Mountain Views

Chronicles of the Consortium for Integrated Climate Research in Western Mountains

CIRMOUNT



Informing the Mountain Research Community

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Resident's Cabin, Rocky Mountain Biological Lab, Gothic, Colorado, where *MtnClim 2018* convened in September. Photo: Jeff Wyneken

Front Cover: Gothic Mountain rises directly above the Rocky Mountain Biological Lab, Gothic, Colorado. Photo: Stu Weiss

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Read about the contributing artists on page 71.

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EDITOR'S INTRODUCTION

Even-numbered years have become my favorites in that they herald a new *MtnClim* conference. For years we had hoped to use the Rocky Mountain Biological Lab (RMBL), in Gothic, Colorado as a meeting venue, but space was a concern. Recent completion of a large, modern conference center means that RMBL now has capacity to hold us. *MtnClim 2018* convened September 17-21, with the overall theme of "Anticipating climate change impacts in mountains: Embracing variability." The setting of RMBL, high in the Colorado Rocky Mountains and nestled below breathtaking Gothic Mountain (this issue's cover photo by Stu Weiss) couldn't have been a more impressive and fitting place for MtnClim to meet. Thoughtfully organized and meticulously coordinated by Andy Bunn (WWU), Scotty Strachan (UNR), and Ian Billick (RMBL), newcomers mingled with seasoned CIRMOUNTeers for a week to hear and discuss cutting-edge science and science applications in a gorgeous mountain environment. You can feel the excitement that characterized the meeting when you read University of Washington graduate student Meera Sethi's essay on page 2, in which Meera captures the science and the spirit of *MtnClim 2018*.

Taking a cue from the *MtnClim* meeting at RMBL, I decided to feature western mountain field stations in this issue of *Mountain Views Chronicle*. In the general articles you can read overviews and recent projects from a smattering of field stations (and find more information on their websites and in references); the *Brevia* articles summarize recent publications for which research was conducted at field stations; *First Person* essays describe visionary possibilities for future field science; and *Voices in the Wind* correspondents share their perspectives about working at mountain field stations. Individually and collectively, these articles portray the critical role that these stations have played in mountain science. Thanks to all the directors and field managers for your dedication to these special places. Here's to keeping them well funded and thriving!

In that *Mountain Views Chronicles* seeks to highlight the artistic sides of our community as well as our scientific work, I decided to combine our traditional back-cover photograph with a bit more science, making it (ala "postcards from the field") a new section, *Field Frames*—thanks to Toni Lyn Morelli for the first contribution from her work with Arctic ground squirrels in Alaska. If you have a great photo of science in action, please share that with me!

As I write, it is raining and snowing in California. For autumns in our drought-susceptible West, that is a good thing, as Bob Coats writes in his "In Praise of Rain" (pg. 72).

--Connie Millar

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The billy barr community center, where *MtnClim 2018* sessions took place, Rocky Mountain Biological Lab, Gothic, Colorado. Photo: Jeff Wyneken

MtnClim 2018: Gold in Them Hills

Meera Lee Sethi
Biology Department, University of Washington, Seattle, Washington

The drive between Denver International Airport and the grounds of Rocky Mountain Biological Laboratory (RMBL) is a journey of five or six hours. This was not enough time to get used to how far open the spine of the sky had been cracked, or grow tired of the soft fire of trembling aspens burning across the mountains. The trees drew closer as we moved up into the high country, and by the time my lab mate Kavya Pradhan and I were climbing the narrow road from the resort city of Crested Butte to the old mining town of Gothic, Colorado, where RMBL makes its home, deep gold leaves all but touched the windows of our rental car. It felt as if we were driving into a jewel box. The glory of this was almost, but not quite, enough to distract us from noticing the signs guarding the rough-grassed meadows to our left and right. SCIENTISTS ONLY BEYOND THIS POINT, they announced. Or invited. I thought about the years before graduate school, when as a freelance writer with no science training it was my job to read about science and write about science from what felt like just outside the glass. I had an urge to stop the car next to one of the signs and set my feet down on the other side.

