15th Biennial Scientific Conference
on the Greater Yellowstone Ecosystem

EXPANDING the SCOPE of SCIENCE TOGETHER

THE NEXT 150 YEARS..

May 15-18, 2022
MONTANA STATE UNIVERSITY
Bozeman, Montana

Sponsors

The 15th Biennial Scientific Conference on the Greater Yellowstone Ecosystem is hosted by Montana State University.

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Welcome

Dear Conference Participants,

Welcome to the 15th Biennial Scientific Conference on the Greater Yellowstone Ecosystem (GYE). Since 1991 this conference series has been a critical forum for sharing science between researchers, management partners, conservation groups, and other stakeholders with a common interest in understanding the natural and cultural resources of the region.

This year our theme is Expanding the Scope of Science Together: The Next 150 Years. Yellowstone's 150th birthday is a special occasion to reflect on the science and conservation accomplishments that have brought us to the present day, as well as a time to envision solutions for some of the grand challenges facing Greater Yellowstone's future. Our goal is that this conference will emerge as the preeminent forum for bringing together researchers and practitioners from academia, state and federal agencies, non governmental organizations, and tribal communities to discuss scientific findings and management needs associated with the Greater Yellowstone region.

For the first time in the history of this conference series we are partnering with Montana State University for an on-campus event. We are thrilled to be in Bozeman, Montana. Spending time in a recreation-based community that is inextricably linked to its surrounding federal lands will help to highlight our conference theme - and its state of the art conference facilities will facilitate efficient presentations and productive networking.

The conference programming is once again organized around concurrent sessions. For each time slot you can choose to hear science talks from a wide variety of disciplines.

This year we are introducing a new panel format with representatives from Indigenous Voices, Community Leaders, Agenda Administrators, and Working Scientists. Tom Olliff will be facilitating these conversations which look for answers to the following questions: 1. What does the GYE mean to you? 2. What are the greatest threats to the GYE and what actions can we take to address them? and 3. What are the greatest opportunities you see in the GYE's future?

These are consequential questions, and we believe that all attendees have a responsibility to connect with each other and to strive together for answers.

Thank you!

The Conference Program Committee
15th Biennial Scientific Conference on the Greater Yellowstone Ecosystem

15th Beinnial Scientific Conference Planning Committee

- Brendan Moynahan, NPS-Rocky Mountains CESU
- Bruce Maxwell, Montana State University
- Cathy Whitlock, Montana State University
- Charissa Reid, Yellowstone National Park
- Claudia Regan, US Geological Survey
- Dan Tyers, Gallatin National Forest
- David Diamond, National Forest Service
- Douglas (Gus) Smith, Grand Teton National Park
- Hillary Robison, Yellowstone National Park
- Holly McKinney, Grand Teton National Park
- Kitty Griswold, Idaho State University
- Kristen Legg, Greater Yellowstone I&M Network
- Libby Metcalf, University of Montana
- Naomi Schadt, Montana State University
- Paige Tolleson, Montana State University
- Walter Fleming, Montana State University
- Walter Fleming, Montana State University

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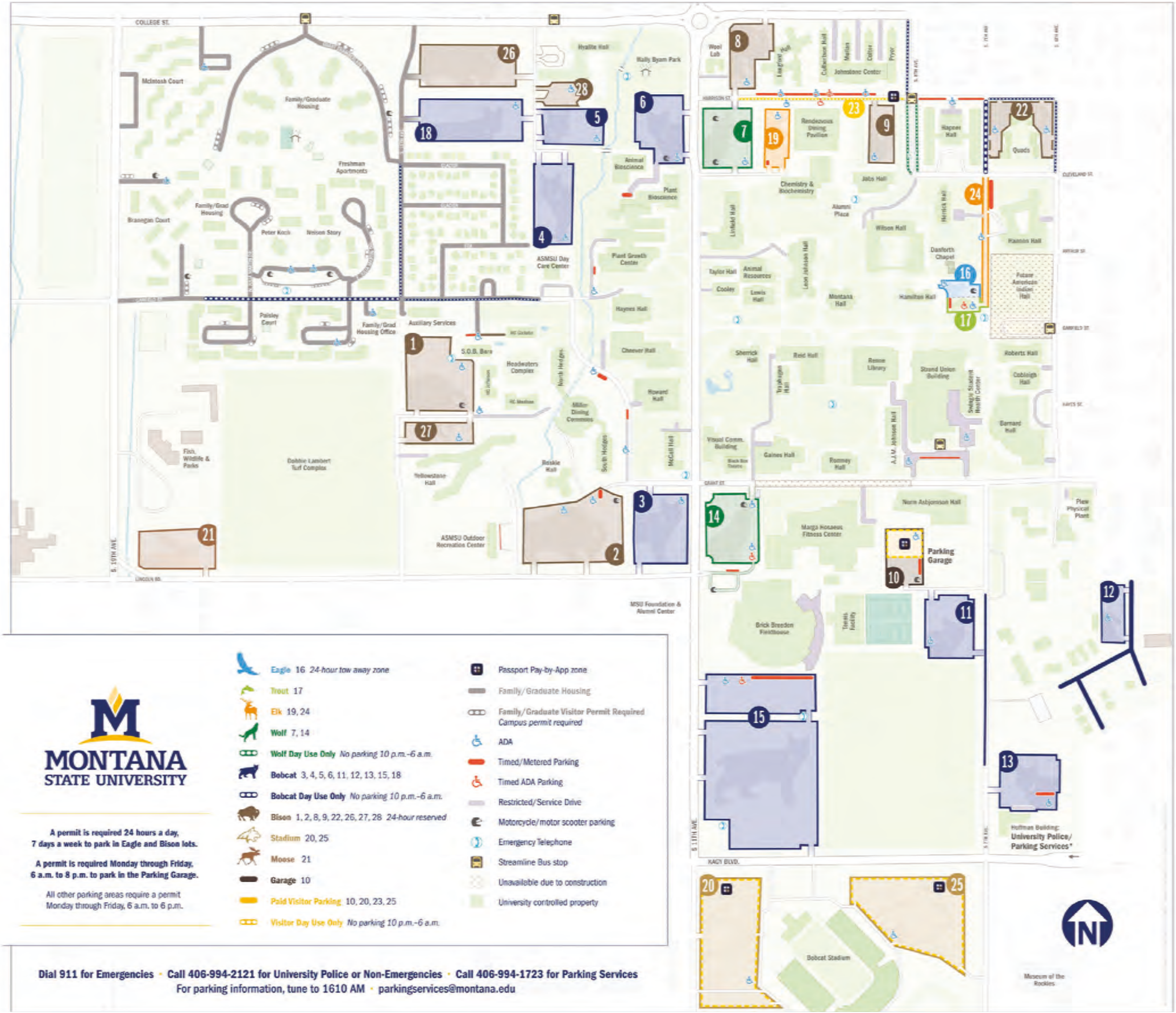

MONTANA STATE UNIVERSITY

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A permit is required Monday through Friday, 6 a.m. to 8 p.m. to park in the Parking Garage.

All other parking areas require a permit Monday through Friday, 6 a.m. to 6 p.m.

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- **Elk** 19, 24
- **Wolf** 7, 14
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- **Bobcat Day Use Only** *No parking 10 p.m.–6 a.m.*
- **Bison** 1, 2, 8, 9, 22, 26, 27, 28 *24-hour reserved*
- **Stadium** 20, 25
- **Moose** 21
- **Garage** 10
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Opening Keynote Panel

Dr. Waded Cruzado
President,
Montana State University

Since January of 2010, Dr. Waded Cruzado has served as the 12th President of Montana State University (MSU), Montana's largest institution, classified in the Carnegie Classification as one of 130 "Very High Research Activity" universities, one of 69 very high research institutions also recognized as a "Community Engaged University," and the only university to be very high research, community engaged, and very high undergraduate enrollment. As President of MSU, Cruzado has significantly reshaped the face and future of the state's first land-grant institution. An articulate and inspirational speaker on the role of land-grant universities, she has become a well-known champion of the land-grant's tripartite mission of education, research and public outreach.

In 2012, APLU awarded President Cruzado the Seaman A. Knapp Memorial Lectureship. In that same year, President Barack Obama appointed Dr. Cruzado to the Board for International Food and Agricultural Development (BIFAD), a seven-member advisory council to USAID, whose primary role is to advise on agriculture, rural development and nutrition issues related to global food insecurity and the eradication of hunger in the world. She has also been recognized as a Paul Harris Fellow by Rotary International. In 2015, President Cruzado received the Chief Executive HR Champion Award from the College and University Professional Association for Human Resources.

MSU has undertaken and completed numerous major construction and renovation projects since President Cruzado took office. MSU raised $10 million for a renovation of the end-zone of Bobcat Stadium, completing the fund-raising, design and construction phases of the project in under 10 months. MSU also established the new Jake Jabs College of Business and Entrepreneurship and constructed Jabs Hall, thanks to a $25 million donation. Most recently, MSU received a $50 million donation – the largest private gift in the history of the state. From this donation, MSU opened the Norm Asbjornson Innovation Center, an innovative laboratory and classroom facility for the College of Engineering, in December 2018.

President Cruzado serves on the board of the Association of Public and Land-grant Universities (APLU), American Association of Hispanics in Higher Education (AAHHE), American Council of Education (ACE), APLU's Commission on International Initiatives, Campus Compact, International Student Exchange Program (ISEP), PayneWest Insurance, Northwest Commission on Colleges and Universities (NWCCU), TIAA Hispanic Advisory Council, US Bank, and The Burton K. Wheeler Center.

Cameron Sholly

Superintendent, Yellowstone National Park

Cameron (Cam) Sholly assumed duties as the superintendent of Yellowstone National Park in October of 2018. Yellowstone is one of the largest national park operations in the world spanning 2.2 million acres and receiving over 4 million visits each year. The park has a team of over 1,000 employees and volunteers and an annual budget exceeding $60 million. Cam is a third-generation park service manager and began his National Park Service (NPS) career in 1990.

Upon arriving at Yellowstone, Cam worked with Yellowstone's team to set new strategic priorities for the park focused on the Yellowstone workforce, strengthening the Yellowstone ecosystem, delivering a world-class experience, investing in infrastructure, and building coalitions and partnerships. The park is currently in the process of completing a $40 million employee housing improvement project, expanding the bison conservation transfer program, combatting non-native species, developing a more focused approach to ecosystem management and climate change challenges, implementing a new strategy for managing increased visitation, and preparing to execute over $120 million in historic preservation and transportation projects as part of the Great American Outdoors Act. Cam is currently the chair of the Greater Yellowstone Coordinating Committee, an executive group of federal and state managers spanning three states within the Greater Yellowstone Ecosystem.

As midwest regional director, Cam oversaw the completion of the largest public/private partnership in NPS history, a $380 million renovation of the St. Louis Arch. As associate director, Cam implemented a system-wide national safety strategy to improve employee safety and revamped a wide range of major NPS policies and directives, including those that govern wilderness management, fire and aviation, and law enforcement.

Cam holds a bachelor's degree in management from Saint Mary's College of California and a master's degree in environmental management from Duke University. He is a graduate of the Harvard University Senior Executive Fellows Program and the FBI National Academy. He is a veteran of the U.S. Army and deployed to Operation Desert Storm in 1991.

Cam was awarded the Superintendent of the Year Award for the Southeast Region in 2011 and the Department of Interior's Meritorious Achievement Award in 2015 for his wide-ranging executive leadership actions.

Chip Jenkins
Superintendent,
Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway

Palmer "Chip" Jenkins, Jr. is the superintendent of Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway. He has more than 34 years of experience working in and leading national parks including working in 8 parks, two regional offices, the Denver Service Center and, NPS headquarters in Washington DC. He began his career as a seasonal ranger at North Cascades National Park. Chip graduated from the University of California at Santa Barbara with a bachelor's degree in geography and environmental studies and he is a graduate of the Department of the Interior Senior Executive Service Development Program.

Mary Erickson
Forest Supervisor,
Custer Gallatin National Forest

Mary Erickson is the Forest Supervisor for the Custer Gallatin National Forest, a highly diverse and highly valued 3-million acre national forest, with headquarters in Bozeman. She has been in this position since December 2007. During the summer of 2021, Mary served a 5-month detail for the Forest Service Washington Office as the Director of Ecosystem Management Coordination, overseeing planning, environmental compliance, adaptive management and monitoring programs for the agency. Mary is in her 39th year with the Forest Service. She also served as Forest Supervisor for the Fishlake National Forest in Central Utah, and Deputy Forest Supervisor, District Ranger, and Forest Planning Team analyst/economist on the Fremont-Winema in Southcentral Oregon. Prior to time with the Forest Service, Mary was a forester trainee, dispatcher, engine crew member, fire lookout, on a forest inventory crew and as a graduate research and teaching assistant.

Mary was born in Boise, Idaho and spent her youth in Alaska, Utah, Michigan, New York, and Wisconsin. She graduated from Oregon State University's College of Forestry with a BS in Forest Management in 1982 and a MS in Forest Economics in 1986. In 2013, Mary received OSU's Outstanding Alumni Award.

Mary is married to Frank Erickson, a retired BLM and Forest Service employee. They reside in Bozeman and have two daughters. Mary spends her free time gardening, hiking, camping, cycling, and skiing, and doing yoga to relax.

Jennifer Carpenter

Chief,
Yellowstone Center for Resources,
Yellowstone National Park

Jennifer Carpenter is the Director of the Yellowstone Center for Resources at Yellowstone National Park. Her professional careerspans 22 years and includes field and management positions in natural and cultural resource management operations and planning within the National Park Service(NPS) through the senior management level, including Associate Regional Director for Resource Stewardship and Science, Chief of Resources at Yellowstone National Park and Lassen Volcanic National Park, Chief of Planning and Compliance at Yellowstone, Grand Teton, and Bandelier National Monument, and NPS Washington Office of Legislative and Congressional Affairs, as well as private sector and state agency experience.

Jennifer has been with the National Park Service for 18 years. She currently leads the park's science and resource management division, the Yellowstone Center for Resources (YCR). The YCR is responsible for all science, natural and cultural resource management and planning, Native American affairs, as well as environmental policy, compliance, and social science for the park. It has over 55 permanent employees and approximately 50 seasonal employees. The YCR has a budget of approximately $11 million to provide for scientific research, management, and operations.

Jennifer served in Yellowstone from 2012-2019 and recently returned to the park in early 2022 from the NPS Regional Office where she was the Associate Regional Director for Resource Stewardship and Science for 85 NPS units across 8 states.

Jennifer has a Bachelor of Arts in Ecology and Evolutionary Biology from the University of Arizona and a Master of Science in Applied Ecology and Environmental Resources from Arizona State University. She is a graduate of Harvard's Senior Executive Fellows Program and recently received a certificate in Public Leadership from Harvard's Kennedy School of Government, Executive Leadership Program.

A. Starker Leopold Speaker: Cathy Whitlock, PhD

Dr. Cathy Whitlock is a Regents Professor Emerita in Earth Sciences at Montana State University and a Fellow of the Montana Institute on Ecosystems. Cathy is nationally and internationally recognized for her research and leadership activities in the field of climate and environmental change. Since the 1980s, she has been studying Yellowstone's environmental history by collecting sediment cores from lakes that provide information about past vegetation, fire, and climate. This research continues to the present day in Yellowstone and in comparable places around the world. During the course of her career, Cathy has trained dozens of undergraduate and graduate students to join her in the field of paleoecology. She is also an author of the Greater Yellowstone Climate Assessment (2021) and Montana Climate Assessment (2017), which describe the impacts of past and future climate change in the region. Cathy has received numerous awards and honors from professional societies and organizations, and in 2018, she became the first person from a Montana university to be elected to the National Academy of Sciences.

Superintendent's International Speaker: Frank van Manen, PhD

Bear research and management in the Greater Yellowstone Ecosystem has served as a bellwether for bear conservation efforts worldwide. In this presentation, Frank will explore how the coproduction model of science can help bridge research and policy in a complex decision environment, using the Interagency Grizzly Bear Study Team as a case study. He will further compare grizzly bear conservation accomplishments and challenges in the Yellowstone region with those of several bear species in other portions of the world, how those intersect with the global environmental challenges of our time, and how they relate to priorities of the Department of the Interior.

Geosciences Speaker: Bruce Fouke, Phd

Bruce W. Fouke is a professor in Geology, the Carl R. Woese Institute for Genomic Biology, and Evolution, Ecology, and Behavior at the University of Illinois Urbana-Champaign. He is Director of the Roy J. Carver Biotechnology Center and holds a Health Innovation Professorship in the Carle Illinois College of Medicine. Mammoth Hot Springs has long served as a natural laboratory for his geobiological studies of life-mineral-mineral interactions. Results have been directly applicable to better understand biomineralization processes in hot spring and coral reef ecosystems, astrobiology, the deep subsurface of the Earth's crust, Roman aqueducts, and the human body.

Aubrey Haines Speaker: Megan Kate Nelson, Phd

Megan Kate Nelson is a historian and writer, with a BA in History and Literature from Harvard and a PhD in American Studies from the University of Iowa. Her most recent book, The Three-Cornered War: The Union, the Confederacy, and Native Peoples in the Fight for the West (Scribner 2020) was a finalist for the 2021 Pulitzer Prize in History. She writes about the Civil War, the U.S. West, and American landscapes of memory for The New York Times, Washington Post, The Atlantic, Smithsonian Magazine, Preservation Magazine, and Civil War Times. Dr. Nelson was recently elected as a fellow of the Society for American Historians, "in recognition of the narrative power and scholarly distinction of her historical work." Scribner will publish her next book, Saving Yellowstone: Exploration and Preservation in Reconstruction America, in March 2022.

Agenda

Sunday	4:00-5:00PM	Registration/Poster Set-up		
	5:00-6:30PM	Opening Reception - Heavy Apps/Open Bar		
	6:30-8:30PM	Opening Remarks - Cruzado, Sholly, Jenkins, Erickson, Lacey, Carpenter (MC)		
Monday	8:00-8:30AM	Coffee Break - Sponsored by National Parks Conservation Association		
	8:30-9:50 AM	THREE QUESTIONS: Indigenous Voices: Spang Gion, Bull Chief, Doyle, Olliff (moderator)		
	9:50-10AM	Break		
	10:00AM -12:00N	ROOM 233	ROOM 235	MAIN BALLROOM
		UNGULATE & PREDATOR DYNAMICS	CLIMATE CHANGE I	COMPLEX ECOLOGICAL CHALLENGES I
		Moderator: Carpenter	Moderator: Pritchard	Moderator: Debinski
		Barker	Hostetler	Beever
		Meyer	Lunzer	Graves
		Cassidy, B.	Stahle	Kiel
		Metz	Turner	Berg
		Shawler	Thomas-Kuzilik	Rew
		Templin	Durney	
	12:00N-1:30PM	LUNCH		
	1:30-2:30PM	Leopold Lecture, Dr. Cathy Whitlock		
	2:30-4:30PM	ROOM 233	ROOM 235	MAIN BALLROOM
		LIVES ON THE WING & BEAR ECOLOGY	CLIMATE CHANGE II	COMPLEX ECOLOGICAL CHALLENGES II
		Moderator: Robison	Moderator: Thoma	Moderator: Beever
		Haines	Alt	Brooks
		Leavitt	Bloom	Painter
		Lozano	Heumann	McLaren
		Dittemore	Al Chokhachy	Durboraw
		Merkle	Gresswell	Dines
		Finnoff	Duff	Carlson
		Peterson	Dello-Russo	
	4:30-5:00PM	Break		
	5:00-7:00PM	Poster Presentations/Book Signing/Casual Dinner with Open Bar/Entertainment: Holler 'n Pine		
	7:00-9:00PM	Student Natural History Film Showcase		
Tuesday	8:00-8:30AM	Coffee Break		
	8:30-9:50 AM	THREE QUESTIONS: Community Leaders: Whitfield, Berg, Andrus, Olliff (moderator)		
	9:50-10AM	Break		
	10:00AM -12:00N	ROOM 233	ROOM 235	MAIN BALLROOM
		HUMAN DIMENSIONS	COMPLEX ECOLOGICAL CHALLENGES III	DO PROTECTED AREAS PROTECT WOLVES? 35 YEARS OF RESEARCH PANEL
		Moderator: Newton	Moderator: Whitlock	D. Smith, K. Cassidy, Carpenter, and G. Smith
		Santucci	Mumford	
		Anderson-Ramirez	Teichroew	
		Freeman	Sepulveda	
		Gilbertz	Regan	
		Debinski	Low	
		Serfass		
		Folnagy/Strasheim		
	12:00-1:00PM	LUNCH		
	1:00-1:30PM	Award Presentation to the Family of Ken Pierce		
	1:30-2:30PM	Geosciences Lecture, Dr. Bruce Fouke presented by Nature's Fynd - Introductory remarks by Dr. Debbie Yaver		
	2:30-3:00PM	Bob Smith		
	3:00-3:30PM	Coffee Break		
	3:30-5:30PM	ROOM 233	ROOM 235	AIH 166
		GEOLOGY	FISH & WILDLIFE CONSERVATION, NICHE & MIGRATION	HIGH ELEVATION & CLIMATE CHANGE RESEARCH PANEL
		Moderator: Hungerford	Moderator: Griswold	Williamson (NRCC, moderator), Tercek, Schaming, Bloom, and Yufang
		Farrell	Cross, P.	
		Fagan	Gigliotti	
		Schiller	Stahler	
		Lingbloom	Bigelow	
		Yaver	Ertel	
	5:30-6:00PM	Break		
	6:00-7:00PM	Plated Dinner sponsored by Yellowstone Forever		
	7:00-8:00PM	Superintendent's International Lecture, Dr. Frank van Manen		
Wednesday	8:00-8:30AM	Coffee Break sponsored by Nature's Fynd		
	8:30-9:50 AM	THREE QUESTIONS: Working Scientists: Debinski, Turner, Merkle, Olliff (moderator)		
	9:50-10:10AM	Break		
	10:10-12:00N	THREE QUESTIONS: Agency Perspectives: Sholly, Jenkins, Erickson, Olliff (moderator)		
	12-12:30PM	Boxed Lunch		
	12:30-1:30PM	Haines Lecture, Dr. Megan Kate Nelson		
	1:30-3:00PM	ROOM 233	ROOM 235	MAIN BALLROOM
		HUMAN DIMENSIONS II	BISON ECOLOGY & THERMAL BIOLOGY	ADDRESSING COMPLEX ECOLOGICAL CHALLENGES WITH COLLABORATION PANEL
		Moderator: Pritchard	Moderator: TBD	White (moderator), Irvine, Wilder, Thoma
		Sive	Geremia	
		Larson	Fugate	
		Maher	Davenport	
		Smith	Peach	
		MacDonald	Wendt	
	3:00-3:30PM	Birthday Cake and a Toast to Yellowstone		

Three Question Panels: What does the GYE mean to you?
What are the greatest threats to the GYE and what actions can we take to address them?
What are the greatest opportunities you see in the GYE's future?

Moderator: Gus Smith

HUMANS ALTER THE RISK OF WOLF PREDATION ON NATIVE UNGULATES

Kristin Barker, Arthur Middleton

Background: Predatory behavior of large carnivores can influence the structure and function of ecosystems. After being extirpated from significant portions of their historic ranges by the early 20th century, carnivore populations are now recovering in many landscapes where the human footprint is simultaneously expanding. When carnivores encounter humans, the way they behave – and therefore the way they shape ecosystems – often changes. However, little research investigates behavioral mechanisms underpinning carnivore response to humans. Therefore, it is not clear how predation risk, and its associated ecosystem influences, will play out in the anthropogenic areas into which carnivore populations are increasingly expanding. We hypothesized that humans may reduce the risk of predation by disturbing carnivores or threatening their survival. Alternatively, or additionally, we hypothesized that humans may increase predation risk by providing forage that congregates prey in predictable places and times.

Methods: We used wolves (*Canis lupus*) in Jackson Hole, Wyoming as a study species, gathering data from 170 wolf kill sites from 2019 – 2021 by investigating "clusters" of wolf GPS collar locations. We used conditional logistic regression to quantify how the likelihood of predation changed across a range of human influences, while controlling for environmental effects and prey availability. We conducted fieldwork during winter, when ungulates are most susceptible to predation and are located in low-elevation seasonal ranges closest to humans. Human influences ranged along a broad spectrum, from heavily restricted activities in protected National Parks and wildernesses to largely unregulated activities on private lands. Federal and state-run ungulate feeding areas provided supplemental food during winter to bolster populations and reduce conflict with landowners.

