples were collected along a route from Fort Collins, Colorado, up to Trail Ridge Road several times per week. Ozone distributions from Trail Ridge Road and Longs Peak generally tracked well temporally, with the highest ozone levels measured at the high elevation site; maximum hourly values during FRAPPÉ were 82 ppb and 79 ppb, respectively. A mixed signature containing both urban and oil and gas emissions was regularly observed in air masses encountered in the park, with elevated ozone and VOC levels measured during upslope events. On August 18–19, 2014, a major upslope event occurred in which trace gas and ozone levels were significantly elevated in ROMO. The peak hourly ozone value was 74 ppbv, while VOCs such as ethane reached approximately 10 ppbv, factors of 2 and 15 above typical background levels. The photochemical age estimate of the air mass transported to the park indicates a photochemical processing time of ~16 hours and points to oil and gas emissions as the driving factor for the elevated ozone levels observed during this event.

Keywords: *air quality, photochemistry, constituent transport, oil and gas production, urban emissions*

Monitoring the Effects of River Realignment on the Upper Colorado River, Rocky Mountain National Park

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A 2003 debris flow introduced 36,000 m^3 of sediment into a high-elevation wetland on the Upper Colorado River in Rocky Mountain National Park. As the first step in a larger restoration effort, park staff realigned a 100 m-long reach of the Colorado River into its historical thalweg in September 2015. Initial channel dimensions of the constructed segment were 1.6 m wide and 0.4 m deep with an average bed slope of 0.17. Pre- and post-restoration measurements are compared to assess the hydro-geomorphic response to the realignment within the 500 m-long Lulu City wetland. An earthen diversion berm constructed during the realignment has redistributed 80% of river flow from the pre-restoration west side to a central channel, which has altered surface water-groundwater interactions (hyporheic exchange) and sediment transport capacity. A sodium chloride tracer was injected during base flow and electrical resistivity was used to monitor changes in near-channel hyporheic exchange across the constructed channel for 24 hours following the injection. Concurrent surface conductivity measurements throughout the wetland were used to complete a tracer mass balance. Electrical resistivity analyses do not show significant changes in hyporheic exchange between pre- and post-realignment comparisons. However, conductivity analyses indicate local effects on solute retention, which serves as a proxy for hyporheic exchange. The channel realignment appears to have increased solute retention within the bifurcated flow at the head of the wetland, but has decreased system-wide solute retention. Furthermore, local incision greater than 1 m, widening of 0.2 to 1 m, and upstream knickpoint migration within the constructed channel during 2016 runoff indicate increased sediment transport capacity. These results suggest that the channel realignment has had localized, short-term effects on hyporheic exchange and sediment transport capacity. Long-term monitoring and increased instrumentation are required to predict how these changes may be amplified in a larger restoration attempt.

Keywords: r*iver restoration*, *hyporheic exchange*, *wetland hydrology*, *tracer test*

Climate Change Impacts Assessment of Boreal Toad (*Anaxyrus boreas boreas*)

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Four species of amphibian reside in Rocky Mountain National Park, including two frog species, one salamander species, and the Boreal Toad. Due to widespread declines in abundance and distribution, the Boreal Toad is considered endangered in Colorado. Historically in the park, Boreal Toads bred in at least 20 alpine lakes and wetlands, but now breed in only six. Declines in the park and elsewhere in the species' range have been attributed to the fungal disease, *Batrachochytrium dendrobatidis*, with infection resulting in the extinction of many local populations. Concern for this species has led to the annual monitoring of known and historical breeding sites. Disease is believed to be the proximate cause of most population declines, but other environmental factors may contribute to declines in populations and breeding site suitability. One candidate environmental stressor is increasing climate variability. Because Boreal Toads breed in shallow water habitats susceptible to drying, the suitability of a given wetland from year to year depends critically on the amount of precipitation accumulated through snow and summer rains. Additionally, Boreal Toads breed at high elevations, resulting in a narrow temporal window in the summer for tadpoles to metamorphose to the adult stage. In years with freezing temperatures in late summer or early in fall, many breeding attempts fail. Accelerating rates of climate change will lead to greater variability in the overall amount of precipitation, favor rain over snow events, and rising temperatures will increase evaporative losses to the atmosphere. All these events are hypothesized to exacerbate declines in breeding habitat quality. Warming temperatures will tend to increase the summer breeding window. In our research, we are evaluating how projected future climates will affect water availability and the summer breeding window in the Southern Rocky Mountains. These projections will be used to make inference to their expected effects on the quality, abundance, and distribution of Boreal Toad breeding habitats. We report on our preliminary findings and insights.