Kavya and I had come to attend *MtnClim2018*, and after she settled into her nook on the second floor of a well-appointed cabin named Red Rock and I made my home in the tiny, exquisite North Pole (Fig 1), we joined 120-some fellow conference attendees for a delicious RMBL-made dinner eaten at communal tables. PRISM director Chris Daly officially opened the conference after dinner with the first lecture of the week, from which I learned three things: One, the time will come, though the wait may be long, when PRISM products will be relevant at the scale of my study system (small subalpine plants and their even smaller insect herbivores)! Two, in the 14 years since the first *MtnClim* meeting a series of traditions had arisen that those of us who were newcomers this year would get glimpses of throughout the week. That night Chris was speaking in honor of—and filling the shoes of—the late Kelly Redmond, a mountain-climate science legend, by taking on his traditional role in giving an idiosyncratic roundup of weather patterns, outliers, and anomalies across the western U.S. since the previous meeting. And three, I was in the right place. Chris raised many questions in his talk that have nagged at me and everyone in my lab at the University of Washington for a long time: What is the "right" way to measure climate? How representative is a temperature reading taken over a given time interval, at a given height, under a given canopy, and on a given slope and aspect, of temperatures in other places? How meaningful is that reading to an individual organism? These and related ideas about uncertainty and scale in modeling climate impacts came up over and over again in talks and discussions throughout the meeting, and for me was one of the most exciting signs of a community engaged in healthy conversation with itself about its own fundamental assumptions.



Figure 1. View from the loft of the "North Pole." Photo: Meera Sethi

Chris ended with a slide titled "Some Basic Kelly Guidelines." If knowing that this was a meeting with its own established rituals felt intimidating to a first-time MtnClim-er, the Kelly-inspired strictures seemed poised to combat that feeling: *Everyone is important, especially outsiders with new ideas…Always speak positively…Humor lightens the load.* Intentional or not, the fact that the very first talk in the first session was given by a fellow graduate student, Mark Raleigh of the University of Colorado, also struck me as an indicator of how much this community values new voices and ideas. Mark gave a terrific methods talk using pilot data he collected from inexpensive accelerometers attached to high-elevation conifers. By modeling changes in tree sway in relation to temperature and precipitation events, he showed the potential of using tree sway measurements to quantify snow interception by the canopy. ("Fit-bits for trees!") At the

end of the same session, University of Arizona postdoc Bethany Coulthard gave a very different presentation that I thought was one of the best of the week, marked by a set of unusually spare and beautifully designed photographic slides (Fig. 2). Bethany's team has used tree ring chronologies from snow-sensitive montane species to reconstruct the history of snowpack in the western U.S. over the last two thousand years (!), including new insights into an epic 16th-century snow drought in the Pacific Northwest that lasted over a decade. This unremarked-on juxtaposition—between an exciting methodology in development relying on a technology that probably wouldn't have been accessible to a graduate student just a few years ago, and an incredibly rich and mature set of results based on a technique that's been in use since the 19th century—evoked a sense of progress, history, and achievement in mountain research. It was wonderful to witness, and the week was full of moments like it.

Conference talks *had* to be good to compete with the constantly shifting views we could all see through the back windows of the billy barr community center, as the sun played over the laccolith cap of Gothic Mountain or a midafternoon rainstorm sent a temporary waterfall cascading down its side. Thankfully, most were up to the challenge. Some of my other favorites included Caitlyn Florentine (USGS) on how mass losses experienced by cirque glaciers become less directly influenced by climate and more influenced by local topography as they retreat and S. McKenzie Skiles (University of Utah) on accelerated snowmelt driven by the episodic deposition of dust and black carbon onto the snow surface at high elevations. Both were important reminders that even assuming we have managed to achieve an accurate understanding of climate, it often isn't acting alone to shape the outcomes we care about. And speaking of outcomes we care about, something I truly appreciated about this meeting was the space made for presentations about natural resource management and the connections between people and nature, like the case study Molly Cross (Wildlife Conservation Society) shared about a researcher-stakeholder partnership to better plan for the social and ecological impacts of drought, Liz Burakowski's (University of New Hampshire-Durham) examination of the links between a declining snowpack and the economics of winter recreation, or Piyush Dahal's (The Small Earth Nepal) work modeling the suitability of sites for surface rainwater harvesting in mountain catchment areas in the Himalayas.