Results/Conclusions: Wolves selected kill sites where prey were most available and most vulnerable, but kill site selection was better explained with the inclusion of human influences than by prey availability and environmental characteristics alone. Wolves responded less strongly – if at all – to humans where prey were scarce, suggesting they prioritized acquiring prey over avoiding human interactions. Notably, different types of human influences had converse effects on wolf predation. Where prey were readily available, wolves preferentially killed animals far from motorized roads but close to trails (i.e., over-snow travel routes). We hypothesize wolves may perceive roads as a mortality risk while perceiving trails as energetically-efficient travel corridors that increase access to prey. Our finding that roads decreased predation risk whereas trails increased predation risk provides equivocal support for our hypothesis that humans would reduce predation risk. Simultaneously, increased predation risk near ungulate feeding areas supported our alternative hypothesis that forage provisioning can increase predation risk for native ungulates. Our work reveals that the effect of humans on predation risk is more nuanced than previously appreciated, suggesting that predators' influence on prey populations and ecosystem processes can vary widely across different types of human influences. Results shed new light on the drivers of large carnivore behavior in anthropogenic areas while helping natural resource professionals anticipate complexities of predator-prey dynamics in and around the wildland-urban interface.

PARASITIC INFECTION IN A SOCIAL CARNIVORE: *T. GONDII* EXPOSURE INCREASES RISKY DECISION MAKING IN GRAY WOLVES

Meyer, C., K. Cassidy, E. Stahler, E. Brandell, D. Stahler and D. Smith

Background: For decades, researchers have sought to understand the complex relationships between gray wolves (*Canis lupus*) and cougars (*Puma concolor*). Much of this research has focused on the spatio-temporal and dietary overlap between the two species, or direct interactions, avoidance, and mortality. However, due to parasite transmission between the two species, the relationship may be even more complex. *Toxoplasma gondii* is a protozoan parasite capable of infecting any warm-blooded species, yet requires a feline definitive host to reproduce. Infection with *T. gondi*i may increase an individual's risky decision making. Extensive research has been conducted on *T. gondii*'s effect in lab settings but rarely demonstrated in the wild. We sought to understand the demographic and ecosystem drivers of T. gondii infection, and the effects of seropositivity on risky-decision making. To do so, we examined demographic and ecosystem covariates of infection and the effect of seropositivity on four behaviors associated with risk-taking: (1) dispersal, (2) achieving dominant social status (i.e., pack leader), (3) approaching people or vehicles (i.e., habituation), and (4) dying of a specific cause, measured two ways: intraspecific mortality or anthropogenic mortality.

Methods: In this two-part study in YNP, we first used generalized linear mixed models (GLMMs) and 25 years of gray wolf serological data from captured wolves, demographic covariates (i.e., sex, age, coat color, and social status at time of capture), and an environmental covariate (i.e., percent territory overlap with ≥1.8 cougars/100km2) to test for *T. gondii* seroprevalence. Second, we used GLMMs and 25 years of wolf behavioral data to test whether infection affects gray wolf decision-making.

Results: We found that wolf pack overlap with areas of high cougar density was a significant predictor of T. gondii infection, whereas all other demographic covariates were not significant. We also demonstrated that *T. gondi*i infection directly affected wolf behavior in two of the four behaviors tested. Using our long-term dataset, we found that seropositive wolves were 11 and 46 times more likely to disperse or become a pack leader, respectively, than seronegative wolves. Our study reveals an important and novel link between *T. gondii* infection and behavioral alterations in a free-living wildlife population.

This study provides an important basis for further unlocking the complexity of the Greater Yellowstone Ecosystem. The behaviors associated with *T. gondii* infection (i.e., dispersal and leadership) have the potential to impact vital rates at the individual, group, population, and ecosystem levels. In addition, our results suggest a potential feedback loop that may trigger dramatic changes to wolf-cougar disease dynamics and highlight the hyper-effectiveness of *T. gondii* in this system.

ESTIMATING ADULT SURVIVAL OF GRAY WOLVES (*CANIS LUPUS*) IN YELLOWSTONE NATIONAL PARK

Cassidy, B., M. Hebblewhite, D. W. Smith

Background/Questions: Carnivore restoration has gained worldwide attention for bolstering not only individual species, but ecosystem-level processes such as predation at a level that sustains the structure and function of an ecosystem. Reintroduction of gray wolves (Canis lupus) to Yellowstone National Park (YNP) has been amongst the more innovative 'natural' experiments in the world, and successful in bringing these large carnivores back to parts of their native range. Many populations have recovered enough to even allow state-level harvest. Most wolf populations, and thus studies, are therefore highly exploited by humans. In contrast, wolves in YNP have been largely unexploited since the 1995 reintroduction. The wolf population in YNP may be driven by prey availability, intraspecific strife, or possibly both, depending on wolf density. Intrinsic factors such as sex, age, reproductive status, and coat color may play a significant role in adult wolf survival. Extrinsic factors such as pack size, pack location, and harvest may also contribute. We used 321 radiocollared adult wolves over 26 years (1995-2021) to estimate adult wolf survival. This project's aim is to estimate adult wolf survival and the influence of different intrinsic and extrinsic factors.

Methods: We first estimated survival rates using Kaplan-Meier methods. We then used Cox-proportional hazard models to test our specific predictions of the influence of intrinsic and extrinsic factors on adult wolf survival. CPH models have been used in previous wolf survival analyses and can flexibly integrate individual and pack-level covariates.

Results/Conclusions: We conclude that adult survival remains an important factor in population stability and that adult wolf survival could be affected by both prey availability and intraspecific strife. Preliminary results indicate resident adult wolf survival is similar to other protected areas in North America which is generally between 0.64 and 0.89. This work is another step in understanding the long-debated topic of wolf population regulation, an important goal for the future of wolf management. Further work will consider the strength of prey availability and social conflict on natural wolf population regulation. Additionally, this work can be extrapolated to other social species that are not as heavily studied as gray wolves in North America.

DENSITY-DEPENDENT CHANGES IN WOLF PREDATION IN NORTHERN YNP ARE INFLUENCED BY SEASONALITY AND PREY DEMOGRAPHY

Matthew C. Metz, Douglas W. Smith, Paul M. Lukacs, Sara H. Williams, Daniel R. Stahler, Daniel R. MacNulty, & Mark Hebblewhite

Background: Gray wolves were restored to the Greater Yellowstone Ecosystem through wolf reintroductions to Yellowstone National Park (YNP) beginning in 1995. The northern Yellowstone elk population subsequently declined and 'stabilized', while the northern Yellowstone bison population has generally increased. Estimating how wolf predation metrics respond to changes in ungulate populations provides insights for understanding wolf-prey dynamics.

Methods: We first used mark-recapture methodology to estimate the number of carcasses fed on by wolf packs in northern YNP during early (mid-November to mid-December) and late (March) winter for each winter from 1997–2019. We next used these estimates, along with subsequent predictions for the demographic characteristics (e.g., species) of undetected carcasses, to estimate wolf predation metrics (e.g., wolf diet, kill rate) for each season and year. Finally, we evaluated how our estimated predation metrics were affected by time. Here, we used time as a proxy for ungulate abundance because time was well correlated with both the decline in elk abundance and increase in bison abundance.

Results and Conclusions: Our results generally indicated that wolf predation metrics on their primary prey, elk, declined through time. Specifically, predictions throughout our study for the proportion of elk among acquired biomass declined from >0.9 during both early and late winter to ~0.6 during early winter and ~0.4 during late winter. The decline in elk among wolf diet was mostly driven by wolves' use of bison, acquired primarily through scavenging. Nonetheless, wolves most often killed their food, and elk was the dominant species killed by wolves. On average, we estimated that a wolf killed 1.0 elk over 30 days during early winter and 1.5 elk during late winter. Per-capita kill rate on elk did not significantly decline through time during early winter. However, kill rate on elk did display longitudinal declines, consistent with density-dependent theory, when considering kill rate on elk calves or female-adults. This observation is important in that, for example, female-adults is the demographic segment of the elk population that most affects future growth. During late winter, overall kill rate on elk declined with time. For example, per-capita kill rate on elk over 30 days declined from 2.0 (1997–2001) to 1.0 (2014–2019). Similar to early winter, this longitudinal decline was most prominent when focused on elk calves or female-adults. In summary, our work suggests that wolf predation on elk was i) affected by the use of bison and ii) displayed density-dependent characteristics that suggest it is likely now a regulating force on northern YNP elk.

INVESTIGATING THE RELATIONSHIP BETWEEN ELK MIGRATIONS AND WOLF MOVEMENTS AND PREDATION PATTERNS IN THE EASTERN GYE

Avery Shawler

My research is focused on the eastern frontier of the Greater Yellowstone Ecosystem (GYE) around Cody, Wyoming, where recolonizing wolves, their native ungulate prey, and range cattle have commingled for 20 years, leading to chronic cycles of wolf-livestock conflict and lethal control. Since January 2019, we have tracked elk and wolves using GPS collars and have also conducted fieldwork to investigate whether and how a key ecological dynamic in the GYE, the migratory behavior of elk – wolves' primary prey - influences these cycles of conflict.

The Cody elk herd with approximately 6,000 individuals, is one of the largest predominantly migratory herds in the GYE. To evaluate how migratory elk movements affect wolf movement, we deployed GPS collars on 70+ individual elk in the Cody elk herd and 20+ different wolves that hunt the Cody elk herd. Preliminary analysis of the wolf movement data reveals that wolves deploy a range of strategies, including evidence for migratory coupling, where migrant prey induce large-scale movements of predators. Some packs fully follow migratory elk into their summer ranges and remain until the elk depart. A few wolves exhibit partial migratory behavior with occasional extraterritorial forays to follow migrating elk. We also found that many individuals and packs don't migrate at all and instead remain in areas where non-migratory resident elk, other native prey such as mule deer, and cattle share the landscape.

To better understand how these non-migratory wolves cope with the departure of migratory elk in spring and early summer, we conducted fieldwork in the winters and summers of 2019, 2020 and 2021 to investigate patterns of wolf predation. Using data from GPS collared wolves, we employed a protocol called cluster searching, to investigate clusters of GPS points to investigate wolf activity. While many of these clusters were bed site locations or unknowns, when we found a carcass, we conducted a necropsy to determine whether or not wolves killed or scavenged. Our preliminary analysis of this cluster data shows that while our GPS collared wolves mainly predated on elk in both winter and summer, the non-migratory wolf packs predated on a greater diversity of prey in the summer potentially showing evidence of prey switching in the absence of their main prey. We also recorded several instances of cattle depredation and even more occurrences of the wolves scavenging dead cattle that either died of natural causes or from other large carnivores such as grizzly bears.

Understanding how elk migrations relate to patterns of wolf-livestock conflict can inform management attempting to apply lethal and non-lethal management interventions to control depredation. Mitigating conflict is crucial for keeping working landscapes intact, which is essential for wildlife conservation in the GYE as exurban development threatens wildlife habitat.

RESPONSE OF WOLVES TO RECREATIONAL HUNTING AND ANTHROPOGENIC SUBSIDIES IN GRAND TETON NATIONAL PARK

Elizabeth Templin

The gray wolf (*Canis lupus*) is a widely distributed and highly adaptable social carnivore whose decline and recovery has been a focus of both conservation effort and of controversy. Wolves are apex predators whose position in food webs can strongly influence ecological communities and ecosystem processes. However, the presence of anthropogenic food subsidies and human activity poses a risk as wolves are generalist predators and are one of the most abundant apex predators to be reported consuming subsidies. Carnivores subsisting off anthropogenic subsidies could have displayed reduced predatory behavior which could lead to altered ecosystem roles and trophic cascades.

This study evaluated territory size, overlap, and resource selection patterns of wolves in response to hunter activity and a harvest-related subsidy (elk remains) in Grand Teton National Park. We analyzed wolf movement at two scales. First, we compared wolf territory size and overlap across three time periods of hunting and non-hunting from multiple years. Then, we compared fine-scale wolf movement using step selection models to better understand how wolves may perceive the risk of human-caused mortality on landscapes as they search for prey and potential human provided subsidies during the Elk Reduction Program. Understanding how large carnivores respond to hunting activity and hunter-provided subsidies within a protected area can inform wildlife and habitat management, conservation, and restoration.

At the territory scale, we found wolves did not spatially shift territory use away from hunting areas. Then our fine-scale results indicated that packs disproportionately respond to recreational hunting. Packs with territories closer to urban environments showed behavioral responses during active hunting that suggest these packs are more tolerant to humans and hunting activity. Packs also select for active hunt areas and locations of hunter-related subsidies. Furthermore, our results highlight the importance of utilizing fine-scale, diel specific movement analyses to evaluate carnivore responses to human activity and hunter-related subsidies. Understanding where and how wolves forage in diverse, human-influenced landscapes and minimizing those human influences could further human-wildlife coexistence by decreasing habituation and human-wildlife conflict.

Climate Change I

Moderator:James Pritchard

CLIMATE CHANGE IN GREATER YELLOWSTONE: A CHALLENGE FOR THE FUTURE

Steve Hostetler, US Geological Survey, Northern Rocky Mountain Science Center

Cathy Whitlock, Earth Sciences, Montana Institute on Ecosystems, Montana State University

Bryan Shuman, Geology and Geophysics, University of Wyoming

David Liefert, Midpeninsula Regional Open Space District

Charles Wolf Drimal, Greater Yellowstone Coalition

Scott Bischke, Mountain Works

The Greater Yellowstone Climate Assessment (http://gyclimate.org), released in 2021, summarizes past, historical, and projected future changes in temperature, precipitation, and water in the six major river basins within the Greater Yellowstone Area (GYA). The Assessment was produced as a federal-university-NGO partnership and is intended to guide further research, discussion of the important impacts, and adaptation and mitigation strategies related to climate change in the region.

Since 1950, over the GYA mean-annual temperature has increased by 2.3°F (1.3°C), annual snowfall below 8000 feet elevation has decreased by 25% (nearly 24" or 61 cm), peak streamflow occurs earlier in the year, and the growing season is now longer by about 2 weeks. Geological studies indicate that the average temperature of GYA over recent decades is as high or higher than any period in the last 20,000 years, and probably is the warmest of the last 800,000 years.

Observed climate trends since 1950 are likely to continue and accelerate in the future. Depending on the path of 21st century global greenhouse gas emissions, relative to the 1986 2005 base period the GYA is projected to warm 5oF (3°C) by 2040 and possibly as much as 10oF (5.6°C) at the end of the century. As a result, a greater portion of winter precipitation will fall as rain instead of snow and snowpack will continue to decline. Snowmelt and runoff will progressively occur earlier in spring, adding to water shortages in summer.

The projected changes have major implications for the region. Both irrigated and non-irrigated agricultural practices will need to adapt to earlier timing of snowmelt and runoff, greater summer evaporation demand, and reduced summer and late-season soil moisture. Warming in winter will lessen demand for commercial and home heating, but projected warming in summer will increase the need for cooling, given an increase in the number of days over 90 oF (32 °C). Warmer temperatures and changes in snow and runoff will affect most aspects of the winter and summer recreation economy and promote increased wildfire in the GYA.

Interviews with stakeholders and rights holders in the GYA suggest a need for a climate information hub that is comprehensive, understandable, and accessible. Scientific gaps remain about regional climate-driven changes in the GYA that deserve investigation. For example, better understanding of the connections between climate change, the carbon and water cycle, urbanization, agricultural practices, and biodiversity. Monitoring, adaptation, and mitigation efforts are needed, including (1) engaging GYA residents and visitors on the topic of climate change, (2) community planning to develop local adaptation strategies, (3) long-term monitoring of at-risk habitats and species, and (4) sustained efforts to build a scientific knowledge base for the GYA.

ENHANCING HYDROLOGIC MODELING AND WATER SUPPLY FORECASTING IN MONTANA'S UPPER YELLOWSTONE BASIN

John Lunzer, Sara Meloy, Todd Blythe, David Ketchum
Montana Department of Natural Resources and Conservation – Water Management Bureau

Stakeholders and managers in the Upper Yellowstone Watershed are increasingly forced to balance the growing demand for water with uncertainty in water supply, the latter of which is primarily driven by climatic shifts towards earlier season snowmelt runoff, warmer temperatures, and persistent drought conditions. This complexity in water management has created tension throughout the community in recent years, but the turning point was in August of 2016, when low flows and warm water conditions led to a parasite outbreak that caused an unprecedented die-off of native mountain whitefish. The resulting temporary closure of a large stretch of the river and the associated economic and ecologic impacts underscored the need for a modern hydrologic toolset to forecast water supply conditions, enhance water management decision-making, and inform drought planning efforts.

Methods: In response to this need and ongoing concerns from a wide variety of local stakeholders, the Montana Department of Natural Resources and Conservation is developing a robust water balance, precipitation-runoff hydrologic model, and water supply forecasting tools for the watershed. This suite of tools use established methodologies to improve water supply decision-making and modeling capabilities for the watershed. Modeling is focused on water usage while considering irrigation, domestic use, municipal use, and future development. Consideration and measurement of actual use will produce forecasts that are not simply natural flow. Water supply forecasting will be enhanced by incorporating a physical precipitation-runoff technique, which will complement the existing statistical methods. Evapotranspiration and crop consumption estimates will also be improved using remote sensing data and existing modeling software. This method has been applied in other parts of Montana, and it has been shown to improve modeling and forecasting accuracy, reduce error, and contribute to a better understanding of the watershed hydrology. Monitoring and development of the modeling framework is currently on-going with simulations, and forecasts anticipated in 2023. The modeling framework developed in this watershed can be expandable to basins throughout Montana.

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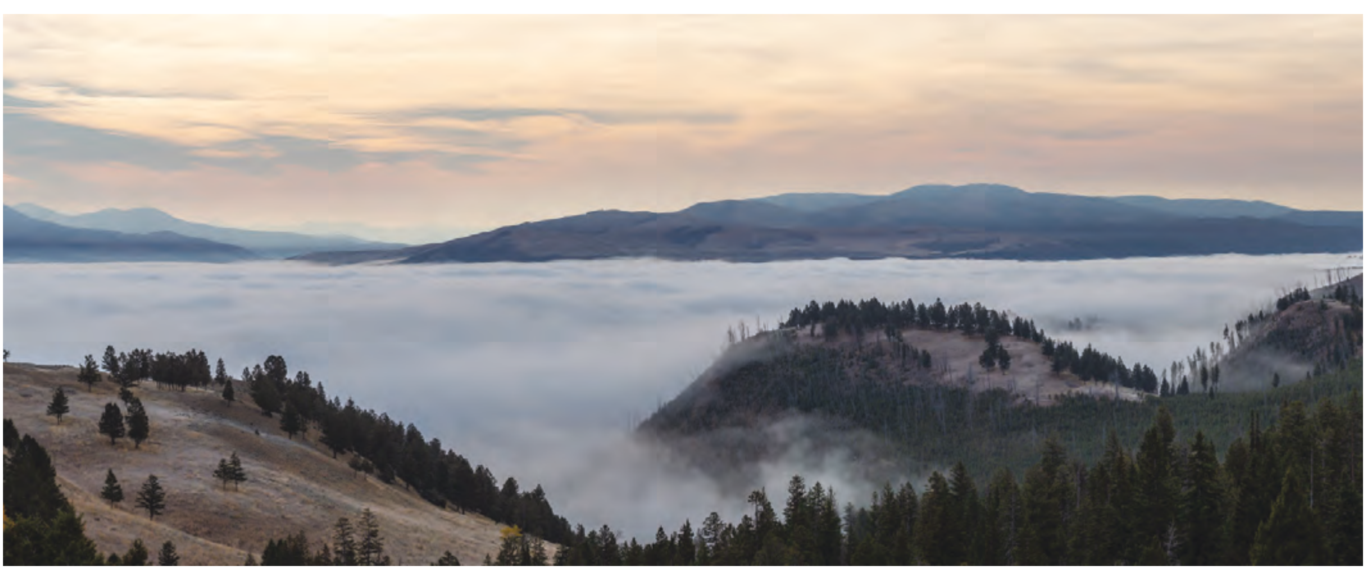
A FOREST ENTOMBED IN ICE: A UNIQUE RECORD OF MID-HOLOCENE CLIMATE AND ECOSYSTEM CHANGE

Daniel Stahle, Greg Pederson, Dave McWethy, Craig Lee, Nathan Chellman, Joseph McConnell

Across the high country of the northern Rocky Mountains small vestiges of perennial ice have persisted for thousands of years. These ice patches reside hundreds of meters above modern treeline, with some persisting through mid-Holocene warmth and others establishing at the onset of a cooler period that began around 5,000-5,500 BP. During the mid-Holocene warm period (ca. 10,000 – 5,500 BP) evidence suggests conifer forests thrived at higher elevations. However, progressive summer season cooling reduced treeline elevations and enabled snow and ice to persist on the landscape through the growing season. In some locations, snow and ice developed into permanent ice patches, preserving proxies of environmental change – including windblown sediments, animal dung, pollen, charcoal, and entire trees that would have disintegrated millennia ago. Recent warming driven melting at the margins of one ice-patch exposed over 30 intact whitebark pine (Pinus albicaulis) tree boles high on the Beartooth Plateau of Northern Wyoming. We extracted cross-sectional samples from the stems of 27 preserved logs, and radiocarbon dated the growth rings of 11 of these trees which indicated they stopped growing approximately 5,552 ± 164 BP. Through classic dendrochronological cross-dating methods, we discovered that all of the sampled trees grew contemporaneously over a 600-year period between 5200–5800 years ago.

Here we present initial efforts towards developing estimates of evolving climate conditions during the mid-Holocene at high elevations from this fossil wood chronology. To identify the predominant climate-growth relationships of the whitebark pine trees from the ice patch, we sampled live trees growing at an adjacent treeline site approximately 100 m lower in elevation, or ~1.3°C (annual average) warmer than the ice-patch. A modern whitebark pine annual ring-width chronology was then constructed and compared against nearby snowpack measurements and instrumental climate data interpolated to the site. Annual temperature was found to be the major driver of variability in tree-growth at the adjacent upper treeline location, with trees producing narrower (wider) rings during periods of cooler (warmer) growing season temperatures. Warming over the past half-century has increased productivity in these upper elevation whitebark pine forests, and a stable statistical relationship between growth and temperature suggests a transfer function is suitable for use in developing temperature estimates from the ice patch subfossil ring-width chronology. Our unique dataset suggests great sensitivity of whitebark pine tree growth to temperature and snowpack depth and duration, with declining growth rates in the subfossil wood and the eventual death of the trees coinciding with regional cooling and formation of the ice-patch. This high-quality paleo-ecological dataset reveals a major shift in the alpine and forest ecotone on the Beartooth Plateau following the mid-Holocene warm period, and offers further insight on the thermal limits of whitebark pine trees. This record also provides new insights into the climatic conditions favorable for ice patch development and persistence in the Greater Yellowstone Ecosystem.



ANTICIPATING FORESTS OF THE FUTURE: LANDSCAPE CHANGES IN GREATER YELLOWSTONE IN A WARMER WORLD WITH MORE FIRE

Monica G. Turner, Kristin H. Braziunas, Tyler J. Hoecker, Werner Rammer, Rupert Seidl

Background/Questions: Forests are the backbone of the Greater Yellowstone Ecosystem (GYE), yet their future is uncertain as climate change intensifies and fire activity increases. High-severity fires that burned historically at 100-300 yr intervals are projected to burn much more frequently during this century. Understanding how, where and why forests may change and whether forests can remain resilient is a pressing scientific challenge. We explored future climate-fire scenarios in the GYE to address multiple questions: Where are changes in forest structure, composition and extent most likely? Will old-growth forests persist? Will forests still rebound after fire? What happens to carbon stocks? How will native wildlife respond to novel landscape patterns and a changing climate?

Methods: Landscape dynamics were simulated from 2017 to 2100 using iLand, a next-generation spatially explicit process-based forest model that we adapted for GYE forests. We simulated fire (with fuels feedbacks) and forest dynamics on five landscapes in the GYE for six climate scenarios. For each year, we tracked burned area, forest extent, stand age, tree density and basal area, aboveground carbon stocks, and dominant forest types at 1-ha resolution. We explored wildlife consequences by assessing habitat suitability for three forest-dependent vertebrates: red squirrel (*Tamiasciurus hudsonicus*), a small mammal; pine marten (*Martes americana*), a mesopredator; and Black-backed Woodpecker (*Picoides arcticus*), which uses recently burned forests. Species distribution models were developed for each species, and we analyzed the individual and combined effects of climate and vegetation. To project postfire tree regeneration across the entire GYE, we integrated artificial intelligence methods with iLand simulations for the same climate-fire scenarios.