Keywords: *Boreal Toad, climate change impacts, subalpine wetlands*

The Application of Visitor Use Research: Case Studies from Rocky Mountain National Park

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Chaos Canyon and its surrounding areas of boulders provide climbers with a unique public enjoyment of Alpine bouldering rarely available in any other parts of the world. With this opportunity of recreation comes a variety of resource protection challenges. We will discuss how research conducted by scientists in the last several years focusing on Boulderers as a user group and their impacts on the Wilderness directed the park to implement a plan to first and foremost protect the resource and second to balance the recreational pursuit of alpine bouldering in Rocky Mountain National Park. Components of this discussion will include how we collected key natural and cultural resource information, provided a strategy to mitigate known immediate impacts for short term, facilitated collection of resource information, organized outreach to local and national climber user groups and others as identified, and identified other similar areas, less impacted, for use as a control reference.

Keywords: *alpine bouldering*

The Restoration of Lulu City Wetland: Phase I Preliminary Results and Current Restoration Designs

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The Grand Ditch breach in 2003 sent tens of thousands of cubic yards of sediment into Lulu Creek and the Colorado River, a portion of which was deposited in the Lulu City wetland. Data collection on wetland water table dynamics and vegetation composition indicates the need to restore the Lulu City wetland, as well as the Colorado River flowing through the wetland. A key goal of this restoration is the return of a meandering Colorado River channel with a hydrologically connected riparian zone that can support a complex of tall willow communities. The dispersed flow of water across the wetland, as the result of sediment deposition eliminated the historical channel connections and created conditions conducive to sedge marsh conditions due to the perennial saturation. To identify the excavation required within the wetland and ensure that the creation of a main river channel would lower the water table in places where it is currently too high, a Phase I pilot channel was excavated in the fall of 2015. This presentation will outline the results from Phase I as well as the preliminary designs for the Colorado River channel and restoration of the Lulu City wetland.

Vegetation Monitoring for Climate Change Effects in Rocky Mountain National Park and other NPS Units

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In 2009 the National Park Service (NPS) installed and monitored an alpine vegetation site in Rocky Mountain National Park (ROMO) using the methodology developed by the GLORIA network (Global Observation Research Initiative in Alpine Environments). The GLORIA network comprises approximately 50 alpine monitoring sites worldwide using the GLORIA protocol, which is a long-term monitoring method with a repeat monitoring interval of 5 years.

Since 2011, the NPS and the Colorado Natural Heritage Program have collaborated to install and monitor alpine sites in Yellowstone (YELL), Great Sand Dunes National Park and Preserve (GRSA), and at a site near Bandelier National Monument (BAND). The GLORIA sites in ROMO, GRSA, and YELL have each been monitored twice. An additional site installed and monitored by the US Geological Survey is located in Glacier National Park.

The primary objective of this project is to examine climate-induced changes of alpine vegetation cover, species composition, and species migration at ROMO and other NPS units along the latitudinal gradient of the Rocky Mountains in North America. We will give an overview of the GLORIA methodology being used in NPS units, the initial results from two years of monitoring data from ROMO, applications to Park management, and a roadmap for future monitoring of GLORIA sites in NPS units along the north-south gradient of the Rocky Mountains.

Hydrologic and Fluvial Organic Carbon Source-Sink Dynamics of Mountain Meadows Across Land-Use/Land-Cover Change Gradients

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Fluvial networks of mountain landscapes alternate between confined and unconfined valley segments. In unconfined reaches, river-connected wet meadows often establish, and recently have become recognized as ecological nexus points in mountain landscapes. These meadows are characterized by broad well-connected floodplains, high groundwater tables and extensive riparian corridors. Although comprising less than 25% of channel length in mountain fluvial networks, meadows such as these can store as much as 75% of fluvial and floodplain carbon, making bulk DOC source-sink dynamics in these meadows an important consideration in discerning carbon storage and cycling patterns. When beaver occupy these meadows the retention capacities of the fluvial system are particularly enhanced. Prolonged overbank flow promotes the formation of side-channels and ponds, maintaining high subsurface water levels, and enhancing water, sediment, carbon, and nutrient retention. In this research, we are quantifying hydrologic and carbon fluxes and retention and whole stream ecosystem metabolism along river segments of varying valley-confinement and beaver activity. Preliminary results suggest substantial differences between meadow types in hydrologic and carbon source-sink dynamics across the snowmelt hydrograph. These data and analyses should not only provide insight into fundamental catchment processes, but also highlight areas for targeted management strategies to improve river-floodplain function. Cumulatively, these meadows have the potential to provide important ecosystem services at the network scale, controlling water-carbon dynamics, transforming water quality, and attenuating floods and maintaining baseflows.