Figure 2. One of Bethany Coulthard's slides. Photo: Meera Sethi

Having the meeting be hosted at RMBL, which celebrated its 90th anniversary as a field research station this year and houses several buildings original to the abandoned silver mining town on whose ruins it was constructed, contributed an additional depth of meaning to many events. On Wednesday morning, for instance, John Harte (University of California) gave a keynote address about the long-term artificial warming experiment he first set up in the subalpine meadow habitat surrounding the station in 1990. We looked at figures showing differences he's found in biomass, soil nutrients, and community composition between warmed and unwarmed plots—and just over an hour later, I was one of about 20 conference attendees getting a tour of some of those very plots (Fig 3). Steel towers bookended the meadow, crunchy with end-season seed heads and spent leaves, and pockmarked with boxes and wires. Heavy cables threaded the air above, from which a series of infrared lamps was suspended a couple of meters above the ground, toasting it by several degrees. John told us he had found the heaters being sold by an agricultural company to keep chickens and pigs cozy during northeastern winters, and that all but two had now been running continuously day and night for



Figure 3. Hiking to the warming meadow. Photo: Meera Sethi

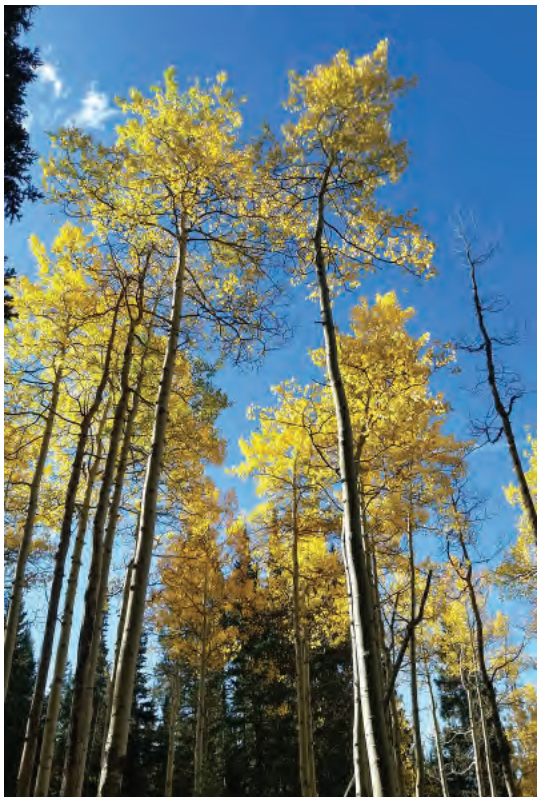


Figure 4. John Harte in the warming meadow. Photo: Meera Sethi

28 years. It was sobering to listen to him talk about decisions he'd made about the project when I was eleven years old, already knowing how important it would be to measure the impacts climate was going to have on this place; and to see him standing there now (Fig. 4), in front of what we all understood was a view of its likely future. Sagebrush bulldozing aster.

Later that night David Inouye (University of Maryland), who has been counting things at RMBL for over 40 years, gave another keynote. For those of us in the audience it was a little like being given permission to page through his exquisitely detailed field journal, or watching Hercule Poirot wearing a conference lanyard and revealing the solution to one ecological mystery after another. I marveled at the patience it took, for instance, to uncover a deep set of connections between early snow melt, frost-damaged aspen fleabane, reduced nectar availability, caterpillar mortality, and a large drop in the Mormon fritillary butterfly population. But if a delight in the ability to unpack complexity with data was one motif of this hour-long talk, loss and change followed closely behind. At one point David laughed, regretting that he didn't have the time to relate one by one the individual life histories of the hundreds of long-lived monument plants (*Frasera speciosa*) he began to tag and track in 1974. There were two greater regrets, we understood. One is that this species—which grows so gradually that many plants spend years making do with just a single pair of leaves, and flowers spend four growing seasons developing to maturity—is likely to be on a timeline too slow to keep up with the pace of climate change. The second is that in an era when 3-year ecological studies are the norm, few of us in the room could imagine embarking on a project that would span the decades we clearly need to understand these organisms and predict their future. I was grateful that David closed his talk with a reminder that there was nothing to be done but begin:





Fall in the shadow of Gothic Mountain. Photo: Meera Sethi

"Ecological projects don't need a lot of equipment," he advised, meaning *the thing you pay attention to for the next 40 years might not be something for which you need either funding or permission.*

"Just pick something and start it," he said. "And then keep doing it."