Results/Conclusions: Warming alone did not cause forests to decline, and historical forest resilience was maintained in warming scenarios accompanied by increased precipitation. However, the more likely scenarios of warming plus increased aridity led to more fire and profound forest change. Forest extent and the area of high-severity fire peaked in mid-century and then steeply declined. Forest area shrunk by ~50%, and remaining forests were young and sparse. Old-growth forests and carbon stocks also dropped precipitously. Tree species adapted to resist or regenerate following fire [lodgepole pine (*Pinus contorta var. latifolia*), Douglas-fir (*Pseudotsuga menziesii*), aspen (*Populus tremuloides*)] persisted, but species not adapted to fire [Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*)] were often extirpated. Steep topography buffered change, but forests on the gently rolling plateaus were very vulnerable to decline. When assessing implications for wildlife habitat, we found that areas of suitable climate often did not overlap with suitable vegetation; marten habitat declined most among the three vertebrate species. Across the entire GYE, failure of trees to regenerate after fire led to 28-59% forest loss by 2100. Declines were most pronounced on the central plateaus, and loss of seed sources could prevent forest recovery for decades to centuries. While some forest changes are likely unavoidable, stabilizing atmospheric greenhouse gas concentrations by mid-century would dampen these effects and bolster forest resilience. However, GYE forests will look drastically different compared to today if climate change continues unabated.

BEHAVIORAL PLASTICITY IN THE FACE OF CLIMATE CHANGE: HOW AND WHY LARGE MAMMALS IN THE GREATER YELLOWSTONE ECOSYSTEM MODIFY THEIR BEHAVIOR AS TEMPERATURES INCREASE

Rebecca R. Thomas-Kuzilik, Justine A. Becker, Jeffrey L. Beck, Alyson Courtemanch, Gary L. Fralick, Chris Geremia, L. Embere Hall, Matthew J. Kauffman, Blake Lowrey, Hollie M. Miyasaki, Hall Sawyer, Daniel R. Stahler and Jerod A. Merkle

Background & research questions: Climate change is altering temperature dynamics worldwide, resulting in an increase in overall temperatures, more days of extreme heat, and fewer days of extreme cold. In the Greater Yellowstone Ecosystem (GYE), climatic changes mirror worldwide trends. Behavioral plasticity, the alteration of behavior in response to stimuli, is becoming increasingly important in the context of this human-induced rapid environmental change. The ability of an animal to behave plastically, and the magnitude of that response, is likely facilitated or constrained by the characteristics of its physical environment, the magnitude of the stressor, and the animal's endogenous traits. Despite empirical research demonstrating that climatic changes are already impacting species' behavior worldwide, there are relatively few studies that have compared the magnitude and causes of behavioral plasticity in response to increasing temperatures at different levels (i.e., population and individual) across species, especially in large mammals.

We employed a comparative, multi-species approach to examine the importance of environmental context and endogenous constraints on the expression of behavioral plasticity in response to variation in temperature. Our objectives were two-fold. First, we quantified behavioral plasticity at the individual level, and then calculated population-level metrics to evaluate the extent to which plasticity varied among and within populations. Second, we tested hypotheses to explain the observed variation in behavioral plasticity.

Methods: We operationally defined behavioral plasticity as the degree to which habitat selection and movement characteristics change as ambient temperatures increase. To quantify plasticity at an individual level, we ran a separate resource selection function (RSF) and a movement model for 1068 unique animal-years representing 17 populations of 9 species of large mammals, including 12 populations in the GYE. We then aggregated these individual-level measurements into two population-level metrics: mean population behavioral plasticity and mean variation in behavioral plasticity among individuals within each population. Finally, we tested hypotheses to determine the extent to which environmental context and endogenous traits facilitated or constrained the expression of behavioral plasticity with a suite of univariate linear regression models.

Results & Conclusions: All study populations displayed behavioral plasticity in response to increasing temperatures, modifying aspects of their relative habitat selection and movement characteristics. We also demonstrate individuals within each population display strong variation in their responses to warmer temperatures. We also found evidence that differences in the physical environment explained variation in both mean population behavioral plasticity and mean variation in plasticity among individuals within each population.

Our results provide a novel understanding of the factors that facilitate or constrain the expression of behavioral plasticity, providing insight into the ecology and evolution of behavioral plasticity in large mammals. More specifically, this work describes the extent to which multiple populations and species of large mammals in GYE respond plastically to increasing temperatures. These results can assist wildlife managers in prioritizing the allocation of limited resources that best facilitate plasticity in the face of rapid climate change.

CLIMATE CHANGE CAUSING GLOBAL SHIFTS IN PHENOLOGY

Simone Durney

Climate change is causing global shifts in phenology, altering when and how species respond to environmental cues such as temperature and the timing of snowmelt. These shifts may result in phenological mismatches among interacting species, creating cascading effects on community and ecosystem dynamics. Using passive warming structures and snow removal, we examined how experimentally increased temperatures, earlier spring snowmelt, and the poorly understood interaction between warming and earlier spring snowmelt affected flower onset, flowering duration, and maximum floral display of the spring flowering montane species, Arrowleaf Balsamroot (*Balsamorhiza sagittata*), over a seven-year period. Additionally, potential cumulative effects of treatments were evaluated over the study duration and correlations between plant responses were investigated to understand how onset, duration, and maximum floral display may be related to one another. The combination of heating with snow removal led to earlier flower onset, extended flowering duration, and increased maximum floral display. While there was year-to-year variation in floral phenology, the effect of heating with snow removal on earlier onset and maximum floral display strengthened over time. This suggests that short-term studies likely underestimate the potential for climate change to influence phenological plant traits. For all treatments, including the control, correlations among floral response variables revealed that earlier flower onset was associated with extended flowering duration and greater maximum floral display, and extended flowering duration was associated with greater maximum floral display. These patterns imply consistent relationships among these variables, regardless of treatment, with earlier onset linked to longer flowering and greater flower production. Overall, this research indicates that Balsamorhiza sagittata's flowering onset responded more strongly to snow removal than to heating, but the combination of heating with snow removal allowed plants to bloom earlier, longer, and more profusely, providing more pollinator resources in the spring. If warming and early snowmelt cause similar responses in other plant species besides *Balsamorhiza sagittata*, these patterns could mitigate phenological mismatches with pollinators by providing a wider window of time for interaction and resiliency in the face of change. This example demonstrates that a detailed understanding of how spring-flowering plants respond to specific aspects of predicted climatic scenarios will improve our understanding of the effects of climate change on native plant-pollinator interactions in montane ecosystems. Studies like this help elucidate the long-term physiological effects of climate-induced stressors on plant phenology in long-lived forbs.

COMPLEX ECOLOGICAL CHALLENGES I

Moderator: Diane Debinski

PATTERNS, TRENDS IN, AND DRIVERS OF OCCUPANCY AND ABUNDANCE OF A CLIMATE-SENSITIVE SPECIES ACROSS THE GYE

Erik A. Beever, Peter D. Billman, Dylan K. Ryals, April Craighead, and Adam B. Smith

Background and Overarching Objectives: Although effects of contemporary climate change have been pervasive and pronounced for many species, the GYE has been forecasted by multiple investigations to constitute a long-term refugium for species associated with cold, snowy climates. The American pika (Ochotona princeps) has proven to be a model species to elucidate and test much ecological theory, including metapopulation dynamics, Island Biogeography Theory, plus source-sink, stepping-stone, and extinction dynamics. In addition, the species has illustrated in great detail, across diverse contexts of western North America, the mechanisms by which species' dynamics can be influenced by climatic variability and change.

We have sought to: assess whether there had been change in abundance or occupancy between our two sampling periods (and, using old fecal pellets as indicators, whether distributional change occurred pervasively before our first period); identify the factors that most strongly governed patterns of occupancy and abundance; and predict patterns of relative vulnerability to future loss of occupancy and change in abundance.

Methods: During each of 2014-2016 and 2019-2021, we surveyed 332 talus patches for American pikas, microclimate, microtopography, vegetation, and incidental observations of other mammal and bird species. We are using mixed-effects models in an information-theoretic approach to identify the combination of climatic and other variables (e.g., patch size, herbaceous-vegetation cover) that best explain patterns in occupancy and abundance. Relative to existing research on pikas, we are implementing a novel modeling approach to account for the fact that, due to several safety issues, we could not restrict sampling exclusively to crepuscular sampling periods. Namely, we quantified the number of minutes to day end (either sunrise or sundown, whichever was closer) that the middle of the survey was separated from.

Results and Conclusions: Given that the survey and re-survey dates at each patch were only 3-7 years apart, there was little change in occupancy between the two periods in GRTE and YELL. In contrast, Red Rock Lakes NWR had three patch-level recolonizations to zero extirpations, whereas Custer-Gallatin NF had 7 recolonizations to 18 extirpations. GYE-wide, abundance differed little between the two periods. In YELL, however, abundance appeared to decline by nearly 40% between the 2 periods (consistent with recent predictions from NPS-funded research across 8 park units in 2010-2011: Schwalm et al. 2016), and our fieldwork uncovered that pikas were recently distributed much more extensively along the Yellowstone River than earlier research suggested. Although not objectives initially, we've anecdotally observed pikas: using non-traditional habitats across the GYE (which is important because behavioral plasticity can confer resilience to contemporary climate change); and apparently being associated with raspberry cover. We will share our hypotheses, particular predictions, and further results in the presentation. Our work highlights that GRTE has a 'secret sauce' for cold- and snow-loving species (best status and trend of O.p., nation-wide), and provides clear implications for management, climate-adaptation, and conservation.

FUTURE ALTERED PLANT PHENOLOGY PROJECTED TO REDUCE BENEFIT OF MIGRATION FOR MULE DEER

Tabitha A. Graves, Ethan E. Berman, Ellen O. Aikens, Sarah R. Dewey, Troy Fieseler, Aaron N. Johnston, Matt Kaufman, Jerod A. Merkle, Kevin Monteith, Jill Randall, Imtiaz Rangwala, David Wood

Background: Climate influences on phenology will influence not only the ecology of the vegetation, but also all of the species that depend on vegetation. Therefore understanding climate influences on key vegetation phenology metrics could provide insight for multiple species. In particular, forage phenology may lead to future changes in the benefits of migration as animals follow the pattern of highly nutritious vegetation green-up in the spring. Ungulates with high site fidelity to migration routes, such as mule deer, may be among the species most influenced by changes in phenology. We therefore assessed the influences of a range of climate futures on the phenology of 210 spring mule deer migration routes representing herds spanning most of western Wyoming.

Methods: We first evaluated the drivers of two key land surface phenology metrics most tied to spring migration patterns, the peak instantaneous green up date (PIRGd) and the length of the peak period of spring green-up (spring scale) across Wyoming using model selection approaches. We then projected future phenology metrics at mid (2040-2069) and end of century (2070-2099) to better understand impacts of future phenology on ungulates, considering 2 emissions scenarios (RCP 4.5 and 8.5) and 5 global climate models (GCM) bracketing projected future conditions in temperature and precipitation. We also projected future metrics annually for the middle GCM.

Results/Conclusions: Models for PIRGd and spring scale included covariates related to both temperature and precipitation. We projected earlier PIRGd and longer spring scale with longer spring scale under drier conditions. Our projections indicated the duration and order of migration rates would likely decrease, while the spring scale would increase. This pattern is expected to be less beneficial for migrating mule deer, which could lead to a decline in the proportion of migrating deer. If alternate migration routes do not counteract this pattern and local forage resources limit resident mule deer abundance, over time a decline in the number of mule deer is possible. This research provides an approach for projecting climate change effects on important aspects of ungulate ecology and useful information for biologists to plan habitat treatments, consider effects of energy developments, prioritize land conservation and manage big game populations.

PEEKING UNDER THE CANOPY: EFFECTS OF SHORT FIRE-RETURN INTERVALS ON HERBACEOUS UNDERSTORIES IN GREATER YELLOWSTONE

Nathan G. Kiel, Kristin H. Braziunas, and Monica G. Turner

Background and Questions: Anthropogenic climate change is contributing to increased fire activity throughout western North America. Short-interval fires that reburn areas at fire-return intervals (FRI) considerably less than observed historically are becoming more common, and this trend is expected to continue through the end of this century. Such fires often burn forests before trees produce seeds (i.e., immaturity risk), reducing postfire tree establishment and potentially eroding forest resilience (ability of a forest to return to its pre-fire state). However, the consequences of short-interval fires and reduced postfire tree density are less well understood for understory plant communities, the most diverse floral stratum in temperate forests. In the Greater Yellowstone Ecosystem (GYE), forests are adapted to historical FRI of 100-300 yrs, but recent fires reburned areas at <30 yr FRI. We quantified plant community composition across a range of FRI, time since fire (TSF), post-fire tree density, and abiotic conditions to ask: how do plant communities vary following short- (<30 yr) v. long- (>125 yr) interval fire?

Methods: Plant communities were sampled in 31 paired short- and long-interval plots (total n=62). In each 0.25-ha plot, percent cover by species was measured in 25 0.25-m2 quadrats distributed along three 50-m transects and plot richness determined for the whole plot. Paired t-tests were used to determine differences in species cover grouped by lifespan (annual, biennial, perennial), native status, and functional group (graminoid, forb, shrub). Compositional differences across pairs were assessed using the Jaccard's dissimilarity index.

Results and Conclusions: Species richness did not differ between paired short- and long-interval plots (~36 species per plot), and cover of understory vegetation was only marginally higher following short-interval fire (~32% v. ~28%). Graminoid (~14% v. ~11%) and non-native (1.1% v. 0.8 %) cover was slightly greater following short-interval fire, while cover by lupines was two times greater (2.4% v. 1.2%) and cover by annuals was low but three times greater (0.6% v. 0.2%). However, more species were unique to short- v. long-interval plots (29. v. 22), with more graminoid, forb, annual, and non-native species recorded only after short-interval fires and more shrub species only after long-interval fires. As such, plant community composition differed substantially between paired plots (mean Jaccard's dissimilarity = 0.77, SE = 0.015). Pairwise dissimilarity declined with increasing species richness (R2adj = 0.83) but did not vary with TSF, postfire tree density, or abiotic conditions. Our analyses suggest that understory plant community composition is more sensitive to FRI than biotic cover or species richness. As annual area burned in the GYE continues to increase, a rise in the area burned at short FRI is likely to alter the distribution of understory species across the GYE landscape.

NO TITLE PROVIDED

Collette Berg

Yellowstone National Park, home to the majority of the world's geothermal features, is one of the most extreme environments on the planet, and the organisms that call Yellowstone home have developed a suite of adaptations to survive there. *Mimulus guttatus*, an emerging model species for evolutionary genetics, has colonized in a broad range of inhospitable habitats, including serpentine soils, copper mine tailings, and the geothermally heated soils of YNP. *M. guttatus* grows both on and off thermal areas in the park, and the thermal monkeyflowers bloom in early spring, when geothermal inputs melt the snow and provide a wet, warm microclimate. Common garden studies have revealed that this difference in flowering time is based on variation in daylength cues between thermal and nonthermal *M. guttatus*: the most extreme thermal populations only require a 12-hour daylength to flower, while the nonthermal populations require the 15-hour days of Wyoming summers. The ability to flower under the shorter days of early spring is an important adaptation for the survival of these thermal plants, since under long days in July and August these thermal soils are uninhabitably dry and hot. Interestingly, population genetic analyses have revealed ongoing gene flow between thermal and nonthermal *M. guttatus* in the park: rather than being in the stage of incipient speciation, these populations provide a great example of divergent adaptation in the face of gene flow. My research focuses on identifying the genes underlying adaptations to thermal areas in Yellowstone in order to understand their evolutionary history and their impacts on reproduction and fitness in the field. Using complimentary approaches of F2 mapping, linkage disequilibrium mapping, and gene expression analyses, I have identified a novel locus that underlies the change in minimum daylength requirement for flowering in Yellowstone thermal M. guttatus. My preliminary data indicates that the locus governing daylength is packaged with the locus that governs annuality (another important aspect of thermal adaptation) in a region of low recombination on the end of chromosome 6. Broadly, understanding the genetics of adaptation to extreme warming has applications for both agriculture and conservation. Although daylength is a common cue for flowering across the plant kingdom, daylength has become increasingly decoupled from suitable temperature and moisture conditions for flowering due to anthropogenic change. The thermal soils of Yellowstone National Park provide an extreme natural example of the evolutionary consequences of warming. Exploring the genetics of flowering time adaptation in response to warming can shed light on evolutionary processes and inform us of how plant populations my respond to anthropogenic warming in the future.

NON-NATIVE ANNUAL MUSTARDS WITHIN THE MOUNTAIN SAGEBRUSH OF YELLOWSTONE NATIONAL PARK

Jordan Meyer-Morey, Josie Rodrigue, Matthew Lavin, Heidi Anderson and Lisa J. Rew

Non-native plants can reduce biodiversity and disrupt essential ecosystem services and functions. For most non-native plant species however, quantitative evidence of negative effects is lacking. Annual mustards (*Alyssum spp.*) are found in mountain sagebrush (*Artemisia tridentata ssp. vaseyana*) habitats close to disturbances within Yellowstone National Park. Three alyssum species have been observed, *A. alyssoides, A. desertorum and A. simplex*, and they require careful attention to both flower and fruit detail to distinguish. Our observations at six sites from Mammoth to Hayden Valley suggest that A. desertorum is most frequent at these sites (4 of 6) and is present along the entire elevation gradient. However, little information is available on how these species differ ecologically. To address this we evaluated, seed viability of *A. desertorum* and *A. simplex* (no seeds were available for *A. alyssoides*), their competitive ability with each other and a non-native annual grass, and their effect on the native plant community in-situ. *Alyssum desertorum* had higher seed viability than *A. simplex*. Both species were weak competitors to the non-native grass. Finally, in the field, the presence of either species did not affect species richness nor Shannon's diversity, and functionally similar native annual forbs were not displaced in invaded areas. Our study suggests that both species are relatively weak competitors within the mountain sagebrush steppe but a better understanding of the potential impacts of these non-native species could help direct future management.

ENVIRONMENTAL DRIVERS OF REPRODUCTION BY GOLDEN EAGLES IN THE NORTHERN RANGE OF YELLOWSTONE NATIONAL PARK

David B. Haines, Victoria J. Dreitz, Todd E. Katzner, Douglas W. Smith

Golden Eagles (*Aquila chrysaetos*) are a North American species of conservation concern throughout their range. Within the northern range of Yellowstone National Park (YNP), territories of golden eagles occur at fairly high densities. However, average reproductive rates over the past ten years (2011-2020) have been low (productivity = 0.34, nest success = 28%), stimulating questions as to what environmental factors limit reproductive success. Hypotheses include extreme weather, variation in prey availability, and the recovery of large carnivores within YNP. We evaluated spatial and temporal components of golden eagle habitat that could explain reproductive output of eagles in YNP's northern range. Preliminary results indicate that increasing periods of prolonged precipitation during winter was negatively associated with apparent nest initiation. Nest success was negatively associated both with increased snow levels and with increasing periods of severe weather during early spring when eagles initiate nesting. Additionally, we found evidence to suggest that territories with more rugged terrain and in closer proximity to neighboring territories tended to have greater nest success than flatter, less densely packed territories. Our findings highlight potential drivers for the contrasting trends in territory density and nest success of YNP eagles and could be used to inform management of this population.

COMMON LOON MANAGEMENT IN THE GREATER YELLOWSTONE ECOSYSTEM

Arcata Leavitt

Common Loons (*Gavia immer*) in the Greater Yellowstone Ecosystem (GYE) are part of a small, island population consisting of about 60 adults as of 2021. The population experienced a historic low of five observed pairs in 2008, which highlighted the need for a better understanding and stronger conservation efforts for the species. Since comprehensive monitoring and territory management began in 2013, the population has grown to 26 observed pairs and experienced above replacement-level productivity. Loons are very sensitive during their nesting period, and human disturbance can cause loons to flush off nest, leaving eggs vulnerable to scavengers, or even to abandon their nest entirely. Nest failures, especially repeated ones, can cause a loon pair's bond to weaken and can lead to divorce or individual turnover within the pair. Human disturbance has been identified as one of the leading causes of loon nest failures in the GYE, and so management actions have been taken to protect nesting loons.

Across the loons' range, resource managers use targeted management, including closures and nest rafts, to prevent human disturbance of nesting loons. Closures and raft installation or placement vary between managing agencies and are re-evaluated on an annual basis. Closures are designed to best protect nesting loons based on nest location and recreation patterns, while still allowing recreationists to use as much of the area as possible. Closures may include boating restrictions, trail closures, campsite closures, partial lake closures, whole lake closures, or whole area closures. Closure efficacy is evaluated through loon hatching success and after closure implementation. Trail cameras are used to identify closure compliance by recreationists. In 2021, eleven territories (42%) across the GYE had targeted, loon-specific closures to protect nesting loons from human disturbance. Seven territories (27%) were under closures for other species, including Trumpeter Swans (Cygnus buccinator) and Yellowstone National Park Bear Management Areas (BMAs). Of the 23 total chicks hatched, nine were hatched in territories with targeted loon closures (39%). Five active territories (19%) have nest rafts installed, which provide a nest site that can be placed in different areas to prevent disturbance of nesting loons. Two of those nest rafts were used by loon pairs, both of which successfully hatched chicks.

Additional research is needed to further improve closure design to best protect nesting loons. Even with proper signage, closure compliance has been identified as an issue, and because many visiting the GYE are occasional or first-time visitors, public education is needed to ensure recreationists are not unintentionally breaking loon closures. However, some territories are in remote locations that are difficult to access and would benefit from remaining unknown to the public. Balancing the need to educate visitors on their impact on nesting loons with protecting sensitive territories that don't receive regular human visitation is an ongoing management issue, especially due to the growing visitation to national parks in the GYE and increased recreation in surrounding public land.

EXPANDING THE SCOPE OF GRIZZLY BEAR CONSERVATION THROUGH A BETTER UNDERSTANDING OF FOOD RESOURCES AT MOTH AGGREGATION SITES IN THE GREATER YELLOWSTONE ECOSYSTEM

Katerina Lozano, Clare Dittemore, Daniel Tyers, Robert K.D. Peterson

Background/Questions: Migratory army cutworm moths (Euxoa auxillaris) (ACM) were recognized as an important food item for Greater Yellowstone Ecosystem (GYE) grizzly bears (Ursus arctos horribilis) in the mid-1980's. From mid to late summer, ACMs migrate to alpine peaks in the eastern GYE, attracting foraging bears. The Shoshone National Forest is preparing a management plan to address grizzly bear conservation and human safety concerns at ACM aggregation sites. This highlights the importance of understanding the foraging behavior of bears at these locations. A food habits study in 1991 (French et al.1994) predictably indicated a reliance on ACM at aggregation sites but also highlighted the importance of vegetation. We investigated the diet of grizzly bears at two primary ACM aggregation sites. The vulnerability of migratory ACMs to climate change and other environmental factors is unknown. However, annual or long-term decreases in ACM abundance due to these factors could negatively affect grizzly bears that rely on these sites to meet caloric needs. The grizzly bear is highly adaptable and can adjust to seasonal and annual changes in food availability, but a more diverse diet would allow bears utilizing these sites more diet flexibility if ACM abundance fluctuates. In 2017 and 2018, Nunlist (2020) investigated grizzly bear food habits at the targeted ACM sites using scat analysis, which we continued in 2020 and 2021. Diet studies involving scat analysis can have differing results because of subtleties in the areas sampled and annual diet variation, which motivated us to conduct this follow-up assessment.

Methods: We determined the frequency and volume of each food item in the contents of 298 grizzly bear scats collected at two ACM sites in July and August of 2020 and 2021. We compared these results with analysis of 376 scats collected in 2017 and 2018.