Keywords: *mountain hydrology, carbon cycle, biogeochemistry, water quality, floodplain meadow, climate change, park science, beaver restoration, source-sink dynamics, restoration*

Clark's Nutcracker Seed Use and Limber Pine Metapopulation Structure in Rocky Mountain National Park: Predicting Future Trends

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Clark's Nutcracker (*Nucifraga columbiana*) is an iconic species in Rocky Mountain National Park (RMNP) and the major seed disperser for limber pine (*Pinus flexilis*). This conifer exhibits a metapopulation structure: regional populations consist of local populations connected by seed dispersal. Threats for limber pine include mountain pine beetle (*Dendroctonus ponderosae*) outbreaks, larger wildfires, and especially exotic white pine blister rust (pathogen *Cronartium ribicola*). Extensive limber pine mortality may force nutcrackers to rely on alternative conifer seed sources.

In RMNP, we investigated the importance of alternative seed sources for nutcrackers, limber pine's metapopulation structure, and how subpopulation connectivity might be influenced by nutcracker spatial use. From 2014 to 2016, we examined: 1) cone production in stands of limber pine, ponderosa pine (*Pinus ponderosa*), and Douglas-fir (*Pseudotsuga menziesii*); 2) timing of nutcracker stand visitation; and, 3) nutcracker seed harvest and caching behavior. 4) We also constructed the RMNP limber pine metapopulation using GIS layers, and from 2015 to 2016 we radio-tracked nutcrackers.

We mapped limber pine component populations (n=32), which range from 6-400 ha in size with inter-population distances of 1-36 km (median=3 km). We observed nutcracker movements of 1-12 km (n=7 nutcrackers), indicating potentially high limber pine metapopulation connectivity even with a smaller nutcracker population. Annual variation in cone production influenced nutcracker foraging preferences and the transition timeframe. Each year starting in mid-late August, nutcrackers foraged extensively on limber pine seeds, which ripen in early September. In 2014 and 2015, nutcrackers transitioned to ponderosa pine seeds, which ripen in early October. In 2016, they transitioned to Douglas-fir seeds, which ripen in late September. With potential limber pine losses, we believe that alternative seed sources will support a nutcracker population, although carrying capacity may drop. We suggest that ponderosa pine will serve as an increasingly critical food resource if limber pine declines.

Keywords: *Clark's Nutcracker, limber pine, ponderosa pine, Douglas-fir, white pine blister rust, mountain pine beetle, metapopulation*

Changes in a Mixed Conifer Stand Following Prescribed Fire and Mountain Pine Beetle Outbreak in Rocky Mountain National Park

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Prescribed fire is a management tool used to reduce hazardous fuel loading and simulate the effects of naturally occurring wildfire. In 1998 permanent monitoring plots were established in the Beaver Meadows area to measure the effects of planned prescribed fire treatments. These plots were sampled prior to burning and periodically in the 16 years following treatment.

Five to eight years following prescribed fire treatment, the forested stands in which these plots are located were impacted by mountain pine beetle (*Dendroctonus ponderosae*). Bark beetles are native insects that have shaped the forests of North America for thousands of years. Recent outbreaks of mountain pine beetle (MPB) have resulted in extensive mortality of pines, particularly lodgepole pine, throughout the park.

Surface woody fuels were reduced by 83% immediately following the prescribed burn. However, as trees killed by MPB fell to the ground, coarse woody debris levels are now almost four times higher than initial pre-burn levels. Trees taller than 1.37 m (4.5 ft.) have been reduced by 86%. The opening of the canopy has had dramatic effects on understory vegetation, with shrub density measured in 2015 over 15 times higher than in 1998. Total herbaceous cover has increased by 8 times relative to pre-burn values.

The primary objective of the 1999 prescribed burn was to reduce fuel loading and decrease the risk of wildfire hazard. In the wake of the MPB outbreak, fuel loading (both dead woody material and live understory vegetation) has increased dramatically, greatly increasing wildfire hazard. Seedling regeneration suggests a shift from a pre-outbreak stand dominated by mature lodgepole pine and ponderosa pine to a more structurally diverse (unevenly aged) and compositionally diverse stand. These shifts in stand structure and composition will likely influence the type, extent, and severity of future disturbances.

Keywords: *disturbance*, *bark beetle*, *prescribed fire*

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

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