Results/Conclusion: Scats collected in 2020 and 2021 contained, by volume, 23% insects, 32% graminoids, and 36% forbs. The two most prominent foods were ACM (22.9%) and roots and tubers (38%). Findings in 2017 and 2018 (n=376) show similar results: 20% insects, 33% graminoids, 19% forbs. Similarly, the two most prominent foods were ACM (20%) and roots and tubers (45%). The "roots and tubers" category is inclusive of biscuit root (Lomatium spp.), clover (Trifolium spp.), vetch (Astragalus spp.), and locoweed (Oxytropus spp). Our 2-year follow-up investigation in 2020 and 2021 corroborated the findings from the 2017 and 2018 study, which confirms the importance of both ACMs and vegetation at these sites. Rather than relying solely on ACMs, grizzly bears at 2 ACM sites utilize vegetation as an important part of their diet, especially roots and tubers from biscuit root and clover. This demonstrates a diverse diet that may allow bears to adjust to seasonal or annual variations in the abundance of diet items at these high-elevation sites.

PATTERNS AND PREDICTORS OF GREEN WAVE TRACKING IN OMNIVOROUS BROWN BEARSS ACROSS NORTH AMERICA

Nathaniel R. Bowersock, Lana M. Ciarniello, William W. Deacy, Doug C, Heard, Kyle Joly, Clayton T. Lamb6, William B. Leacock, Bruce N. Mclellan, Garth Mowat, Mathew S. Sorum, Frank T. van Manen, And Jerod A. Merkle

Herbivorous animals tend to seek out plants at intermediate phenological states of spring green-up to maximize resource gains. In some ecosystems, the timing of green-up becomes heterogeneous or wave-like, providing opportunities for mobile herbivores to prolong their exposure to higher quality forage if they track such resource waves, known as the green wave. While there is empirical support for such foraging strategies among herbivorous taxa, the generality of the green wave hypothesis is nuanced, with tracking varying based on factors such as body morphometrics and digestive ecology. Furthermore, little is known if omnivores, who eat both plant and animal matter, track the green wave. Our objective was to assess whether the green wave hypothesis can be extended to explain the movements of omnivores. Using GPS telemetry data from 7 populations of brown bears (Ursus arctos) (n = 127 individuals) across their North American range, we tested whether bears tracked the green wave. Using conditional resource selection functions, we found that spatiotemporal variation in vegetative forage quality better explained bear movement and habitat selection than forage abundance. Nearly half of bears in our study tracked the green wave. Next, we examined factors that explained variation in green wave tracking (use/selection of quality forage) using linear mixed effects models. Brown bear use of high-quality forage was best explained by the greenscape (defined as the rate and spatial transition of spring green-up) and phenological variation of landscape features (defined as the duration and start of spring green-up, elevational range, and mean landscape productivity). Selection for high-quality forage was best explained by the amount of protein in a bear's diet and sex. Our results demonstrate that the green wave can partially explain the movement and foraging ecology of a non-migratory, omnivorous species during spring. The green wave is yet another resource wave brown bears track to help build bodily reserves to recover from and later prepare for their prolonged denning season and demonstrates a higher level of selection for vegetative resources. Overall, our findings can also help predict both the spatial and temporal distribution of omnivores, which could be used to inform future conservation and habitat restoration efforts in an ever-changing world.

NO TITLE PROVIDED

Finnoff

Background: Greater Yellowstone Ecosystem grizzly bears have recovered under the Federal protections of the Endangered Species Act. Citing ecological evidence of population recovery, the U.S. Fish and Wildlife Service has twice delisted GYE grizzlies from the Endangered Species Act. Both times, ensuing litigation led to the reversals of the decisions. The negative reactions to proposed management changes by groups of stakeholders indicate a disconnect between various stakeholder preferences and ecological science.

People clearly value the opportunity to view grizzly bears, however, grizzly bears in the GYE pose risks to local economic activity, local individuals, and GYE visitors. As the grizzly bear population has recovered, there has been an increase in the number of grizzly bear-human conflicts. These conflicts may erode public support for conservation, and if severe enough, federal and state agencies may respond by removing offending grizzly bears and risking mortality on the species. As a result, grizzly bears incur high rates of human-caused mortality even while being federally protected.

To help provide some insight to managers of this challenging situation we link the general public's policy preferences, ecological science, and management responses together in a bioeconomic model that allows an evaluation of a switch from reactive management under federal protections to active management under federal and state agencies.

Methods and Results: To better understand the general public's preferences, we administered a nonmarket valuation survey to 2,500 residents of the GYE states from December 2020 to January 2021. The survey instrument described the likelihoods of both desirable and undesirable grizzly-related conditions, linked to the underlying grizzly population. We refined two choice experiments. The first, was specific to areas of the GYE within Yellowstone and Grand Teton National Parks and considered the chance of seeing a grizzly, risk of being injured by a grizzly, and the park entrance fee. The second, was specific to areas of the GYE outside of parks and concerned annual grizzly-human conflicts and the 100-year grizzly extinction probability. We find both locals and non-locals are willing to pay to increase the chance of a grizzly sighting, decrease the risk of a grizzly attack, decrease grizzly-human conflicts, and decrease grizzly extinction probability. Locals are willing to pay more than non-locals to decrease both the risk of an attack and the extinction probability. Non-locals are willing to pay more than locals to increase the chance of a sighting and decrease the number of conflicts.

The findings of the survey were then used to parameterize a bioeconomic model to evaluate the recovery of grizzly bears and consider the potential for a switch from reactive management under federal protections to active management under federal and state agencies. In the model, grizzly-dependent benefits and damages adjust along the recovery path, which tracks the natural capital value of an additional live grizzly bear in the wild as the population recovers. The natural capital value depends on ecological and human characteristics, as well as form of management employed. Whether or not active management is preferential depends keenly on key ecological and economic characteristics.

HOT SPRINGS, COOL BEETLES: EXPANDING THE SCOPE OF EXTREMOPHILE SCIENCE

Robert K. D. Peterson, Leon G. Higley

Background/Questions: Microbes that tolerate the extreme conditions of the hot springs in Yellowstone National Park (YNP) have been studied for decades and are relatively well understood. However, we know little about the insects that live in and on the hot springs. One of these extremophile insects is an apex invertebrate predator known as the wetsalts tiger beetle, Cicindelidia haemorrhagica. Although this species inhabits moist saline flats in the western U.S., its presence in YNP is unique because it is only found on hot springs. We have observed adults hunting on shallow water and soil surfaces with temperatures as high as 60 oC (140 oF), but, amazingly, they behaviorally cool themselves much less frequently than their conspecific counterparts outside YNP that are not associated with hot springs, even though surface temperatures in YNP are much higher. This discovery is astonishing. A population of a species of tiger beetle in a specialized, extreme habitat behaves very differently than a population of the same species in another habitat. The beetles behave very differently, but is it only behavioral? Because YNP beetles do not show thermoregulatory behavior consistently during extended periods of increased temperature from sunlight and thermally active soil and water, there must be some component to their physiology, genetic makeup, or chemical sequestration that contributes to their heat tolerance or resistance. Therefore, we are studying the ecophysiological causes of these fascinating behavioral differences.

Methods: In a series of lab and field studies since 2017, we systematically characterized behavioral, physiological, and physical responses between adult beetles in YNP and a non-hot spring location in Idaho. Based on our results, we focused studies on internal body temperatures to determine causes for the behavioral differences. We recorded internal body temperatures of freshly killed adults using thermocouples over a water bath.

Results/Conclusions: YNP beetles had a lower mean internal temperature of 1.03 °C than Idaho beetles with water surface temperatures of 40 °C to 55 °C (104 oF to 131 oF). We conclude that the YNP adult beetle has adapted to resist internal heating. Specifically, the increased heat resistance is the result of an adapted ventral abdomen that has enhanced reflectivity to infrared radiation. This heat resistance seems to be morphological rather than physiological. The beetle's adaptation is remarkable because the beetle has only been in YNP—at most—since the Pinedale Glacial Icecap that covered most of the area of YNP with 1,500-m thick ice receded 14,000 years ago. In other words, there has been relatively little time for these behaviors and morphological structures to diverge between the populations. Metazoan extremophiles in YNP have much to teach us and we must expand the scope of extremophile science to include them. Not only are they important for fundamental understanding of physiological ecology and evolution, but they relate directly to adaptations to climate warming, insect conservation, exobiology, and bioinspired materials.

POLLEN AND MACROFOSSIL EVIDENCE FOR SHIFTS IN HIGH-ELEVATION TREELINE THROUGHOUT THE HOLOCENE, BEARTOOTH PLATEAU, WY

Alt, M., Puseman, K., Lee, C., Pederson, G., McConnell, J., Chellman, N., McWethy, D.

At large scales, mean annual and growing season temperatures are the primary control on treeline elevation, yet there is little information on how the upper extent of alpine treelines shifted in response to long-term (millennial-scale) changes in temperature. Here we examine proxies of vegetation and treeline change (via pollen and plant macrofossils) from a wetland and semi-permanent ice patch (~ 3150 masl) located approximately 800 m apart above present-day treeline in the Beartooth mountains, WY. We evaluate pollen and macrofossils preserved in organic layers within the 10,000-year-old high-elevation ice patch and from a 6000-year-old wetland sediment core to explore the relationship between shifts in treeline elevation and climatic variability, and explore similarities and differences in the signals evident in each of the proxies. The ratio of arboreal to non-arboreal pollen from organic layers in the ice cores reached a low point ca. 9000-6500 cal yr BP during the mid-Holocene warm interval, suggesting treeline moved downslope during warm and dry conditions. Increases in arboreal pollen and an increase in Picea pollen and needles suggest treeline may have expanded upslope coming out of the Holocene warm period after ca. 6500 cal yr BP. Pollen from the wetland shows an increase in Poaceae pollen ca. 3000-1000 cal yr BP suggesting treeline shifted downslope (perhaps a second time) as winters became cooler and wetter. Microscopic charcoal in the organic lags from the ice patch indicate elevated fire activity ca. 10,000 and 2,500 yrs ago, both periods of time with evidence of increased woody cover. Charcoal accumulation rates in the wetland sediments were relatively low from ca. 6000 until ca. 500 cal yr BP suggesting minimal fire activity occurred in the high alpine for the last several thousand years. Pollen and plant macrofossils from these two sites indicate climate was an important driver of vegetation and treeline change during the past 10,000 years. While both records document evidence of millennial to centennial shifts in treeline position, the timing of these shifts were not always synchronous. This could be the result of differences in processes that control pollen accumulation and preservation on the surface of ice-patches versus pollen that accumulates in wetland systems. The ice patch record has more pollen from anthers and plants that are not wind pollinated suggesting a possible accumulation and/or preservation bias towards local herbs and shrubs. By providing a continuous record of pollen accumulation, wetland sediments may provide a more reliable picture of treeline shifts compared to the discontinuous record of pollen from organic lags preserved in the ice patch.

FLOWERING TIME ADVANCES SINCE THE 1970S IN A SAGEBRUSH STEPPE COMMUNITY: IMPLICATIONS FOR MANAGEMENT AND RESTORATION

Trevor D.S. Bloom, Donal S. O'Leary, and Corinna Riginos

Climate change is widely known to affect plant phenology, but little is known about how these impacts manifest in the widespread sagebrush ecosystem of the Western US which supports a number of wildlife species of concern. Shifts in plant phenology can trigger consequences for the plants themselves as well as the communities of consumers that depend upon them. We assembled historical observations of first flowering dates for 51 species collected in the 1970 and 80s in a montane sagebrush community in the Greater Yellowstone Ecosystem and compared these to contemporary phenological observations targeting the same species and locations (2016-2019). We also assembled regional climate data (average spring temperature, day of spring snowmelt, and growing degree days) and tested the relationship between first flowering time and these variables for each species. We observed the largest change in phenology in early spring flowers, which as a group bloomed on average 17 days earlier, and as much as 36 days earlier, in the contemporary data set. Mid-summer flowers bloomed on average 10 days earlier, nonnative species 15 days earlier, and berry-producing shrubs 5 days earlier, while late summer flowering plants did not shift. The greatest correlates of early spring and mid-summer flowering were average spring temperature and day of snowmelt, which was 21 days earlier, on average, in 2016-2019 relative to the 1973-1978. The shifts in flowering phenology that we observed could indicate developing asynchronies or novel synchronies of these plant resources and wildlife species of conservation concern including: Greater sage-grouse, whose nesting success is tied to availability of spring forbs; grizzly bears -- which rely heavily on berries for their fall diet; and pollinators. This underscores the importance of maintaining a diverse portfolio of native plants in terms of species composition, genetics, phenological responsiveness to climatic cues, and ecological importance to key wildlife and pollinator species. Redundancy within ecological niches may also be important considering that species roles in the community may shift as climate change affects them differently. These considerations are particularly relevant to restoration and habitat-enhancement projects in sagebrush communities across western North America.

THE ROLE OF CRYPTIC NITROGEN FIXATION IN POST-FIRE FOREST RECOVERY WITHIN THE GREATER YELLOWSTONE ECOSYSTEM

Robert E. Heumann, Cory C. Cleveland, Monica G. Turner, Katherine A. Dynarski, Nathan G. Kiel

Background and Questions: Increasing forest fire frequency and intensity throughout the intermountain western U.S. – including the Greater Yellowstone Ecosystem (GYE) – depletes forest nitrogen (N) stocks, a critical nutrient for plants. Fire-driven N depletion may inhibit post-fire forest regeneration and thus reduce forest resilience, as N is the primary growth-limiting nutrient in northern conifer forests. Yet, the processes that replenish N lost during fire in these forests are poorly understood. The most likely source of new N is biological nitrogen fixation (BNF). This process is carried out by bacteria that exist in a variety of forms, the most conspicuous being those that occur in symbiotic relationships with vascular plants. However, throughout YNP, symbiotic N-fixing plants are rare, suggesting that other, more cryptic forms of BNF that live freely in soil, on mosses, and in lichens, are more critical for N recovery following fire. Here, we explored the role that cryptic N fixation (CNF) plays in the N cycle and its importance as a mechanism for N recovery. More specifically, we asked what are the actual rates of CNF during the summer in recovering forests? Furthermore, since CNF is strongly regulated by moisture, how do CNF rates change under differing moisture conditions and thus how might precipitation patterns influence annual N inputs from CNF?

Methods: We directly measured actual CNF rates in mineral soil and fire moss (Ceratodon purpureus) from young, aggrading forests (≤21 yr) in YNP during July of 2021. To assess the effects of moisture on cryptic N fixation rates, we conducted a serial hydration experiment with five cryptic niches (ground lichen, moss, pine litter, pine deadwood and mineral soil). Finally, we used CNF rates measured in the hydration experiment to simulate CNF fluxes in response to precipitation throughout the growing season in the GYE.

Results and Conclusions: During the midsummer dry season, N inputs via fixation were modest across all study plots (< 0.5 kg N ha-1 y-1). On a per sample basis, rates of CNF in moss were generally much higher than fixation rates in mineral soil. However, on an area basis, inputs from CNF in mineral soil were generally higher, reflecting the low relative abundance of moss in most study plots. Despite some variability, N fixation rates generally increased with water additions, indicating that moisture strongly controls the process. Further research is needed to understand how climate controls CNF throughout the seasons in YNP. We intend to address these questions in the future by measuring actual CNF rates seasonally, and conducting additional experiments to explore the effects of climate on CNF.

2021 A CLIMATE ANOMALY OR A GLIMPSE INTO OUR FUTURE FOR AQUATIC HABITATS?

Robert Al-Chokhachy, David Thoma, Andrew Ray, Adam Sepulveda, Mike Tercek

Recent climatic studies have demonstrated considerable spatial variation in the magnitude of changes across the GYA, presumably owing to the diverse topography and climatology of the region. However, 2021 was a seemingly anomalous climatic year in the Greater Yellowstone Area (GYA) with exceptional drought and warm temperatures. Indeed, excessively warm temperatures, early snowmelt, and low precipitation led to historically low streamflow conditions in many rivers, widespread angling closures, and desiccation of wetlands. However, it remains unclear just how bad 2021was, and whether this year was a climate anomaly or a glimpse into our future. To address these questions, we evaluate recent climate and hydrologic data against historical conditions to understand (1) the severity of this past year in terms of climate; (2) how 2021 relates to past anomalous years (e.g., 1988); and (3) if the GYA still demonstrated high climatic variation—suggesting the potential for refugia. We then contrast these anomalous climatic years (e.g.,1988, 2021) with expected changes from the recent Greater Yellowstone Climate Assessment (Hostetler and Whitlock et al. 2021) to better characterize the magnitude of change approaching the GYA. Our study provides recent context for likely changes in the future in the GYA as an impetus for identifying climate adaptation strategies to build resilience among growing regional stressors (e.g., population change).

RESILIENCE OF YELLOWSTONE CUTTHROAT TROUT IN YELLOWSTONE LAKE IN THE FACE OF CLIMATE CHANGE

Robert E. Gresswell and Steven W. Hostetler

Yellowstone Lake supports the world's largest genetically unaltered assemblage of Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*, YCT). The fate of the iconic YCT populations in the face of climate change is a major concern of wildlife managers, conservationists, and the public. A confounding issue in Yellowstone Lake is the presence of lake trout (Salvelinus namaycush, LT) which have significantly altered the YCT assemblage through predation since being introduced to lake in the 1990s. Recent questions concerning the effects of climate change on the reproductive capacity of the two species prompted us to undertake a modeling study on the potential changes in thermal properties of the lake and spawning tributaries over the next 80 years. We contrast projected future changes with those of the early Holocene (12 ka, 9 ka, and 6 ka) when YCT experienced a wide range of climate conditions in the absence of LT.

Lake simulations suggest that under a high greenhouse gas emission (GHG) scenario (RCP8.5), the projected annual cycle of lake thermal characteristics (e.g., epilimnion temperature, ice cover, and open water period) at the end of the 21st century will be similar to those of the early Holocene. Under a GHG mitigation scenario (RCP4.5), potential changes in thermal regime are less extreme than those of the early Holocene. Projected future stream temperatures (2-3 °C warmer than present) will also be similar to early-Holocene temperatures but differ substantially in that early season temperatures will be 3-4 °C higher than present.

Based on field data collected from 1970s through the 1990s, the annual timing of YCT spawning in Clear Creek is tightly associated with the seasonality of runoff: peak numbers of fish arrive in late June just after peak flow. We found the timing of peak runoff at present is similar to that of the early Holocene but that projected future peak flow occurs 1-2 months earlier than either period due to projected reductions in snow, snowpack, and early snowmelt. Summer and fall runoff are also reduced in the future with elevated stream temperatures.

Our results suggest that effects of potential changes in the annual cycle of lake thermal habitat over the 21st century will be relatively minor and affect YCT and LT assemblages similarly. Furthermore, projected changes in spawning stream temperatures and discharge suggest that YCT will spawn earlier and larvae will return to the lake sooner than at present. Thus, growing season in the lake will be longer than today so it appears that the within the bounds of our future projections Yellowstone cutthroat trout will be resilient to climate change. At the same time, we found no evidence to suggest any negative effect on lake trout, suggesting that maintaining the current lake trout suppression program would likely improve the long-term persistence of YCT.

INVASIVE POTENTIAL OF A WEED PREDICTED TO INCREASE WITH CLIMATE CHANGE

Hannah Duff

Background/Question: Annual wheatgrass (*Eremopyrum triticeum*) is an introduced, cool season, annual grass that recently established in disturbed areas of the Gardiner Basin of Yellowstone National Park. Local managers are concerned that annual wheatgrass is preventing the reestablishment of native perennials. Although little is known about the reproductive capacity or spread of annual wheatgrass, it is suspected to be highly competitive with native species due to its winter annual lifecycle. Some studies predict that annual grass species will become more competitive with changing climate conditions, while others report inconsistent responses to rising temperatures.

Methods: The goal of this study was to assess the invasive potential of annual wheatgrass with two temperature treatments (ambient and elevated) in the Gardiner Basin using open-top chambers (OTCs). Lifecycle demographics were monitored in the field treatments and used to parameterize a lifecycle model that predicted plant population growth ten years into the future. Additionally, transects were surveyed in 11 other sites to assess the spread of annual wheatgrass throughout the Northern Range.

Results/Conclusions: We found evidence for a temperature treatment effect on annual wheatgrass seedbank density and population growth rates using the lifecycle model. Annual wheatgrass seedbank density is projected to increase by 44.61% by year 5 at elevated temperature conditions compared to an 8.74% increase at ambient temperature conditions. Annual wheatgrass population growth is projected to increase more rapidly (mean annual growth rate, λ= 1.79) by year 5 at elevated temperature conditions than at ambient temperature conditions (mean annual growth rate, λ = 1.1). Projected population growth rates at elevated temperature conditions had 0.8 probability of being greater than rates of controls after 5 years of simulated dynamics and 0.5 probability of being greater than rates of controls after 10 years. Model simulated seedbank densities had 0.95 probability of being greater than densities under ambient conditions after 5 simulated years and 0.98 probability of being greater than densities under ambient conditions after 10 years. We also found that annual wheatgrass percent cover was negatively correlated (R2=0.5288, p=0.002) with three of six neighboring plant species. Climate change projections for the region suggest warming winters may continue to favor annual wheatgrass. However, following a prescribed burn in fall 2019, non-blackened seeds were 27% viable according to a tetrazolium test while seeds blackened from the burn were 0% viable. Thus, higher intensity or frequency of prescribed burn may be needed to fully blacken fallen seedheads and effectively reduce annual wheatgrass live cover. We found high densities of annual wheatgrass at three additional sites in the Northern Range, meaning management options like monitoring and prescribed burning should continue to be explored.

USING THE PALEOENVIRONMENTAL ARCHIVE AT NEW MEXICO'S WATER CANYON SITE TO HELP PREDICT THE EFFECTS OF CLIMATE CHANGE IN THE GREATER YELLOWSTONE ECOSYSTEM

Robert Dello-Russo, PhD

BACKGROUND: Current models of how the climate of the Greater Yellowstone Ecosystem (GYE) could be affected by increasing greenhouse gas emissions derive from many things, including downscaled global climatic model simulations, and comparisons of model predictions to trends observed both in GYE historical data and in proxy-based reconstructions. Yet, according to Whitlock and Hostetler (Yellowstone Science, 2019:1), "the challenge with incorporating a paleo-perspective into a discussion of vital signs is that the past is incompletely known and seen through an imperfect lens". Beyond that, another pressing challenge we have is to understand how the biotic communities in the GYE will respond to the warming climate of the 21st century.

METHODS: To address these challenges, and to hopefully sharpen our imperfect focus, I propose using paleo-environmental data from alluvial fan sediments and an extensive fossil wetland archive at the Water Canyon Paleoindian site (WC) in west-central New Mexico. Although experiencing some minor erosional episodes, these deposits persisted for about 6000 years, from 14,000 to 8000 years ago. Research efforts at the site, since 2008, have recovered a broad suite of proxy paleo-environmental data sets, including pollen, phytoliths, macrobotanical remains, charcoal, diatoms, mollusks, stable carbon isotopes, sediment thin sections and bison bone beds. These, together with a substantial set of chronometric dates, have enabled researchers to reconstruct the evolution of the fauna, flora, hydrology and landforms at the site.

The early Holocene biomes at WC, while not identical, were analogous to some of those found in the GYE today (e.g. seasonal wetlands with obligate wetland grasses). In addition, the temperature regime at that time in New Mexico may have been somewhat congruent to the current temperature baseline of the GYE (e.g. shift from colder to warmer winters). If so, the responses by some components of those WC biomes to the warming climate of the early-to-middle Holocene should be instructive and could be integrated into our understanding of the future ecological dynamics of the GYE.

RESULTS / CONCLUSION: One example is the mid-Holocene arrival at WC of Cheno-ams, in response to the drying and increased alkalinity of soils in that setting. This reinforces the concern that non-native weedy species may rapidly colonize the GYE as climate warms. Additionally, there is evidence at Water Canyon of the local extirpation of deciduous trees, such as maple and birch, by the mid-Holocene. These trees shifted their distributions upslope (Rocky Mtn. maple) and both upslope and up-latitude (bog birch) to their present-day locations. They were replaced at Water Canyon by 4-wing saltbush and oak, among others. These patterns of range adjustment and replacement underscore the expectations of GYE scientists.

Thus, the integration of paleo-ecological data from WC can provide alternative benchmarks to help clarify connections between climate change and biodiversity in the GYE, and, potentially, to identify at-risk habitats and other indicators of ecological health in the GYE.

Complex Ecological Challenges II

Moderator: Erik Beever

A MULTI-TROPHIC LEVEL COMPARISON OF HEADWATER STREAM-RIPARIAN ECOSYSTEMS IN YELLOWSTONE'S NORTHERN RANGE

Jeremy Brooks

In Yellowstone's Northern Range, the extirpation of apex predators had cascading consequences on riparian plant communities, transitioning them from willow/alder to grassland-dominated. In some locations this trajectory has been reversed in recent decades through a trophic cascade triggered by large carnivore restoration, whereas others remain in grassland states. Other biotic (e.g., lack of beavers, increasing bison populations, and human hunters) and abiotic factors (e.g., geomorphology, hydrologic and precipitation regimes, and local soil characteristics) have mediated this transition in context-specific ways. Willow/alder stream-riparian ecosystems in the Northern Range have been described as biological hotspots integral to the broader ecosystem, however empirical investigations into the aquatic portion of these ecosystems remains limited. Across the current mosaic of stream-riparian conditions, we conducted a multi-trophic level comparison evaluating how riparian vegetation state influences food webs and ecosystem processes.

From 2018-2021, we intensively sampled five headwater streams (three willow/alder and two grassland-dominated) to characterize the diversity and productivity of aquatic primary producers, invertebrates, and fishes, as well as food-web linkages and trophic-transfer efficiencies.

Grassland-dominated streams had greater solar radiation and more extreme summertime daily maximum temperatures than willow/alder streams. Mean daily stream temperatures, however, were similar across all streams, except during the winter when only willow/alder streams froze. Annual gross primary production was 2-20 times higher in grassland streams, driven primarily by longer periods of productivity. Prior to spring leaf-out, some willow/alder streams had comparable peaks of productivity. Benthic biofilm community richness varied within and between stream categories, ranging from 6 dominant taxa to as many as 52. Total biofilm richness was not linked to riparian vegetation, however grassland streams had more nitrogen-fixing taxa than willow/alder streams. Invertebrate richness, diversity, and evenness were similar across all streams. The invertebrate taxa present were nearly identical across streams, though relative abundances varied. Annual secondary production of invertebrates and the taxa with the highest contributions varied within and between stream types. Fish assemblages also varied greatly within and between stream types, with both native and non-native fishes present. Annual prey demand by fishes, estimated from comparisons of fish consumption to invertebrate production, exceeded annual invertebrate production once in each stream type.

Despite higher primary production, grassland streams did not exhibit consistently higher annual secondary production of invertebrates or fishes. Together, this suite of observations suggests while riparian vegetation state influences these systems, individual site characteristics, from landscape position to traits of primary producers, invertebrates, and fishes to hydrologic and geomorphic conditions, ultimately all interact to mediate the current diversity, productivity and trophic-transfer efficiency of these Northern Range headwater stream-riparian ecosystems. These results and interpretation are preliminary. Future research directions include additional site-specific analyses and further analysis of aquatic-terrestrial linkages, including estimates of aquatic insect emergence, terrestrial invertebrate flux into streams, riparian spider diversity and abundance, song-bird diversity and abundance, and bat diversity and foraging activity. Through this work, we aim to provide a holistic investigation of stream-riparian food webs and ecosystem processes in Yellowstone's Northern Range.

TALL WILLOWS AND WILLOW THICKETS IN NORTHERN YELLOWSTONE, PAST AND PRESENT

Luke E. Painter and Michael T. Tercek

Background: The northern ungulate winter range, or Northern Range, of Yellowstone National Park provides an example of loss and then passive restoration of riparian shrubs. Wetlands and riparian areas of northern Yellowstone lost most tall willows during the 20th century, due to intensive herbivory by elk

(*Cervus canadensis*). Elk numbers decreased following large carnivore restoration in the late 1990s, and some researchers reported willows growing taller with reductions in browsing, evidence of a nascent willow recovery. Others have questioned the extent and significance of these changes. Using historical and current data, we investigated how willow heights have changed in northern Yellowstone since the 1990s, and assessed the importance of browsing as a driver of willow height and canopy cover.

Methods: We compared data collected by repeated sampling of the same transects over a 30-year period, from 1988-93 when elk densities were high and most willows very short, from 2001-04 when willows may have begun to recover, and from 2016-18. Where possible in the data, we compared the same plants in spring and summer over two years, to ascertain the cause of height suppression. We also located and measured willow thickets (groups of 5 of more willows >200 cm spring height, and <2 m apart) along streams in the study area. Tall willow thickets are an important habitat feature, and an indicator of willow recovery. We calculated the percentage of previously mapped willow patches that now contained willow thickets, as an index of willow restoration that could be compared between stream reaches.

Results: We found a strong contrast between sites along streams, compared to wet meadows (meadow sites). Willows in stream sites increased significantly in height, exceeding 200 cm mean height in summer by 2001-04, and in spring by 2016, a height indicative of recovery. Where height did not increase, as in the meadow sites, this was due to loss of annual growth to herbivory. Overall willow height distribution changed from mostly short, <100 cm, to become clearly bimodal, with a new peak around 300-400 cm. Bison increased, and, in some sites where bison congregate during summer, willows remained suppressed at heights below 120 cm, a condition strongly correlated with summer browsing. We found willow thickets in all stream reaches surveyed, a significant change from past conditions. Thickets occupied >80% of willow patches in some sites, but as little as 22% in others. Recovery of tall willow thickets may allow beavers to return to some stream reaches, possibly expanding willow habitat. Our results demonstrate that the reduction of elk herbivory over the last two decades in northern Yellowstone has allowed willows in existing willow patches to grow taller in many places, despite a warming and drying climate, while herbivory by elk and bison continues to suppress willows in some locations.

CLARK'S NUTCRACKER SEED HARVESTING FOREST COMMUNITY USE IN YELLOWSTONE NATIONAL PARK: A HIERARCHICAL DISTANCE SAMPLING APPROACH FOR MODELLING ABUNDANCE

Thomas McClaren

Clark's nutcrackers (Nucifraga columbiana) are keystone seed dispersers for many western conifer species and thus important agents of forest regeneration. Multiple seed resources within a region are necessary to sustain nutcracker populations but especially seeds of whitebark pine (Pinus albicaulis), a preferred but declining species. Many conifer species are known to display high variability in annual cone production. Annual variation in seed resource availability may be an important factor determining nutcracker forest community use, in part, because nutcrackers are energy sensitive foragers. In this study, we investigated which forest communities within Yellowstone National Park are used by nutcrackers and how that varied annually.

In 2019 and 2020, we established eleven 1 -km virtual transects in five different forest community types including whitebark pine, lodgepole pine, Engelmann spruce, limber pine and Douglas-fir. Each transect consisted of 5 point count stations and 11 tagged trees for annual cone counts. Each transect survey consisted of nutcracker point counts using distance sampling at the five point-count stations, , conifer cone counts from each tagged tree, and behavioral observations to determine habitat and seed resource use. Data were collected each summer and fall between 2019 and 2021. Using annual cone production indices collected along our transects, we analyzed how cone production varies between conifer species and across years. To determine which forest community types in the park are used by nutcrackers within a season and how variation in cone energy availability influences their use within and across years, we applied a hierarchical approach to habitat use modeling using distance observations to estimate detectability. Using AICc, we compared models for nutcracker abundance containing variables for: forest community type, seed harvesting time period, year and cone energy index. In addition to producing a hierarchical distance sampling model of nutcracker habitat use, we are conducting a simulation-based power analysis of the existing study design to determine its ability to detect a decline in the nutcracker population.

A regression analysis of cone count data indicated that cone crops were generally larger at our study sites in 2020 and 2021 compared to 2019, supporting annual variability in conifer cone production. Our hierarchical distance sampling analysis suggested conifer stem density as an important covariate in the detection process, indicating that nutcrackers were less detectable in more densely forested areas. We found that overall, nutcracker density was best predicted by forest community type. Nutcracker density was highest in whitebark pine stands, supporting the importance of the mutualism between the two species, and was comparably low for all other forest community types. These results, along with behavioral observations collected during our point count surveys support the importance of limber pine, and whitebark pine in particular, as seed resources for Clark's nutcracker. Results of our power analysis for long term nutcracker monitoring will provide the park with important planning information in light of the continued threats to whitebark pine within the Greater Yellowstone Ecosystem.

NO TITLE PROVIDED

Tara Durboraw, Diana Tomback, Walter Wehtje, Doug Smith

Background/Question: Clark's nutcracker (Nucifraga columbiana) is a seed-caching obligate disperser of whitebark pine (Pinus albicaulis), a keystone species in the upper subalpine forest throughout western North America. While the large, energy-rich whitebark pine seeds are the preferred seed resource for Clark's nutcrackers to eat and cache for later use, these birds also utilize other seed sources within Yellowstone National Park. Whitebark pine is declining across much of its range, including within the Greater Yellowstone Ecosystem, due to climate-driven mountain pine beetle outbreaks and the exotic white pine blister rust disease (fungal pathogen—*Cronartium ribicola*). In light of this decline and variable annual whitebark cone production, we are studying how nutcrackers utilize different forest communities and their spatial use in general both within and outside of the park. Thus, the objectives of this study are to determine (1) what forest types these birds are occupying seasonally and annually, (2) how individual Clark's nutcrackers use space within Yellowstone National Park, (3) if individuals that move beyond park boundaries return, and (4) nutcracker home range size in the Greater Yellowstone Ecosystem.

Methods: In March 2021, we caught six Clark's nutcrackers at two sites along the northern park road using suet-baited walk-in and bow net traps. Each bird was fitted with a battery-powered satellite GPS tag (3-gram, Lotek PinPoint Argos) programed to transmit GPS locations on varying schedules ranging from once every two days to once every two weeks. All birds were also banded with federal identification and color bands, and their weight, height, age class, and breeding status were documented. GPS locations were uploaded and accessed in Movebank, an online database of animal tracking data.

Results/Conclusions: All six individuals captured had brood patches, indicating that they were all actively breeding at the time of trapping. We have a total of 115 usable locations points from the six birds (24 points were either duplicates or geographically unrealistic and, thus, excluded from further mapping efforts). The individuals that continued to transmit into the fall seed harvesting season (n = 3) were all documented traveling beyond park boundaries, traveling as far as 120 kilometers, likely in search of whitebark pine seed resources. One of these individuals flew 11 kilometers North of park boundaries during this season, and remained in the area for approximately a month before returning to Yellowstone National Park. The other two individuals left park boundaries in June and remained outside the park for the remainder of the study—one flying 120 kilometers west to the Centennial Mountains and one flying 49 kilometers east to the Absaroka Mountains. To further explore the movement ecology of Yellowstone nutcrackers, we will conduct further trapping and tagging of individual birds in March of 2022. We plan to follow similar methods to trap eight more Clark's nutcrackers, more than doubling our sample size. However, rather than finite battery-powered transmitters, we will be affixing Lotek 2-gram Sunbird Solar Avian Argos tags to the birds in an effort to increase lifespan of transmitters and frequency of transmission intervals.

WILLOW RESPONSE TO REDUCED MOOSE HERBIVORY IN THE SOUTHERN ABSAROKA BEARTOOTH WILDERNESS

Rachael Dines, Dr. Daniel Tyers, Dr. Bok Sowell

Background: Our research examines long-term trends in willow (*Salix* spp.) condition in the southern

Absaroka Beartooth Wilderness (ABW) and adjacent drainages north of Yellowstone National Park (YNP). Due to snow conditions, moose (Alces alces shirasi) are the primary wintering ungulate that utilize willow stands in this portion of the ABW. Consequently, our research includes moose population monitoring along with assessments of willow height and browse rates. This is the first long term study on browsing and willow condition that has been done in this portion of the ABW.

Methods: To address concerns of willow suppression and over-browsing in the southern ABW, monitoring was started in the 1980's by the Gallatin National Forest (GNF) to observe long-term changes. As part of this monitoring, 179 1-meter plots have been measured annually since 1988 to track willow height and browsing rates. Further analysis includes a permanent exclosure established in 1962 that has been read approximately every 10 years to measure willow height and percentage of willow that intercepts transects inside and outside the exclosure fence. Additionally, indices of relative moose abundance have been recorded since 1987 through count transects on trails in the southern ABW and along the highway between Gardiner and Cooke City, MT.

Results/Conclusions: We found that willow height at the 179 plots increased on average 66 cm and the percentage of browsed twigs declined from 44% to 2% from 1989 to 2021. We also found that willow increased in height and canopy cover at a much faster rate inside the exclosure where it was removed from browsing. By 2020 height and canopy cover inside and outside were nearly equivalent. Average willow height inside and outside the exclosure has increased from 120 cm to 370 cm, and 80 cm to 350 cm, respectively, from 1963 to 2020. The percentage of willow that intercepts transects inside and outside the exclosure increased from 46% to 100%, and 20% to 100%, respectively, from 1963 to 2020. The average number of moose observed per transect on trails in the ABW has declined from 3.06 to 0.08 from 1988 to 2021, and the average number of moose observed per transect on the highway between Gardiner and Cooke City MT has declined from 1.60 to 0.45. Our findings suggest that a moose population decline and resulting reduced browsing has contributed to increased willow height in the southern ABW.

YELLOWSTONE ECOSYSTEM - HIGHLIGHTING GYE TO THE REST OF THE WORLD

Dave Carlson

Yellowstone Climate Assessment (YCA) represents a remarkable accomplishment. Researchers, forest, water and park managers, writers, and concerned citizens compiled, assessed and reported a wide range of material. Contributors and authors deserve accolades as credible, necessary, proactive messengers.

As advocates and admirers, however, we must recognize these reports as ponderous, unreadable to most, and - despite best intentions - far behind current issues and tools in ecological, environmental and climate research. Washington Post, working from NOAA data, showed large areas of Montana along the Canadian border already warmer by more than 2C; their published analysis reaches more people more quickly at a more frequent update rate than anything from Greater Yellowstone Ecosystem (GYE). Same newspaper this week reported just-published research on past and predicted ranges of Montana trout; the term 'trout' received only two mentions out of >80k words in YCA. Without downscaling (necessary in YCA but largely obsolete), ECMWF produces global forecasts every 6 hours at 9 km resolution. An openly-available global re-analysis covers our entire planet at 30 km resolution for the past 70 years. Recent carbon-interactive climate models explored global resolutions around 10 km. Today's satellite products run from 30 m out to 1 to 5 km spatial resolution with nearly-complete terrestrial coverage, good cloud masks and useful update rates. Research groups use these and other tools to anticipate fire potential and quantify wildfire emissions across western USA. An optimistic list of future monitoring options for GYE (YCA pages 182, 183) includes none of the above sources. Researchers and resource managers have little time, energy or funding to pursue their own good ideas, much less to track external data links. As a consequence, GYE remains a lagging backwater, a popular reliable destination largely silent about future threats.

Establishment of YNP and extension of concern to GYE represent a signal initiative. We now need to lift our location and our work to the center of national and global public attention. We need a "a climate information hub that is comprehensive, collaborative, accessible, and useful to experts and the public alike" (YCA page XIX, my emphasis). While we work to attract resources to and enhance monitoring of our marvelous setting, we must do so much more to expose visitors, residents, enthusiasts and administrators to current issues, changes and challenges. We can show ourselves as alert, aggressive, and responsive to local issues while also a showpiece to the rest of the world. We work in, live in and enjoy an ecological geophysical marvel, a carbon sink of (momentarily) immense value, a water tower for millions of citizens, and a hub for global visitors. We live in too great a place to not make maximum efforts to understand and protect.

Human Dimensions

Moderator: Jennifer Newton

A HISTORY OF PALEONTOLOGICAL DISCOVERIES AND RESEARCH WITHIN YELLOWSTONE NATIONAL PARK

Vincent L. Santucci, Justin Tweet, J.P. Hodnett, Jefferson Hungerford, and Melanie Cutietta

Our collective understanding of Yellowstone's fossil record is revealed at the intersection of the prehistoric realm of deep time and the historic human dimensions involving exploration and discovery. The Yellowstone fossil story can be told either from the perspectives of geologic time or human history. Both perspectives will be explored during the 2022 paleontological resource inventory currently underway in conjunction with the 150th anniversary for Yellowstone National Park.

The geochronological presentation of Yellowstone's fossils yields temporal and taxonomic details that date back in time to the Cambrian Period, presenting a story that spans over 500 million years of Earth history. Yellowstone's fossil-rich strata have been documented through the field observations and scientific investigations, beginning in the early 19th century, by individuals associated with the Lewis and Clark Expedition. Portions of Yellowstone's fossil story are romanticized in the tall tales of mountain men and fur traders, other portions are written by soldiers and scientists involved in government funded surveys. More recently, the story is expanding through fossil inventories undertaken by park rangers and paleontologists. The Sesquicentennial Paleontological Resource Inventory for Yellowstone National Park will carefully follow in the footsteps and review the records of the pioneers for Yellowstone paleontology, including: John Colter, Jim Bridger, Ferdinand V. Hayden, William Henry Holmes, Arnold Hague, George Girty, Timothy Stanton, Charles Doolittle Walcott, Leo Lesquereux, F.H. Knowlton, Erling Dorf, J.D. Love, Ed Ruppel, Estella Leopold, Scott Wing, Elisabeth Wheeler, Elizabeth Hadley, Cathy Whitlock, Vincent L. Santucci, and others who have collectively contributed to a richer understanding of Yellowstone's Paleontological Heritage.

REDUCING LIVESTOCK AND CARNIVORE CONFLICTS ADJACENT TO YELLOWSTONE NATIONAL PARK

Malou Anderson-Rameriz

Tom Miner Basin functions as a unique, biologically productive area for livestock, a diverse and highly desirable habitat for multiple species of wildlife (grizzly bears, wolves, moose, and elk, to name a few), and an established recreational area for hikers, hunters, wildlife enthusiasts, educators, tourists, and more . Adjacent to Yellowstone Park, Tom Miner encompasses dynamic community between people, livestock, wildlife, and wildlands.

The Anderson Family and Tom Miner Basin Association anchors land stewardship practices on adaptation rather than imposition. With an emphasis on curiosity and innovation and through data and observation, we hope to better understand our community holistically. We have learned that shared opportunities for education and understanding along with awareness and accountability greatly supports (and can enhance) a diversified, wild landscape-where large carnivores, elk, people, and livestock all belong and thrive.

Though our work is over-arching, specifically we've spent much of our time exploring different tools and practices to minimize livestock loss due to the large carnivores. We continue addressing coexistence as a crucial layer in agriculture today through the lens of regenerative agriculture. Maintaining open, private lands is fundamental in keeping large and open landscapes as well as essential wildlife corridors intact, healthy, and diverse.

Tom Miner Basin serves as a vital and highly desirable landscape for large carnivores, mainly grizzly bears and wolves. Through years of experimenting with conflict reduction tools and techniques between livestock and large carnivores (grizzly bears and wolves), we utilize the tools we've learned work well in specific seasons in order to reduce livestock loss due to predators. We've combined modern and innovative tools and techniques like fladry, camera traps, range riding, electric fencing, wearable technology, etc., with ancient and indigenous wisdom like recognizing the importance of ritual and ceremony, deep listening and observation, and better understanding around the impact of our often human-centric patterns and practices.

We've learned that the people and livestock on the land itself—land managers and owners, livestock managers, producers—are cornerstones in addressing the climate crisis and should be supported and empowered to engage in reclaiming and restoring open, wild lands. Through the practice of holistic grazing (utilizing livestock as a tool to help build and diversity soil and plants, sequester carbon, manage for soil cover and support healthy watersheds), we can also build a better food system and shift the paradigm of the experience people have with the food they eat and the deep connection between our own health and the overall health of the planet.

Lastly, we believe in the power of place to help reconnect people to a deeper level of curiosity, intention, and understanding of the natural and complex systems we live and work in as well as our impact within these systems. We provide a place where organizations and groups can safely explore the nuances of the natural world and our community (both human and more than human) as we navigate through our own stories and challenges.

THE IMPACT OF PERSUASIVE COMMUNICATIONS ON WILDLIFE APPROACH DURING UNGULATE VIEWING EXPERIENCES IN THE GREATER YELLOWSTONE ECOSYSTEM

Stephanie E. Freeman, B. Derrick Taff, Ben Lawhon, Peter Newman

Background/Question: Every year, millions of people visit parks and protected areas to view wildlife. Human-wildlife conflicts (HWC) occur when people approach animals at inappropriately close distances. Bison are involved in more dangerous interactions than any other species in the Greater Yellowstone Ecosystem (GYE), and conflict between people and elk is becoming increasingly concerning to managers in the GYE. Most of these incidents occur when people approach ungulates at proximities less than the GYE regulation of 25 yards, the equivalent of 2 bus lengths. The purpose of this study was to test how wildlife viewing communication messages impact park visitors' proximity to ungulates in the GYE. The following research questions are explored: 1) Do current NPS messages lead to accurate distance estimations by visitors? And 2) Is there a difference in the distances park visitors maintain from ungulates in the GYE based on message treatments?

Methods: A survey and approach exercise were conducted at Elk Ranch Flats in Grand Teton National Park and Mammoth in Yellowstone. The efficacy of current NPS messaging (i.e., 25 yards, 2 bus lengths) was assessed for the accuracy of distance estimations people made between themselves and wildlife. Additionally, two persuasive communications (i.e., fear appeal with resource protection language, awe appeal with visitor experience language) were tested against current NPS messaging to determine how close study participants would approach life-sized ungulate cutouts (i.e., bison cutout in Grand Teton, elk cutout in Yellowstone) on a 100 yard transect based on message content. One-way ANOVAs were used to analyze differences in approach behavior across messaging treatments.

Results/Conclusions: The results indicate that park visitors overestimate proximity when given the visual proxy and numerical distance currently employed by the NPS. This messaging strategy led to approach behavior of 66 yards away from the bison cutout and 61 yards away from the elk cutout.

Additionally, both persuasive communication strategies led to more conservative wildlife viewing proximities compared to the control. There was no difference in approach behavior across the persuasive communication treatments. Persuasive messages led to approach behavior of 77 yards away from the elk cutouts and 89 yards away from the bison cutouts. The results of this study have practical applications for the indirect management of HWC in the GYE and other parks and protected areas.

OBDURATE OPPORTUNITIES: THE STORIES THAT ANCHOR LOCAL RIVER KNOWLEDGE

Susan Gilbertz and Damon Hall

From the boundary of Yellowstone National Park at Gardiner, the Yellowstone River flows nearly 700 miles before entering the Missouri River in North Dakota. Once outside the park boundaries, over 80% of the riverbanks are privately held. Thus, even though many of the resources of the river and its environs are defined as public, there are thousands of local landowners whose private interests are physically and legally intertwined with public concerns. This project focused on discovering how those intertwined interests are described by people of the valley and the extent to which personal oral accounts were adjusted over time to new accommodate new information or contexts. Over a span of 12 years, researchers formally interviewed 15 people with interests in how the river was managed, including interviews in 2006, 2012, and 2018. Each person was interviewed during each field season, culminating in 45 interview transcripts. The same open-ended interview protocol was used during each field season, but it was designed to encourage the participants to shape the conversations in light of recent events and contexts. The 15 participants are referred to as Recurring Participants (RPs), and the interview data was treated as a longitudinal panel interview study. Qualitative analyses were conducted to reveal patterns of similarity and dissimilarity in the stories that were told by the RPs over time. The stories allowed researchers to track diverse understandings and issues that circulated among the people of the valley. Moreover, the data revealed personal "anchor stories" that individuals' used to explain how the river works, the projects they thought were worthy, their rights and the public's rights, and the degree to which agencies were valued as managerial entities. The anchor stories were place-based and experience-based; however, they often did not obviously dovetail with scientific or abstract information. The stories were proven to have an obdurate quality that appeared to stymie new ways of thinking about physical processes and river management. Yet, trace evidence regarding "channel migration" and "climate change" suggested that the stories were, at times, adapted to incorporate new perspectives. Thus, anchor stories also represented opportunities to document discursive change. As a conclusion, the authors posit that when new information is incorporated into anchor stories, it serves as a local insight, concomitant with staying power.

INNOVATING STEM STORYTELLING TO MORE EFFECTIVELY COMMUNICATE GYE SCIENCE

D.M. Debinski, K. Moss, and J. S. Durney

Background: "STEM Storytelling" is a novel approach for Science, Technology, Engineering and Math (STEM) professionals to engage with the public. The idea is to make science more interesting, compelling, and approachable for the average person. Scientific work can be presented orally, via written word, or through art or music. Scientists have traditionally published results of their research in journals that are read by small numbers of people in highly specialized fields. Similarly, they present work at scientific conferences that are rarely attended by the public. When reporters call scientists to inquire about summarizing their research, they are often met with hesitancy, as scientists fear that oversimplification of the research will lead to misinterpretations. Although there is a growing trend in science to focus on "broader impacts" which include public outreach, and some funding agencies even require such efforts, many scientists still have a way to go in accomplishing effective communication about their research. Given the current disconnect between scientists and the general public, as well as the perceived lack of trust in science, new approaches to communication could be particularly valuable.

Methods: Here we describe the development of an iBook called Wings that Make Waves that showcases scientists conducting a long-term research project in the Greater Yellowstone Ecosystem (GYE) to explain how butterflies can be indicators of climate change. This STEM storytelling endeavor evolved as a partnership between an ecologist and a biological illustrator, and uses a combination of photos, art, embedded videos, and text to communicate the story. The storyline is that butterflies can serve as ecological indicators to quantify changes in montane meadows because they are abundant, showy, easily identified, and tightly linked to the environmental conditions of the meadows. *Parnassius* butterflies, featured in the iBook, are native to montane meadows in the Greater Yellowstone Ecosystem as well as similar habitats in other parts of the globe. *Parnassius* butterflies lay their eggs each year in mid-summer. These eggs overwinter under the deep snow, hatching into caterpillars in the spring when snowpack melts, and flying as butterflies in summer. Although *Parnassius* butterflies in the GYE are not threatened or endangered, sister species in Europe are, and threats to their survival include forest encroachment, heavy metal contamination, and decreased snowpack. Our iBook summarizes how research on a small white butterfly may provide a window into understanding how climate change may be affecting montane ecosystems worldwide. The iBook was written for an audience of NPS visitors, K-12 teachers and students, and the general public. An associated travelling exhibit has been created for display in natural history museums and science centers.

Results/Conclusions: By creating a freely downloadable iBook with beautiful art, embedded videos, learning activities, and explanations about how anyone can become a "public scientist" this iBook is an example of the ways that scientists can partner with artists and biological illustrators to create alternative styles of communication to make scientific information and scientific engagement more easily accessible to a broad public audience.

RIVER OTTER LATRINES AS CARNIVORE-BIODIVERSITY HOTSPOTS: IMPLICATIONS FOR MONITORING CARNIVORES AND THE DEVELOPMENT OF EDUCATION PROGRAMS INTENDED TO PROMOTE CONSERVATION OF RIPARIAN AND AQUATIC HABITATS

Thomas Serfass

We evaluated the efficacy of placing camera-traps at river otter (*Lontra canadensis*) latrines (discrete sites in riparian areas where otters regularly deposit scats, urine, and anal secretions) to detect other carnivores occupying the Snake River in Grand Teton National Park, Wyoming and the Passaic River in Great Swamp National Wildlife Refuge, New Jersey and Grand Teton National Park, Wyoming, USA. We speculated that scents at latrines may serve as an attractant to other carnivores and evaluated this premise by using camera traps to compare carnivore detection rates (overall and by species) and richness and biodiversity (overall and for each survey month) between latrine and non-latrine riparian-control sites at each study location. Overall, carnivore detections at latrines were >10 times than at non-latrine sites, and overall carnivore richness and biodiversity were likewise much higher at latrines. The majority of carnivores known to occupy the study areas were detected at river otter latrines. We focus on outcomes derived from 3 years of camera-trapping along the Snake River where carnivores detected relatively frequently at river otter latrines included grizzly bears (*Ursus arctos*), black bears (*Ursus americanus*), wolves (*Canis lupus*), coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*); stripped skunks (*Mephitis mephitis*), American mink (*Neovision vision*), American martens (*Martes americana*), North American badgers (*Taxidea taxus*), and raccoons (*Procyon lotor*). In addition to detections, we also discuss behaviors indicating that carnivores were attracted to the scents deposited by river otters at latrines, in contrast to being detected as part of normal travel patterns in riparian areas. Our study provides compelling evidence that placement of camera traps at river otter latrines may serve as a new and novel approach for future monitoring of carnivore populations in riparian areas. Such an alternative approach to monitoring carnivores through camera-trapping could be particularly advantageous given limitations of using traditional bait and lure attractants, which contribute possible human safety and legal implications related to attracting large carnivores to areas that may be occupied by outdoor recreationists. We also use evidence from outcomes of camera-trapping efforts to demonstrate the potential for river latrines to serve as novel areas for the future development of public education programs focused on riparian and aquatic habitats, thus using the river otter as a flagship for promoting the conservation of these areas.

YELLOWSTONE CONTROLLED GROUNDWATER AREA – PROTECTING GEOTHERMAL FEATURES BY REGULATING GROUNDWATER

Attila Folnagy and Kerri Strasheim

The Yellowstone Controlled Groundwater Area (YCGA) was established on January 31, 1994. The

purpose of the YCGA is to monitor and regulate groundwater development adjacent to Yellowstone National Park (YNP) to preserve geothermal features. Applicants wishing to appropriate water in the YCGA must apply for a Permit for Beneficial Water Use from the Montana Department of Natural Resources and Conservation (DNRC) and install a meter to measure the total volume of water used. Groundwater with a temperature of 60 degrees Fahrenheit (oF) but less than 85 oF have additional criteria that must be met for use. Groundwater with a temperature of 85 degrees Fahrenheit or more is generally restricted from beneficial use.

Team work has been critical in protecting the geothermal features of YNP with DNRC working closely with State and Federal Partners. A Technical Oversight Committee (TOC) was created in the Montana/National Park Services (NPS) Compact, passed in 1993 by the Montana Legislature. The TOC, whose directive is to ensure that no new groundwater development will impact the hydrothermal system of YNP, is comprised of representatives from DNRC, NPS, Montana University System, United States Geological

Survey, and a Nominated Member. The TOC makes recommendations regarding any water encountered with a temperature greater than 60 oF, steering scientific studies and data collection, and continuously evaluating the YCGA boundary.

Cold water can also present challenges for water management within the YCGA. The Town of West Yellowstone changed the location of their public water supply wells due to Arsenic concentrations in their other wells; however, this created challenges related to the new wells being connected to a different surface water source in a closed basin to new appropriations.

Some private water rights for hot water existed prior to the YCGA. One example is the LaDuke Hot Springs – a new commercial hot springs recently opened using this historical water right. The Gardiner area is a known geothermal resource area where most of the warmer water wells are encountered.

More education and research are needed in this area to help water users and well drillers avoid tapping into this resource. There is limited data available to describe and quantify the hydrothermal flow system in and around YNP; however, the TOC continues to promote additional research and monitoring to help all of us better understand this unique resource.

Complex Ecological Challenges

Moderator: Cathy Whitlock

NATIVE PLANT COMMUNITY RESPONSE TO CHEATGRASS MANAGEMENT IN THE HIGH ELEVATION SAGEBRUSH-STEPPE OF THE CENTENNIAL VALLEY

Colter Mumford, Dr. Matthew Lavin, Dr. Jane Mangold, Dr. Lisa J. Rew

The Centennial Valley of the Greater Yellowstone Ecosystem is home to 18 endemic and 28 rare plant species. Aside from its diverse plant community, the Centennial Valley provides critical habitat for migrating birds, sage grouse (*Centrocerus urophasianus*), and domestic and native ungulates. Historic sagebrush grassland degradation in other parts of the western United States has led to growing concern from private and public land managers about, recent invasion of the Centennial Valley by cheatgrass (*Bromus tectorum*). Cheatgrass invasion is often correlated with a range of disturbances (e.g. fire, grazing, infrastructure development). Early control of cheatgrass is imperative. Our study aimed to: 1) quantify the efficacy of the herbicide imazapic (Plateau, 6oz ai/A) to control cheatgrass, and 2) monitor native plant community response to cheatgrass removal.

Herbicide was applied to 12 south facing hillsides in the Centennial Valley in both fall 2017 and 2018. The efficacy of herbicide to control cheatgrass and its impact on plant biodiversity were monitored at two scales for each hillside, local (10m2) and landscape (hillside), over the course of three years (2019-21). The study consisted of two treatments at the local scale, sprayed and non-sprayed within a cheatgrass infestation, where cover of all species was recorded in five Daubenmire frames (20x50cm). At the landscape (hillside) level there were also two treatments, sprayed and reference: the reference sites were adjacent to the sprayed communities and represent a desired community with very low cheatgrass abundance. Vegetative cover on hillsides were sampled using three 100m transects with five Daubenmire frames per transect. Data were analyzed using generalized linear models that included random effects to account for the nested sampling design of frames (n=5) within sites (n=12) for the local scale model (n=60 total), and frames (n=5) within transects (n=3) within sites (n=12) for the landscape scale model (n= 180 total).

Herbicide reduced and continually suppressed cheatgrass at the local scale over the three years post application ($p<0.001$). However, natural decreases in cheatgrass abundance were also observed in the non-sprayed local plots ($p<0.001$), though the overall abundance was always greater compared to the sprayed plots. At the landscape scale, in the first year after application there was no difference in cheatgrass abundance between the sprayed and reference community ($p=0.967$) but abundance increased slightly (0.45% cover $p=0.023$) over the subsequent three years, but not to the extent that management is warranted. Plant diversity was not different at the local scale ($p=0.867$). At the landscape scale plant diversity remained greater in the reference community compared to the sprayed community each year ($p=0.03$).

Our results confirm that herbicide application is effective at controlling cheatgrass at both local and landscape scales in high elevation sagebrush steppe, and that differences in biodiversity between the landscape scale sprayed and reference communities are becoming more similar over time. Continued monitoring is needed to determine if this trend persists.

EFFECT OF SEEDING METHODS, BROMUS TECTORUM COVER, AND NATIVE GRASS COVER ON RESTORATION OF SEMI-ARID GRASSLANDS

Erin B. Teichroew, Colter Mumford, Lisa J. Rew

The semi-arid sagebrush steppe and grasslands of the Greater Yellowstone Ecosystem support a biologically diverse community of organisms. Since European colonization, multiple invasive species have established in this area, including the annual grass *Bromus tectorum*. Land managers typically use herbicides to manage *B. tectorum* and often seed desired species after treatment. Restoration seeding is required because the recovery of native grasses can be slow due to depleted seedbanks, allowing *B. tectorum* or other non-natives to reinvade. However, restoration seeding is expensive, and recovery of existing species is likely related to abundance of desired species prior to management. Therefore, we conducted a study to evaluate if: 1) natural seedling recruitment increased along a native grass cover gradient and 2) if different seeding methods (broadcast and seed pellets at 20.2 kg/ha) and timing (fall and spring) improved success of restoration seeding. Four seeding treatments (control, fall broadcast (2020), spring broadcast (2021), and spring pellets (2021)) were compared along a native grass gradient, and replicated 4 times. The seeding treatments were applied to south facing slopes in the Centennial Valley of the Greater Yellowstone Ecosystem, that were treated with herbicide (imazapic; fall 2017-2018; 0.42 kg/ha ai) to reduce *B. tectorum.* Complete species counts, seedling counts, and basal cover estimates were collected to analyze changes in biodiversity. Seedling recruitment was very low and did not differ along the native grass gradient, suggesting that seed rain from established native grasses was not increasing aboveground cover. Seeding method did not have any effect on community richness or evenness in the first year. Bromus tectorum cover was associated with increased evenness, but did not affect richness, and did not decrease along the native grass gradient. However, it should be noted that cover of all species was low due to the drought.

Seed pellets remained largely intact over the summer, possibly due to drought conditions, which inspired a greenhouse study to determine the ideal pellet composition and the amount of water required for pellet decomposition and seedling establishment. We compared pellets with different composition ratios (3:3:1, or 1.5:3:1 (clay: organic material: seed)), different sizes (1.5, 2, 2.5 cm), and different watering rates (0, 2.5, 5, 10, 15, 30 mm) which correlate with mean storm totals for winter and spring in our region. Each pot received its prescribed rate of water daily until the pellets sprouted or broke apart. We found that pellets with the 3:3:1 composition never broke apart but did have an average of 18 (±21) seedlings/pellet, with the watering rate of 100 ml producing the most seedlings (35.6± 21). This suggests seeds can germinate within the pellets; however, we are uncertain how the competition will affect the seedling survival if decomposition does not occur.

NO TITLE PROVIDED

Adam Sepulveda

Proliferative kidney disease (PKD) is an emerging disease that recently resulted in a large mortality event of salmonids in the Yellowstone River (Montana, USA). Total PKD fish mortalities in the Yellowstone River were estimated in the tens of thousands, which resulted in a multi-week river closure and an estimated economic loss of US$500,000. This event shocked scientists, managers, and the public, as this was the first occurrence of the disease in the Yellowstone River, the only reported occurrence of the disease in Montana in the past 25 yr, and arguably the largest wild PKD fish kill in the world. To understand why the Yellowstone River fish kill occurred, we used molecular and historical data to evaluate evidence for several hypotheses: Was the causative parasite *Tetracapsuloides bryosalmonae* a novel invader, was the fish kill associated with a unique parasite strain, and/or was the outbreak caused by unprecedented environmental conditions? We found that *T. bryosalmonae* is widely distributed in Montana and have documented occurrence of this parasite in archived fish collected in the Yellowstone River prior to the fish kill. *T. bryosalmonae* had minimal phylogeographic population structure, as the DNA of parasites sampled from the Yellowstone River and distant water bodies were very similar. These results suggest that *T. bryosalmonae* could be endemic in Montana. Due to data limitations, we could not reject the hypothesis that the fish kill was caused by a novel and more virulent genetic strain of the parasite. Finally, we found that single-year environmental conditions are insufficient to explain the cause of the 2016 Yellowstone River PKD outbreak. Other regional rivers where we documented *T. bryosalmonae* had similar or even more extreme conditions than the Yellowstone River and similar or more extreme conditions have occurred in the Yellowstone River in the recent past, yet mass PKD mortalities have not been documented in either instance. We conclude by placing these results and unresolved hypotheses into the broader context of international research on *T. bryosalmonae* and PKD, which strongly suggests that a better understanding of bryozoans, the primary host of *T. bryosalmonae*, is required for better ecosystem understanding.

CLEARING LEGAL BARRIERS TO CONSERVATION LEASING ON PUBLIC LANDS

Shawn Regan, Temple Stoellinger , and Jonathan Wood

Background: Public lands account for more than half of the total land base in the American West, including nearly 66 percent of the Greater Yellowstone Ecosystem. With the exception of national parks, designated wilderness, and other protected areas, rules governing natural resource management on multiple-use public lands are often biased toward extractive uses, requiring leaseholders to extract, graze, divert, harvest, or otherwise develop resources. These rules made sense more than a century ago to discourage waste and prevent speculation, but they create new challenges today. Nongovernmental organizations, for example, generally cannot hold federal grazing permits for conservation purposes and must instead pursue regulatory measures or litigation under various environmental statutes to influence land-use outcomes.

In recent years, there is growing interest in facilitating conservation use of natural resource rights on public lands to protect landscapes, conserve wildlife habitat, or resolve wildlife-livestock conflicts. Such efforts have taken a variety of forms, such as grazing-permit buyouts and timber-leases for conservation purposes, with many examples occurring in the Greater Yellowstone Ecosystem. Legal and institutional barriers to non-use conservation leasing, however, make such arrangements the exception, rather than the norm, and exacerbate political and legal conflicts over public land management.

Methods: We provide an overview of the legal and institutional barriers that inhibit conservation leasing on public lands, with a focus on federal rangelands. We also explore several case studies of conservation leasing in the Greater Yellowstone Ecosystem that demonstrate a market-based alternative to political and legal conflict over public land-use decisions.

Results: We identify several potential policy pathways to clear legal barriers to conservation leasing of federal grazing permits for non-grazing conservation purposes. These include both administrative options that could be advanced under current statutory authorizations as well as potential legislative reforms to support conservation leasing.Success will require proper design and implementation of leasing programs that draw on the experience of existing conservation markets.

CLEARLY CONTAMINATED: NON-BLOOMING CYANOBACTERIA AND THE RISK OF TOXIN EXPOSURE IN GYE LAKES

Katherine E. Low and James F. Haney

Cyanobacteria are normally found in low concentrations in freshwater lakes worldwide, but they can degrade aquatic habitats by rapidly reproducing and condensing to form surface blooms. These blooms can generate potentially harmful levels of cyanotoxins – toxic metabolites with health effects ranging from mild skin irritation to acute respiratory failure and death. Climate change is expected to exacerbate these health risks by supporting greater cyanobacteria densities and increasing the potential for toxin exposure. As a result, there are now widespread efforts to monitor and manage cyanotoxin exposure. However, current monitoring efforts focus mainly on lakes with histories of severe bloom events, and the risk of toxin exposure from historically clear-water lakes like those in the Greater Yellowstone Ecosystem (GYE) remains poorly understood.

Although cyanobacteria blooms are rarely observed in the GYE, previous research identified relatively high accumulations of two cyanotoxins in Common Loons (Gavia immer) breeding in this region. However, because baseline cyanotoxin levels in the GYE have not yet been established, our collective ability to assess and potentially mitigate cyanotoxin-related health threats remains limited. Using a combination of standardized and novel monitoring techniques, we identified sources and baseline concentrations of three common cyanotoxins (BMAA, microcystins, anatoxin-a) in GYE lakes. We then used stable isotope analysis to identify trophic relationships among consumers and track cyanotoxin transfer throughout lake food webs. We are currently using this information to develop models that can predict cyanotoxin exposure risk in various species for use in future monitoring and management.

Preliminary results suggest that non-bloom forming cyanobacteria are present in high densities in GYE lakes and are important producers of cyanotoxins in this region. As a result, the sampled lakes maintain a clear-water appearance but support cyanotoxin concentrations comparable to those found in lakes with harmful cyanobacteria blooms. All three toxins biomagnified between producers and consumers, indicating that exposure through dietary pathways could be especially high. Each toxin accumulated mainly in zooplankton and macroinvertebrates, suggesting that these species can be used as sentinels for dietary cyanotoxin exposure in higher-order consumers, allowing for widespread monitoring of exposure risks based on a limited number of easy-to-obtain samples. Preliminary models using these indicators suggest that cyanotoxin exposure in various GYE species falls below acute management action thresholds but may lead to harmful health effects later in life. However, cyanobacteria abundance can change rapidly and is generally expected to increase in response to climate change, emphasizing a need to continually monitor cyanotoxins in GYE lakes, regardless of their appearance. The development of rapid assessment techniques, such as the model described here, will allow us to better monitor these changes and develop new management strategies that can address the growing risk of cyanotoxin exposure in the GYE.

Panel Discussion On Gray Wolf Management

DO PROTECTED AREAS PROTECT GRAY WOLVES?

Panelists: Douglas W. Smith, Kira A. Cassidy, Jennifer Carpenter, Gus Smith

Transboundary wildlife movements result in some of the most complicated, unresolved wildlife management issues across the globe. Depending on location and managing agency, gray wolf (Canis lupus) management in the United States ranges from preservation to limited trophy hunting to population reduction. Recently some states in the western United States have shifted from more conservative wolf harvests to more liberal population reduction harvests. All three states sharing borders with Yellowstone National Park, and the one state bordering Grand Teton National Park, use wolf harvest seasons as part of the management strategy. Each state has different wolf management objectives. The National Park Service preservation mission mandates that wildlife and biological processes be held to a no-impairment standard for future generations. This panel will discuss recent research from five National Park units on the extent and impacts of human-caused mortality on two gray wolf biological processes: pack persistence and reproduction with a focus on Yellowstone and Grand Teton National Parks. The panel will discuss the benefits and complexities of agency collaboration, including the differences between one protected area established 150 years ago and another established more recently. The panel will also discuss potential futures for transboundary management of gray wolves.

Geology

Moderator: Jefferson Hungerford

IMAGING THE YELLOWSTONE MAGMATIC SYSTEM WITH ACTIVE AND PASSIVE SOURCES RECORDED BY A DENSE GEOPHONE ARRAY

Jamie Farrell, Sin-Mei Wu, Fan-Chi Lin, Brandon Schmandt, Hsin-Hua Huang

The upper-crustal magma reservoir that underlies much of the 0.63 Ma Yellowstone caldera has been extensively studied using both active and passive geophysical techniques, as well as geologic and geochemical techniques on the many surficial deposits from past eruptions. Even though much is known about the Yellowstone volcanic system, many important aspects remain uncertain including whether low-crystallinity (eruptible) magma exists in the upper crust and how the upper crustal magma reservoir is linked to the overlying hydrothermal system. In the summer of 2020, the University of Utah and the University of New Mexico deployed ~650 Magseis-Fairfield 3-component geophones throughout Yellowstone National Park, including two dense lines that cross the 0.63 Ma caldera. The instruments were deployed for roughly 1 month before they were retrieved. Passive seismic recording was intended for noise interferometry methods and analyses of local to teleseismic earthquakes. A small earthquake swarm with events up to ~M3 occurred within the node array near the West Thumb of Yellowstone Lake. In addition to passive seismic recording, a vibroseis truck was used as a seismic source at ~110 pullouts along the two dense lines following the road system where it transects the estimated location of the upper crustal magma reservoir. Data from both the active and passive parts of the experiment will be used to better image the upper portions of the Yellowstone magma reservoir as well as the overriding caldera fill and hydrothermal system. Modeling of the amplitude versus offset of backscattered P to S conversions will be used to better estimate melt concentrations at the top of the magma reservoir. Preliminary ambient noise tomography results show that the addition of the dense geophone array greatly enhances the ability to map the velocity structure of the Yellowstone magma reservoir, requiring much lower shear velocities than previously estimated.

NO TITLE PROVIDED

William Fagan

The Upper Geyser Basin at Yellowstone National Park (Wyoming, USA) harbors the greatest concentration of geysers worldwide. Researchers have long speculated that individual geysers are not isolated but rather are hydraulically connected in the subsurface with other geysers and thermal springs as a dynamical system. To quantify such potential connections, we employed a cutting edge computational analysis technique called 'reservoir computing' (RC) that combines approaches from machine learning, causal inference, and dynamical systems modeling. We used RC to characterize the collective eruptive behavior of a set of 10 geysers over 18 months, focusing on geyser-geyser interactions. Data on the temperature of water in the geysers' outflow channels (collected every 1 to 6 minutes, depending on the geyser) provided the raw material for the analyses. With these data, RC works by training a high-dimensional dynamical system to mimic the time evolution of the geyser temperatures. In this context, the main objective of the RC method is to estimate the influence of the geysers on one another, recognizing that we are not able to measure the full set of relevant interacting variables characterizing the geyser system (e.g., unknown elements include underground connectivity, hydrology, other geysers without temperature loggers). Reservoir computing approaches this objective by constructing a numerical model of the measured geyser temperature profiles that recapitulates the observed data in great detail. This numerical model is able to predict the temperature of all the geysers at some imminent future point using the past temperature data from all geysers, while accounting for strong nonlinearities and multiple time-lags within the geyser network.

Overall, we found that RC did an excellent job emulating the 18-month temperature timeseries across the 10 geysers. Subsequent analyses demonstrated that cone-type geysers have larger impacts on other geysers than do fountain-type geysers. Similarly, cone-type geysers are more insulated from the effects of other geysers. Among Cone-type geysers, Beehive, Grand, and especially Dome experienced the smallest impacts from other geysers and had large impacts on other geysers. Overall, we found that predictions from the reservoir computer were up to 15 times better when we sought to predict a geyser's eruptions from the network of 10 geysers than based on its own eruption history alone, suggesting the existence of an interconnected subsurface complex system. Distance between geysers also affects interactions: nearby geysers had stronger effects on focal geysers than did geysers located further away. Collectively, results support the hypothesis of geyser interdependence at time-scales of 5 min to 10 d. Our analyses highlight the existence of quantifiable geyser-to-geyser interactions that can be resolved through pairwise and system-level analyses. These findings emphasize the subsurface interconnectedness of thermal features, provide information relevant to visitor experiences in Yellowstone, and suggest strategies for exploring patterns of interdependence that may exist among other geological phenomena.

HOLOCENE HISTORY OF LOWER GEYSER BASIN TOLD THROUGH LAKE SEDIMENTS

Christopher M. Schiller, Cathy Whitlock, Sabrina R. Brown, and Petra Zahajská

The ecosystems of the Yellowstone region are strongly influenced by geologic phenomena, notably within thermal basins where heat and thermal waters impact vegetation, in addition to climate and fire. However, how geyser basins and their ecosystems evolve through time and in response to shifting climate is unknown. To this end, we present paleoenvironmental data from a sediment core at Goose Lake (44° 32′ 29″ N, 110° 50′ 33″ W, 2200 m.a.s.l.) in Lower Geyser Basin to explore the influence of climate, fire, and hydrothermal activity over the last 10,300 years. We identify two periods of vegetation and landscape development: (1) From 10,300 to 3800 cal yr BP, the lake was directly influenced by hydrothermal activity, as evidenced by deposition of sapropel enriched in heavy metals (chiefly arsenic), relatively heavy sediment δ13C values, and abundant alkalinity-tolerant diatom taxa. A fluorite mud deposit (~84 wt% fluorite) in this interval clearly points towards hydrothermal provenance. Pollen and charcoal data indicate the lake was surrounded by Pinus contorta forest at 10,300 cal yr BP and the forest became increasingly closed until 3800 cal yr BP; fire activity was high during this interval. Other pollen records from sites in present-day P. contorta forest show similar increases in forest density during this period, which are attributed to a shift from warm, dry conditions in the early Holocene to cool, moist conditions in the late Holocene. (2) From 3800 cal yr BP to the present, hydrothermal activity within Goose Lake ceased, as indicated by deposition of fine-grained diatomaceous ooze that was relatively depleted in heavy metals with more negative δ13C values than before. P. contorta forest became more open at Goose Lake as evidenced by high levels of Artemisia pollen. The Goose Lake record after 3800 cal yr BP diverges from other sites in central Yellowstone that show increasing forest closure to the present. We suggest that the Goose Lake data reflect the ecological effects of local hydrothermal area expansion in Lower Geyser Basin. The timing of this expansion, roughly coeval with a period of centuries-long drought in North America, may hint at a connection between hydroclimate and hydrothermal activity in this system, compelling further study of spatiotemporal variations in hydrothermal activity from a network of sites.

A LANDSLIDE INVENTORY AND GEOSTATISTICAL ANALYSIS FOR GRAND TETON NATIONAL PARK, WYOMING

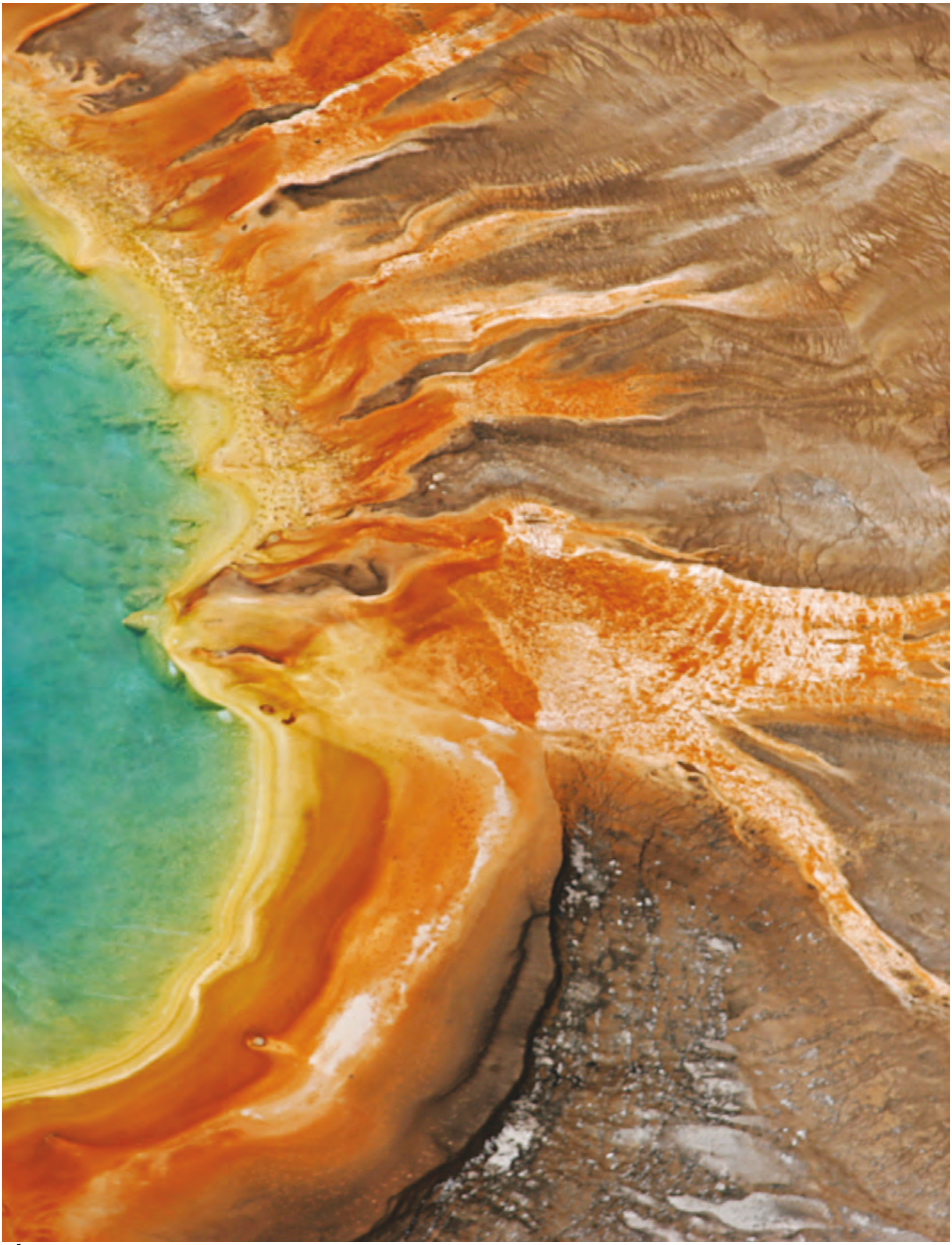
Joshua Lingbloom and Benjamin Crosby

Mass movements are a widespread and frequently destructive occurrence in places with high topographic relief, active seismicity, intense precipitation, and/or glacially-oversteepened topography, such as northwest Wyoming's Teton Range. Because roads, trails, and other infrastructure or populated spaces often co-occur within these landscapes, landslide inventory maps serve as a foundational dataset for modeling landslide susceptibility and assessing the hazards and risks posed by future events. Although mass movements are a known concern in Grand Teton National Park and a management priority, especially in light of the record visitation experienced in 2021, no comprehensive landslide inventory exists to inform park management decisions. In this study, we address this need by using a 0.5-meter LiDAR elevation dataset, aerial imagery, and detailed field observations to produce a novel landslide inventory map encompassing Grand Teton National Park, the John D. Rockefeller, Jr. Memorial Parkway, and the National Elk Refuge. The current inventory includes ~800 independent mass movements throughout the study region. The diversity of mass movement types and topographic and geologic settings enables us to prospect for patterns in the dataset. Toward this end, we apply three geostatistical methods. First, descriptive statistics identify broad patterns in the frequency and distribution of landslides in the park. For instance, the frequency and type of movements is spatially heterogeneous throughout the park, with debris flows, rockfall, and earth flows comprising the majority of observed mass movements but are clustered in unique settings. Second, we use logistic regression tests to explore the extent to which topographic domain (slope, curvature, aspect, and relief) and geologic substrate can predict the presence and absence of landslides. We find that substrate lithology, slope, vertical relief, and plan slope curvature are the most significant predictors. Finally, multinominal logistic regression ascertains the degree to which these same factors control mass movement type. Since the Teton Range has wide variations in topography, structure, and lithology, our statistical findings serve to advance our understanding of where and how mass movements occur in other landslide-prone regions. We also aim to share our findings with the public and management community through a StoryMap web portal, hopefully instigating further research into the triggers, history, and risk mitigation of mass movements throughout the Greater Yellowstone Ecosystem.

SUSTAINABLE PROTEIN PRODUCTION FOR FOOD APPLICATIONS FROM A MICROBE, *FUSARIUM STRAIN FLAVOLAPIS*, ISOLATED FROM YELLOWSTONE NATIONAL PARK

Debbie S. Yaver

In 2009, as part of a NASA and NSF-supported project on extremophiles, a filamentous fungus now called *Fusarium strain flavolapis* was isolated from an acid sulfate chloride spring in Yellowstone National Park. The extreme conditions in which *F. strain flavolapis* thrives are unsuitable for most microorganisms with pH less than 3, high salt concentrations (osmotic pressure), and UV light (elevation of 7500 feet). The fungus was found in an algal mat together with Zygogonium algae and was isolated by serial dilution on autoclaved Zygogonium followed by plating to separate it from bacteria. A draft genome sequence of the strain was obtained and based on phylogenetic analysis it was classified as a Fusarium strain and given the name Fusarium novum yellowstonensis. It was later renamed Fusarium strain flavolapis and is part of the Fusarium fujikuroi complex. F. flavolapis has a pH optimum for growth from 2.5-4; it can grow from pH 0.7-7. It grows well on simple sugars, cellulose, lignocellulose substrates, and oils producing high amounts of secreted enzymes when grown under fully aerated conditions on cellulose, lignocellulose and oil. F. flavolapis hydrolyzes 80-85% of dilute acid pretreated and AFEX (ammonia fiber expansion) pretreated wheat straw and switchgrass into sugar monomers and other soluble substrates within 5-6 days. The conditions for highest enzyme production are 30 degrees C, pH 5, 8% solids loading with AFEX pretreated feedstock after 6 days cultivation. It also accumulates large amounts of lipid bodies when grown on monomeric sugars with nitrogen limitation such as carbon to nitrogen ratio of 40. F. flavolapis produces lipids when grown on AFEX pretreated switchgrass; 95% of the lipids are C16:0, C18:0, C18:1 and C18:2 triacylglycerides. Because of this the strain was being developed to produce biodiesel from lignocellulosic feedstocks. There was an interest in investigating other uses for *F. strain flavolapis*. Under appropriate cultivation conditions, a filamentous mat of mycelial biomass (biomat) can be grown with a texture profile like muscle fibers. Research into fermentation methods to produce biomats of *F. strain flavolapis* led to the development of an air-liquid interface fermentation technology that allows for fast production of protein. Biomats are grown in trays in an acidic growth medium and incubated in a growth chamber under controlled temperature and humidity followed by downstream processing including inactivation by steam, rinsing, and pressing. The processed mycelial mat (Fy) has an excellent nutritional profile as a macronutrient and protein source and supplies all the essential amino acids as well as dietary fiber while being low in fat. Fy is >45% protein based on dry weight, has a protein digestibility-corrected amino acid score (PDCAAS) score of 0.92 like beef, and is high in branched chain amino acids (20-25% of the protein). On a dry weight basis, carbohydrate is 42% with 31% fiber of which 28% is insoluble fiber. Production of Fy emits roughly 94% fewer greenhouse gases, and uses 99% less land, and 99% less water than growing beef, with no methane emissions, and minimal waste. Fy can be left as is, liquified or made into a flour and used to produce a number of food products. Non-dairy cream cheese and meatless breakfast patties made with Fy under the Nature's Fynd label currently available in parts of the United States.



Moderator:Bob Griswold

MODELING CHRONIC WASTING DISEASE SCENARIOS—EFFECTS OF HUNTING AND PREDATION.

Paul C. Cross, Ellen E. Brandell, Will Rogers, Douglas W. Smith, Nathan L. Galloway, Daniel MacNulty, Daniel R. Stahler, John Treanor, Peter J. Hudson

Chronic wasting disease, a fatal disease of elk, deer and moose, is encroaching upon the Greater Yellowstone Ecosystem. As a slow, chronic infection it will be many years before empirical data can assess how hunting and predation may affect CWD prevalence and impact in this region. We use a modeling framework to investigate different hunting and predation scenarios. Male mule deer and white-tailed deer tend to have higher prevalence of CWD than females and this is the basis for increasing male harvest as a CWD control strategy. However, high prevalence does not necessarily mean that males are responsible for most transmission. We show how multiple transmission mechanisms may lead to higher prevalence among males and the mechanism affects how effective male-biased harvests will be. Predators may create healthier and larger prey populations by selectively removing diseased individuals. Predators typically prefer some ages of prey over others, which may, or may not, align with those prey age classes that are most likely to be diseased. Model results suggest that under moderate, yet realistic, predation pressure from cougars and wolves independently, predators may decrease CWD outbreak size substantially and delay the accumulation of symptomatic deer and elk. The magnitude of this effect is driven by the ability of predators to selectively remove late-stage CWD infections that are likely to be most responsible for transmission, but this may not be the age class they typically select. Predators that select for infected young adults over uninfected juveniles have a stronger cleansing effect, and these effects are strengthened when transmission rates increase with increasing prey morbidity. Current CWD management focuses on increasing hunting as the primary management tool. However, management agencies may consider how controlling predator population sizes could have subsequent impacts on CWD in deer and elk. Protected areas will play a large role in informing the debate over predator impacts on disease.

WILDLIFE MIGRATIONS HIGHLIGHT IMPORTANCE OF PRIVATE LANDS IN THE GREATER YELLOWSTONE ECOSYSTEM

Gigliotti, L.C., W. Xu, G. Zuckerman, G. Anderson, P. Atwood, E. Cole, A. Courtemanch, S. Dewey, J. Gude, M. Hurley, M.J. Kauffman, K. Kroetz, B. Leonard, D. MacNulty, E. Maichack, D. McWhirter, T. Mong, K. Proffitt, B. Scurlock, D. Stahler, and A.D. Middleton

Background: Formally-protected areas are an important component of habitat and wildlife conservation, but are sometimes limited in their effectiveness for migratory or wide-ranging species. Improved protection and stewardship of private working lands around protected areas is increasingly seen as a solution for conservation planning. However, private lands can be vulnerable to land use change, which can reduce habitat connectivity for migratory species. In the Greater Yellowstone Ecosystem (GYE), ungulates such as elk (Cervus canadensis) use a matrix of formally-protected areas and multi-use private lands throughout their seasonal migrations. Elk also structure food webs, and are important both economically and culturally; thus elk can be used as a proxy for better understanding conservation challenges within the GYE. We studied landscape-scale patterns of landownership, protection, and conservation challenges within the ranges of migratory elk within the GYE.

Methods: We used GPS data from 1,088 individual elk in 26 different herds in the GYE to define herd-level summer, winter, and migratory ranges using Net Squared Displacement and Brownian bridge movement models. Using the seasonal ranges, we extracted covariates related to land ownership, land protection (including public conservation land and conservation easements), number of private landowners, fence density, road density, density of energy infrastructure, current building density, and potential future building density (based on county zoning regulations). We summarized each covariate at the herd-level during each season and investigated seasonal and among-herd variation for all covariates.

Results/Conclusions: All elk herds included in our analysis used land encompassing more than 1 ownership type. The majority of migratory elk herds (92.3% of herds, n=24) used the highest proportion

of private land in the winter (range = 3.3% - 85.4% private land; mean = 36.2% private land). For all herds, winter ranges also contained the lowest proportions of protected areas (range = 12.4% - 95.2% protected; mean = 62.1% protected), including both public conservation land and conservation easements. Most elk herds' winter ranges contained the highest building densities (mean = 1.24 buildings/km2), fence densities (mean = 1.02 km fence/km2), and cattle grazing (mean = 1.9 cows/km2), compared to migratory and summer ranges. Out of all seasonal ranges, 36.5% of ranges did not have any zoning regulations in place, indicating the potential for future land conversion. Our results show that elk in the GYE rely heavily on habitat outside of federally-owned protected areas and conservation easements, and also face a variety of potential landscape-scale conservation challenges such as habitat fragmentation from human development and infrastructure, particularly in winter ranges. Future conservation strategies for elk as well as other wildlife in this system are going to need to encompass coordination across both public and private land to ensure continued migratory connectivity.

PERPETUATING WILDLIFE IN THE GYA: YELLOWSTONE'S CONTRIBUTIONS TO SCIENTIFIC DISCOVERY AND MANAGEMENT

Daniel R. Stahler, Chris Geremia, Douglas W. Smith, and PJ White

Today, Yellowstone National Park protects one of the most diverse and abundant wildlife communities in one of the largest temperate ecosystems in the world. This fact is testament to the great American principal that wildlife populations are managed as public resources for the benefit and enjoyment of all people. Importantly, the path that has led to today's ecological restoration of native species and ecological processes has been guided by lessons learned from past human actions and interventions in Yellowstone over the last century. From the restoration of bison, native fish, and threatened bird species, to multiple species of large carnivores and other ungulates, Yellowstone biologists and their collaborators have been leaders in developing many wildlife management practices that conservationists seek to emulate worldwide. Here, we will highlight the history and evolution of park management and science using several case studies, including the restoration of large carnivore and ungulate populations and documenting changes in bottom-up and top-down food web dynamics. From this, we will discuss specific examples of long-term monitoring and scientific discoveries that have advanced our development of best management and restoration practices for wild, wide-ranging animals. These include information about ungulate migratory landscapes and grazing dynamics, the relative role of large carnivores and humans on northern range elk population dynamics, and the application of cutting-edge technologies and traditional field methods for advancing knowledge. The ability to address future management challenges, such as loss of habitat, increased visitation, emerging diseases, and climate change, will require continued scientific information to help guide management decision-making. The perpetuity of healthy, native wildlife populations and ecological processes in the Greater Yellowstone Ecosystem will benefit from Yellowstone's continuing contributions, as well as through diverse stakeholder and constituent support of collaborative, long-term research and monitoring.

YELLOWSTONE CUTTHROAT TROUT CONSERVATION IN YELLOWSTONE LAKE

Patricia E. Bigelow

Nonnative Lake Trout were first detected in Yellowstone Lake in 1994. Lake Trout, efficient piscivores, pose a serious threat to native Cutthroat Trout, a keystone species in the complex ecology of the Yellowstone Lake ecosystem. Yellowstone National Park has worked to suppress the Lake Trout population mainly by gillnetting since 1995. Over the past 26 years more than four million Lake Trout have been netted. Over the years, other suppression actions have been implemented to complement the gillnetting: electrofishing and other netting techniques for direct removal, treatment of spawning areas with various materials to kill embryos and fry, and acoustic tracking of adults to identify movement corridors and potential spawning areas. While these actions have all had some success, gillnetting remains the most versatile and effective method of removing Lake Trout from this system.

Gillnetting begins on Yellowstone Lake as soon as melting ice allows access, typically mid-May, and continues through mid-October. Four crews are used throughout the season with up to six deployed during high-catch periods - just after ice-off and during spawning movements. One experienced crew can easily process 20,000 feet of gill net in a day and catches can range from single digits to almost 5,000 per boat per day. To maximize Lake Trout catch while minimizing Cutthroat Trout bycatch, data from previous years' fishing and Lake Trout movements from acoustic tracking are readily available to crew captains via electronic or paper maps. These are used to help guide decisions regarding most appropriate depths, locations, and mesh sizes to fish each week throughout the season. Netting is distributed throughout the lake's waters shallower than 200 feet and concentrated in high catch areas. Although all size classes 2 years and older are targeted, 50% of the effort focuses on removal of large, adult Lake Trout.

A statistical catch-at-age model has been used to annually monitor population responses to suppression effort. Results suggest the population is decreasing: a > 50% decline has been documented in abundance of older (age 6+) Lake Trout since the peak in 2012. Mid-sized Lake Trout, ages 3-5, have also significantly declined during this period. Although recruitment of young Lake Trout has become highly variable over the same time frame, numbers remain high despite fewer adults.

Numbers of Yellowstone Cutthroat Trout are improving, but not as rapidly as hoped. Annual monitoring shows a small but positive trend in population abundance. Number of Cutthroat Trout seen in Lake Trout stomachs has increased dramatically over the last several years, and reports of Cutthroat Trout spawners in lake tributaries, as well as bear activity feeding on those trout, have increased. The population of Yellowstone Cutthroat Trout in Yellowstone Lake, however, is still well below pre-Lake Trout levels of abundance, emphasizing the need for patience with the current restoration strategy while continuing to search for novel techniques to improve recovery of this keystone species.

FISHERIES RESTORATION IN YELLOWSTONE NATIONAL PARK

Brian Ertel

The biggest threat to many inland fisheries is from nonnative fish species. Few families of animal have been manipulated around the world as much as Salmonidae. In particular, "trout" (genus Oncorhynchus, Salmo, and Salvelinus), have been moved globally for centuries. Fish stocking was often done to "improve fishing" by increasing opportunity through stocking fishless waters, increasing species diversity, or increasing fish numbers. Yellowstone National Park was not immune to these practices. From 1891 through 1980, over 310,000,000 fish were stocked into Yellowstone's waters. Unfortunately, over 16,000,000 of these fish were not native to the Yellowstone ecosystem. In many instances, fish introductions were "successful" and angling opportunities were considered "improved" by fisheries managers and anglers alike. These introductions however, often had negative consequences to native fish and other aquatic organisms within the now altered ecosystem.

Yellowstone and Westslope Cutthroat Trout and Arctic Grayling now occupy less then 50% of their historic range. Many factors have contributed to their decline, but the number one threat is the presence of nonnative fish. Yellowstone National Park is free of many of the anthropocentric issues that plague trout species, but has not escaped the negative impacts of nonnative species. Many fish introductions were purposeful plantings, but some more recent introductions have come at the hands of "bucket biologists". Regardless of the route in which they arrived; nonnative fish are negatively impacting native fish throughout the park. Because of this, the National Park Service has moved to protect existing and restore lost populations of native fish.

Many elements are considered when determining the best way to protect or restore native fish populations. Factors include presence of target species for preservation/restoration, presence of other native fish, presence of migration barriers, system size, habitat complexity, system access, and project goals. Based on the answers to these questions, a plan is formulated on how to best protect or restore the systems native fish species assemblages. The resulting projects can range from no action to complete removal of all fish from a stream or section of stream and establishment of the target species.

Within Yellowstone National Park, a full range of these projects have been ongoing since the early 2000's. Streams such as the Madison River have been deemed not suited for restoration efforts at this time and continue to be managed as Blue-Ribbon trout angling streams. In several waters, including Slough

Creek, where native fish coexist with nonnatives, mechanical control of nonnative fish has been ongoing for years. Finally, in waters such as Grayling Creek and the upper Gibbon River system, where no native fish species were present, complete fish removal via piscicide and restocking with native species has been completed. To uphold the recommendations of the Leopold Report, to maintain or recreate as nearly as possible, the condition that prevailed when the area was first visited by the white man, Yellowstone National Park will continue to be a leader in native fisheries protection and restoration.

High Elevation & Climate Change Research Panel

Panelists: Williamson, Tercek, Schaming, Bloom, and Yufang

Background: High-elevation ecosystems are distinguished by thin soils, low temperatures, high winds, and short growing seasons. Given the specialized biotic communities and climatic characteristics that exist at and above tree line, unique challenges are associated with this landscape: rapidly changing climate, heavy visitor impact to sensitive species, invasive species, and changes to symbiotic processes. High-elevation ecosystems are difficult to study and receive limited research, management, and conservation emphasis, and so, it's important to bring critical attention to this important landscape in the GYE.

A team of researchers at the Northern Rockies Conservation Cooperative (NRCC) are working in high-elevation ecosystems to expand understanding of these ecosystems and the stressors they are experiencing, with the goal of improved management, public awareness, and conservation of these unique areas. We propose a special session at the Biennial Scientific Conference that examines the many layers to the challenges high-elevation ecosystems face, from an interdisciplinary and integrated perspective.

Format: Each panelist will focus on presenting new research findings, as well as how their topic relates to the other panelists – and how these connections and collaborative work lead to effective conservation. The second half of the session will focus on specific questions from the moderator to the panelists, as well as opening the discussion to the audience.

TAZA SCHAMING, NRCC RESEARCH ASSOCIATE, WILDLIFE ECOLOGIST

Abstract: Clark's nutcrackers are obligate mutualists of whitebark pine, a keystone and foundation species at high elevations, and this mutualism is under threat as whitebark pines continue to decline. Better understanding of nutcracker behavior in relation to habitat across years and seasons, is critical to the development of management and conservation strategies.

MIKE TERCEK, NRCC RESEARCH ASSOCIATE, CLIMATE SCIENTIST AND FOUNDER OF WALKING SHADOW ECOLOGY

Abstract: Historical and forecast changes to high elevation hydrology in the Greater Yellowstone Ecosystem. A brief description of how changes differ from lower elevations, with potential implications for vegetation.

TREVOR BLOOM, NRCC RESEARCH ASSOCIATE, COMMUNITY ECOLOGIST AT THE NATURE CONSERVANCY OF WYOMING

Abstract: A visual and scientific summary of how the diversity of high-elevation plants native to the Greater Yellowstone Ecosystem are impacted by climate change.

REBECCA WATTERS, NRCC RESEARCH ASSOCIATE, EXECUTIVE DIRECTOR OF THE WOLVERINE FOUNDATION

Abstract: Wolverines are emblematic of high-elevation ecosystems within the Greater Yellowstone Ecosystem, and indisputably linked to cold and snowy habitat that is threatened by climate change.

Human Dimensions II

Moderator: James Pritchard

WINTERTIME AIR QUALITY IN YELLOWSTONE NATIONAL PARK THROUGH 2020; THE POSITIVE IMPACTS OF POLICY IMPLEMENTATION

Barkley C. Sive, Lisa M. Devore, Munkhzaya Boldbaatar

Snowmobile use in Yellowstone National Park has been shown to impact air quality, with implications for the safety and welfare of Park staff, resources, and visitor wellbeing. In response to these impacts, wintertime air quality in Yellowstone National Park has been monitored by the NPS at two locations (West Entrance and Old Faithful) since 2002-2003 as part of the adaptive management program on the use of over-snow vehicles. The leading indicators of air quality used are ambient concentrations of carbon monoxide (CO), particulate matter of 2.5 microns or smaller (PM2.5), and nitrogen oxides (NOx). Monitoring data from the West Entrance is used as a comparison to Old Faithful because of its proximity to West Yellowstone, MT. The air quality monitoring at the West Entrance is crucial because it serves as the indicator for understanding air quality impacts from incoming vehicles and other city traffic. Old Faithful is the primary destination for most of the winter use vehicles within the park and provides additional vehicle usage impacts as well as background concentrations at times of lower usage or during other seasons.

Perspectives derived from the historical background of wintertime over-snow vehicle usage and the subsequent observed changes in air quality after policy implementation will be presented. The 2013 long-term winter use management rule that established transportation event limits and standards has resulted in dramatic air quality improvements for CO and PM2.5 levels in the park. The rule also ensured that historic data exists in order to understand and quantify changes in overall air quality data and to evaluate trends. The culmination of the air quality monitoring aimed at understanding the impacts of over-snow vehicles in Yellowstone National Park provides an excellent example of how balancing policy and public interests can result in positive environmental impacts.

AN INVESTIGATION OF A NOVEL METABOLISM IN YELLOWSTONE LAKE BACTERIA WHICH PRODUCED THE GREENHOUSE GAS METHANE FROM METHYLAMINE

James Larson, Will Christians, Kristen Gregg, Alexi Panos, Celina Sanchez, Jordan Pauley, Grace Ludlow, Angela Patterson, Qian Wang, Tim McDermott, Brian Bothner, Roland Hatzenpichler

Background/questions: High levels of methane, a potent greenhouse gas, have been detected in oxygen-rich surface waters across the globe. Over the past two decades, these findings have challenged the paradigm that biogenic methane production is an anaerobic process done strictly by methanogenic archaea. It has recently been demonstrated that bacteria isolated from Yellowstone Lake can convert methylamine to methane. Genome-wide mutagenesis showed that an aspartate-amino transfers is required for methane production. The metabolic pathways involved and the enzymatic mechanism are currently a mystery.

Methods: Homologous bacterial aminotransferases from across the globe were studied to determine the natural prevalence of this aerobic production of methane. A UV-Vis coupled enzymatic assay was developed for the detection of canonical aspartate aminotransferase activity. Differential scanning fluorimetry was used to screen for methylamine binding in these homologous. When applying the aminotransferase mechanism to methylamine, formaldehyde is the predicted product. An LCMS based approached was developed for the detection of formaldehyde from enzymatic reactions. To gain a better understanding of this unique biological process, global metabolomics and proteomics were conducted on a Yellowstone Lake bacterial isolate grown on methylamine or ammonium as the sole nitrogen source.

Results/conclusions: This unique metabolism may be ubiquitous in nature and may have a large contribution to freshwater methane emissions. Thorough characterization of the aminotransferase, in conjunction with the global analysis of the metabolome and proteome, give us better understanding of this unique metabolic pathway. Understanding this biological system is important for understanding the sources of biogenic methane and its contribution to climate change.

A MIXED METHODS ASSESSMENT OF THE ECOSYSTEM SERVICES AND DISSERVICES ASSOCIATED WITH UNGULATE MIGRATIONS IN THE GREATER YELLOWSTONE ECOSYSTEM

Samantha Maher

Migratory ungulate (hoofed mammal) species are ecologically influential because they move nutrients across landscapes, influence plant communities, and serve as key prey items. Migratory herds are also economically and culturally important through their provision of ecosystem services and disservices (ESDs). However, their dependence on movement across large spatial scales and access to seasonal resources puts them at risk from habitat alterations. The Greater Yellowstone Ecosystem (GYE) harbors long-distance migrations of six ungulates species, which migrate seasonally between protected areas and public lands, where they benefit wildlife-watchers and hunters; and private working lands, where they create costs and benefits for landowners and complicate management. Increasing protections for GYE herds is hampered by a failure to account for the full spectrum of associated ESDs and resolve the conflicts that occur between stakeholders, who possess heterogenous perspectives on which ESDs wildlife should be managed for. Peer-reviewed and "gray" scientific literature retains scattered, but detailed knowledge on particular ESDs, and expert and observational knowledge from GYE residents and practitioners can enhance that information and clarify the context under which ESDs are provided and to whom. We identify core stakeholder groups and combine these sources to create a comprehensive accounting of ESDs provided by ungulate migrations in the GYE. We use the widely recognized Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) guidelines to review academic literature, then ground truth and expand our findings through semi-structured interviews with key informants. We assess how stakeholder knowledge corroborates or contradicts the literature and characterize stakeholder perspectives on ESDs and migratory species management. We find substantial basis for policy that recognizes ESDs, and we suggest that formal assessments of these services could mobilize resources for conservation and foster conflict resolution between groups seeking to manage wildlife for different objectives.

POLLINATOR CITIZEN SCIENCE PROJECT IN NATIONAL PARKS

Alia Smith

Background: The goal of this study was to observe how student perspectives on stewardship and nature may be impacted by a citizen science experience in Yellowstone and Grand Teton National Parks. Students participated in the Pollinator Hotshot program, a citizen science pollinator inventory project within the Greater Yellowstone Ecosystem (GYE), or the Rocky Mountain Sustainability and Science Network (RMSSN), a two-week research program focused on equipping a diverse group of students with research skills while encouraging leadership in sustainability. Both programs afford students the opportunity to be immersed in the Parks while conducting valuable pollinator research for National Parks.

Research Question: How might students' stewardship motivations be impacted by a citizen science experience in the National Parks?

Methods: The student experience was evaluated using a mixed method approach that included a pre-post survey and a focus group. Students took surveys before and after their National Park experience to understand how internal and external stewardship motivations may shift. Additionally, specific stewardship actions were explored such as willingness to volunteer in the Parks in the future, write to Senators or Congressmen in support of the Parks, or join a 'friends of' the Parks group.

Results/Conclusions: We found that there was a statistically significant shift toward stronger stewardship motivations and actions following the citizen science experience. This study offers indications that a citizen science experience in the Grand Teton and Yellowstone National Parks can serve as a tool to encourage stewardship motivations. While this study represents a small sample in two parks, the findings are encouraging with broader exploration planned. This research set the foundation to examine an array of elements within the citizen science experience.

Future Research: Research taking place this summer among the Pollinator Hotshots, will focus on the data collected by students through their citizen science experience in National Parks. Students spread across four separate field crews covering parks in numerous NPS regions, including the GYE, will collect, photograph, and identify pollinators before releasing them. These field crews will follow standardized protocols for pollinator and associated plant identifications. The goal of this research is to understand perceptions of contributing factors to data accuracy. Pre/post surveys and focus groups with participants will be used to assess how various protocol elements support accurate pollinator identification. Additionally, there will be a quantitative analysis to determine the accuracy of taxonomic identifications of species collected among the field crews. We also hope to interview experts within the field of citizen science and Park staff to see how their perceptions of accurate identification methods align with those of the students and actual field results. Through this research we hope to discover the elements of a pollinator citizen science project that are essential for making accurate pollinator identifications in National Parks. This research, combined with what has already been done, will contribute to a more cohesive understanding of what goes into conducting citizen science projects from both social and data-oriented standings.

Bison Ecology & Thermal Biology

Moderator: Bob Gresswell

HOW UNGULATES LEARN TO MIGRATE: A CENTURY-LONG CASE STUDY WITH YELLOWSTONE BISON

Janey Fugate

The bison (*bison bison*) of Yellowstone National Park are one of very few examples of reintroduced ungulates learning to migrate over a landscape they historically roamed. The century of documentation available on this evolution offers a globally unique case study to assess learning and migration as they have played out in an intact ecosystem over 100 years. Here, we draw together research from several disciplines to assess the roles of social learning and cultural transmission in bison migration, bridging the fields of animal cognition and movement ecology. As the ecological phenomena of migrations around the world are increasingly threatened, this study integrates history and ecology to better inform conservation and wildlife management.

Questions: Amidst climatic conditions, management actions and other ecological influences, how did bison learn to migrate over the last century? As scientists continue to document evidence of cultural transmission in a range of taxa, I propose to evaluate several predictions of the social learning hypothesis over the last century of bison migration in YNP. First, I will test the prediction that the migration evolved slowly over generations, as animals learned new habitats and transmitted that knowledge. Second, I will expand the social learning hypothesis to evaluate ecological factors that spark knowledge acquisition, which presumably occurs when animals explore new areas through learning processes behavioral ecologists refer to as "observational conditioning" and "local enhancement."

Methods: We have collected and digitized historical references to bison movements and management as far back as the late 1800s. For the first half century, I will plot each movement event on a timeline and digitize the spatial extent of the migration annually in a GIS. Second, I will document the expansion of the migration over the last 50 years using contemporary movement data from flight counts and GPS collar data. To evaluate the prediction that the migration evolved slowly over generations, I will map out the linear extent of the migration through time and plot a cumulative distribution of the percent of the modern migration extent occupied through time. To evaluate how migration knowledge was acquired, I will begin by defining unique "migration expansion events," representing expansion of the migration footprint annually. Next, I will use time-to-event models implemented with Cox proportional hazards regression to evaluate which factors triggered the events, thereby allowing the population to gain new knowledge of their migratory landscape.

Results/Conclusions: Our preliminary research identified seven key events, or turning points, in the bison's history from 1902-1989 that show significant effect on their movements. These points in time serve as markers by which to analyze in greater detail the climate data, management techniques, and other influences surrounding these key events. Considering these findings, we find sufficient information to recreate the evolution of bison migration and the environmental factors at play over time. Coupled with a century long time series of snow and drought, this will be a powerful way to understand the factors that influenced migration, with a focus on animal learning.

30 YEARS OF GROWTH IN THE RELATIONSHIP BETWEEN INTERTRIBAL BUFFALO COUNCIL AND YELLOWSTONE NATIONAL PARK

Megan Davenport

ITBC has been involved in the issues surrounding bison management at Yellowstone National Park for 30 years, since the organization's inception, with the first proposal to quarantine Yellowstone bison submitted in 1993. This relationship has evolved over the years, with the culmination of successful partnership resulting in the transfer of now 150+ Yellowstone buffalo to Tribal Nations through ITBC's Surplus Program. 2022 marks another milestone – a new partnership between YNP, Yellowstone Forever, and ITBC to facilitate 4 new internships for Tribal youth with Yellowstone's Bison Conservation Transfer program. This presentation highlights the early challenges, recent successes, and continued advocacy in the relationship between the Park and Tribal Nations in preserving Yellowstone buffalo.

LONGITUDINAL ANALYSIS OF THE FIVE SISTERS HOT SPRINGS IN YELLOWSTONE NATIONAL PARK REVEALS A DYNAMIC THERMOALKALINE ENVIRONMENT

Jesse Peach

Background: Yellowstone National Park is home to a variety of hot springs with variations in pH, temperature and a myriad of other characteristics which allows for a wealth of diverse environments and microbial populations. Among the many types of springs in Yellowstone are thermoalkaline springs, thermal features with high-pH and temperatures. Research focused on microbial populations of thermoalkaline springs has been driven in a large part by the lure of discovering functional enzymes with industrial applications in these unique environments. Several studies have also focused on understanding the fundamental ecology of these springs and, while the available collected data sheds light on the ecology of thermoalkaline springs, gaps in knowledge remain. One such area is the small molecule profiles of thermoalkaline springs, which have largely been overlooked. Gaining extracellular small molecule and metabolite-based understanding of thermoalkaline environments has broad implications including improving culturing efforts by providing insight into environmental small molecule and metabolic networks.

Methods: To better understand how geochemistry, small molecule composition, and microbial communities are connected, a three-year study of the Five Sisters springs in Yellowstone National Park was conducted. Data collected at each sampling trip included high-resolution geochemical measurements, 16S rRNA sequencing of the bacterial and archaeal community, and mass spectrometry-based metabolite and extracellular small molecule characterization. Integration of the four datasets facilitated a comprehensive analysis of the interwoven thermoalkaline spring system.

Results: Over the course of the study, the microbial population responded to changing environmental conditions, with archaeal populations decreasing in both relative abundance and diversity compared to bacterial populations. Decreases in the relative abundance of Archaea were associated with environmental changes that included decreased availability of specific nitrogen- and sulfur-containing extracellular small molecules and fluctuations in metabolic pathways associated with nitrogen cycling. The multi-factorial analysis shows that the microbial community composition is more closely correlated with pools of extracellular small molecules than with the geochemistry of the thermal springs. This is a novel finding and suggests that a previously overlooked component of thermal springs may have a significant impact on microbial community composition.

BISON DISTRIBUTION AND ABUNDANCE RESPONSES TO CLIMATE CHANGE IN LATE QUATERNARY NORTH AMERICA

John A.F. Wendt, Dave B. McWethy, Chris C. Widga, Bryan N. Shuman

Background/Questions: Bison have demonstrated marked resilience to millennia of environmental challenges including climate change, biome shifts, and predation. Bison survived the late Pleistocene extinction event that eliminated 70% of North American megaherbivores, and subsequently thrived in mid-latitude North America during the Holocene. Prior to their near extinction in the early 20th century due to industrial-scale market hunting, the spatial distribution and abundance of bison were on par with the world's most expansive herbivore populations. The importance of bison for the evolution of North American ecosystems and indigenous cultures is widely acknowledged but there has been little research examining changes in the distribution and abundance of bison across North America since the Last Glacial Maximum c. 21,000 years ago. We ask, how does climate change influence the distribution and abundance of bison? And which climate variables best explain observed bison distribution patterns at millennial time scales?

Methods: We used archaeological and paleontological observations from the past 20,000 years of the North American fossil record to characterize changes in the distribution and abundance of bison at 1000-year intervals. Observations were fit to a simulated climate reconstruction (TraCE-21ka) within a distribution modeling framework (MaxEnt) to map the distribution of bison and identify important climate variables for predicting bison presence. Additionally, spatial patterns of bison abundance changes were inferred from the directionality of change in the number of observations within a given 2.5° grid cell between intervals.

Results/Conclusions: Our analysis of the bison fossil record reveals dynamic changes in the bison distribution and abundance, and highlights linkages between these changes and environmental variability. Results suggest that late Quaternary changes in the distribution and abundance of bison were directly influenced by large-scale climate trends (e.g., warming temperatures) and by biophysical and environmental changes (e.g., ice sheet recession and biome shifts such as expansions and contractions of rangelands). The fossil record and climate-driven distribution maps show that bison have inhabited the Greater Yellowstone Ecosystem since at least the Pleistocene-Holocene transition c. 13,000 years ago.

ADDRESSING COMPLEX ECOLOGICAL CHALLENGES WITH COLLABORATION PANEL

Moderator: Christina White, Panelists: Kathryn Irvine, James Wilder, and David Thoma

REALITIES OF WORKING OUTSIDE YOUR POSTAGE STAMP: COLLABORATIVE LONG-TERM MONITORING OF AT-RISK HIGH ELEVATION TREE SPECIES

Kathryn M. Irvine, Katharine M. Banner, Richard J. Byron, Rob Daley, Emily A. Guiberson, Nicole R. Hupp, Abby L. Kirkaldie, Kristin L. Legg, Jacob Oram, Erin Shanahan

Whitebark pine is a keystone species found in mountainous environments throughout the Western U.S. and Canada. Significant declines in whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*) communities due to forest pathogens, insect outbreaks, wildland fires and drought have been documented throughout their ranges and within the Greater Yellowstone Ecosystem (GYE). A collaborative team of foresters, agency biologists, GIS specialists, and statisticians from different entities was assembled to expand field-based surveys of whitebark pine beyond the GYE to encapsulate five-needle pine communities located on Bureau of Land Management (BLM) lands throughout Montana. The common goal was to inform status and trend estimation of five-needle pine and their stressors. In our development of a comprehensive survey design, we leverage the valuable lessons learned from monitoring whitebark pine within the GYE since 2004, and the experience expanding to encompass adjacent BLM lands in 2013. Specifically, we discuss the benefits of model-based trend estimation, utility of simplified and quicker data collection, and adaptively re-assessing the statistical assumptions throughout the course of a long-term program. We highlight our collaborative development of a probabilistic spatial design that accommodates the practical realities of tracking the health of a species (whitebark pine) that is sparsely distributed making it difficult to safely and frequently access and can be confused with a co-occurring species (limber pine). We overview the core statistical design elements upon which defensible inferences rest. Then we expound on the real-world challenges of meeting these requirements and present our solutions for broad-scale monitoring of five-needle pine species. Our efforts have required frequent communication and commitment from group members to develop a common language and allow for education about the field-level challenges juxtaposed with the theoretical desires of statisticians. We benefit from working together and our collective persistence developing the survey design, data collection, and proposed reporting will increase the opportunity for informed conservation decisions both within and outside the GYE in the future. Moving forward our collaborative framework could be adopted by other entities and leverage on-going efforts within the GYE to inform conservation of whitebark pine and other species in the future.

EXPANDING PARTNERSHIPS TO ADDRESS THREATS TO WILDLIFE IN THE GREATER YELLOWSTONE ECOSYSTEM

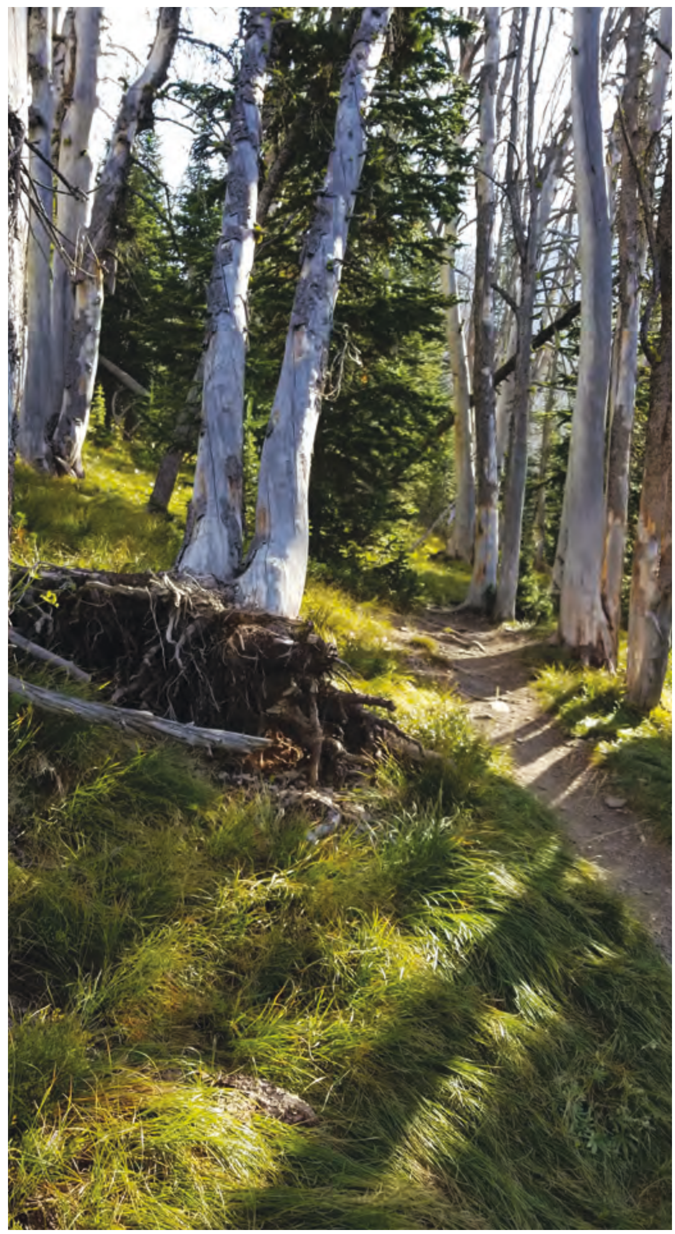
James Wilder

The 15 million acres of federal lands in the GYE include the world's first national park and our country's first national forest. These public lands are managed by four federal agencies, each with differing missions and organizational structures, and encompass 12 individual jurisdictions. The Greater Yellowstone Coordinating Committee (GYCC) was formed by these four federal agencies in 1964 to identify and facilitate resolution of emerging issues within the GYE; as such it is the best organization to effectively address those issues at a holistic, ecosystem-level. The growing threats facing the GYE are exacerbated by unprecedented increases in human-use of the landscape and the pernicious effects of climate change. In addition, decades of reduced budgets and staffing levels have affected federal land managers' ability to proactively address cross-jurisdictional issues in the GYE. For example, over the last 10 years, the GYCC has provided an average of $50,944/year to address priority issues identified by its wildlife subcommittee. Additional funding is needed to more adequately to deal with ecosystem-scale issues. Over the last year, the wildlife subcommittee of the GYCC has re-evaluated the most pressing priority threats and issues facing wildlife in the next 10 years. This talk will briefly describe this work, the subcommittee's past partnerships and successes, and present a vision for moving forward. Focus will be given to increased human use of the GYE, loss of North America's bird species, invasive species, wildlife diseases, conservation of pollinators, securing winter range and migration corridors, as well as research and management ideas to effectively address those issues at the GYE scale. The subcommittee hopes to expand our partner base to leverage the creative energy, personnel, resources, and funding that potential partners can bring to the table. Specifically, we hope to expand our partnerships with tribes, non-governmental organizations, the business community, and researchers from academia and federal agencies. Our goal is to engage these partners to help plan, fund, and implement collaborative projects that proactively address the pressing issues and threats facing wildlife at the GYE level. Our vision is to hold a recurring workshop at the Biennial Scientific Conference on the GYE whereby GYCC subcommittees can present proposals and generate dialogue with potential partners who might then support projects of interest to them. This approach could allow the GYCC to generate new partnerships and resources to adequately address priority issues in the GYE, and to more fully realize its role as the pre-eminent conservation organization in the GYE.

ACCOMPLISHMENTS OF THE 2021 GREATER YELLOWSTONE ECOSYSTEM AQUATIC CONSERVATION WORKSHOP

Tom Olliff, Molly Cross, David Thoma, Andrew Ray, Patrick Barry, Justin Peterson, Mike Tercek, Ann Rodman, Scott Barndt, Janelle Christensen, David Lawrence, David Diamond

Climate change is arguably the most pervasive conservation threat to the Greater Yellowstone Ecosystem (GYE)—preparing for it will require a well-informed and well-coordinated understanding of impacts at both project and ecosystem scales as well as efficient collaborations across management jurisdictions. Aquatic resources are already feeling the effects with warming water temperature, low flow, disease and species on the move. Robust projections for warming and drying will further stress aquatic systems in the GYE. In 2021 the Greater Yellowstone Coordinating Committee (GYCC) hosted an interdisciplinary workshop to explore a Climate Smart Conservation framework to a) restore native biodiversity to Blacktail Ponds in Yellowstone; b) conserve and restore native Yellowstone cutthroat trout in Buffalo Creek; and c) protect and restore resilient riparian areas through fire management in drainages of the Gallatin River. The workshop brought together 50 participants who worked in groups to identify project goals, assess climate vulnerabilities, identify and select adaptation actions that guide actions according to resistance, acceptance or directed change management paradigms. Lessons learned from this project will help inform aquatic conservation and Climate Smart planning for other natural resources in the future. This talk will summarize workshop findings and recommendations for follow-on work in aquatic conservation that is on-going.



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