Like David, I regret that I don't have the time to tell you about every surprising reward the week held. Not every scientific conference can promise a movie night, or warm conversation next to a bonfire with a person who was a stranger four days ago, a whiskey bottle passing from hand to hand. Was it perfect? Well, in one of our last sessions, led by tireless organizers Scotty Strachan (University of Nevada, Reno) and Andy Bunn (Western Washington University), we considered the past and present evolution of this community. Some who had traveled across borders to be here noted that there might be an opportunity to ease the understandable, but perhaps not inevitable, bias towards meeting locations in the western United States. And as one of the few brown faces in the room, I found myself thinking about what we could do to make that less true next time around. Still, the fact that we all, veteran MtnClim-ers and newcomers alike, had been invited to be part of this conversation felt important; as did those words running through my mind. *Next time around.*

I'm very grateful to have had the great pleasure of attending this meeting, and if you missed it this year I hope to see you at *MtnClim 2020*—wherever it is held, and whoever you are.



Evenings around the campfire. Photo: Meera Sethi

Highlights from the MtnClim 2018 Conference Managers' Workshop

◆

Identifying Climate Refugia in the Spruce-Fir Ecosystem: Connecting Modeling Outputs with Field Characteristics and Managers' Needs in the Upper Gunnison Basin

Gothic, Colorado (Rocky Mountain Biological Lab (RMBL) and
Judd Falls/Copper Creek Basin walking tour), September 22, 2018

Page Buono[1], Imtiaz Rangwala[2, 3], Renee Rondeau[4], Marcie Bidwell[1]
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[4]*Colorado Natural Heritage Program, Colorado State University, Ft. Collins, Colorado*

Introduction

A managers' workshop at the recent *MtnClim 2018* conference engaged climate scientists and ecologists who attended the conference with local land managers in a discussion to elucidate approaches for identifying climate refugia on a landscape. The primary intention was to facilitate in-the-field, face-to-face interactions among scientists and land managers to ground-truth climate models, identify useful strategies to characterize for climate refugia, and better understand the complicating factors of layering "climate refugia" approaches in the context of land-management decision-making that is designed to protect a myriad of values and interests.

This workshop was built off of a four-year stakeholder driven Social Ecological Climate Resilience (SECR) project (Rondeau et al. 2017) to identify climate change adaptation strategies in different social-ecological landscapes in Southwest Colorado. One of the leading adaptation strategies that came out of this project was to identify, conserve, and manage climate refugia within the Spruce-Fir ecosystem. This workshop was primarily motivated by concerns expressed by managers involved in the SECR project who shared that while they could appreciate the recognition of this high-level strategy, they do not have adequate information and tools to operationalize this strategy in the real world. More specifically, some of their concerns included: (a) how to identify climate refugia on a landscape, (b) what is the right spatial scale to consider, and (c) what are some approaches that managers can adopt to do this correctly? The workshop was designed to examine these and other questions by facilitating interactions among local land managers and the attendant climate and ecological science expertise at the conference.

Climate Refugia: *Concept*

For the purposes of the workshop and this article, we have adopted the concept of climate refugia as defined by Morelli et al. (2016) as "areas relatively buffered from contemporary climate change over time that enable persistence of valued physical, ecological, and socio-cultural resources." Figure 1 illustrates different bio-physical criteria which enables certain geographical locations to experience greater buffering from climate change. The examples shown in Figure 1 are relevant within the Upper Gunnison Basin. In addition to enabling the persistence of desired resources and functionalities in specific areas, strategically managed climate refugia may also enable persistence of valued resources and functionalities beyond just the climate refugia site;



Participants from the workshop that included land managers, scientists, and ecologists from diverse backgrounds and geographies. Photo: Marcie Bidwell

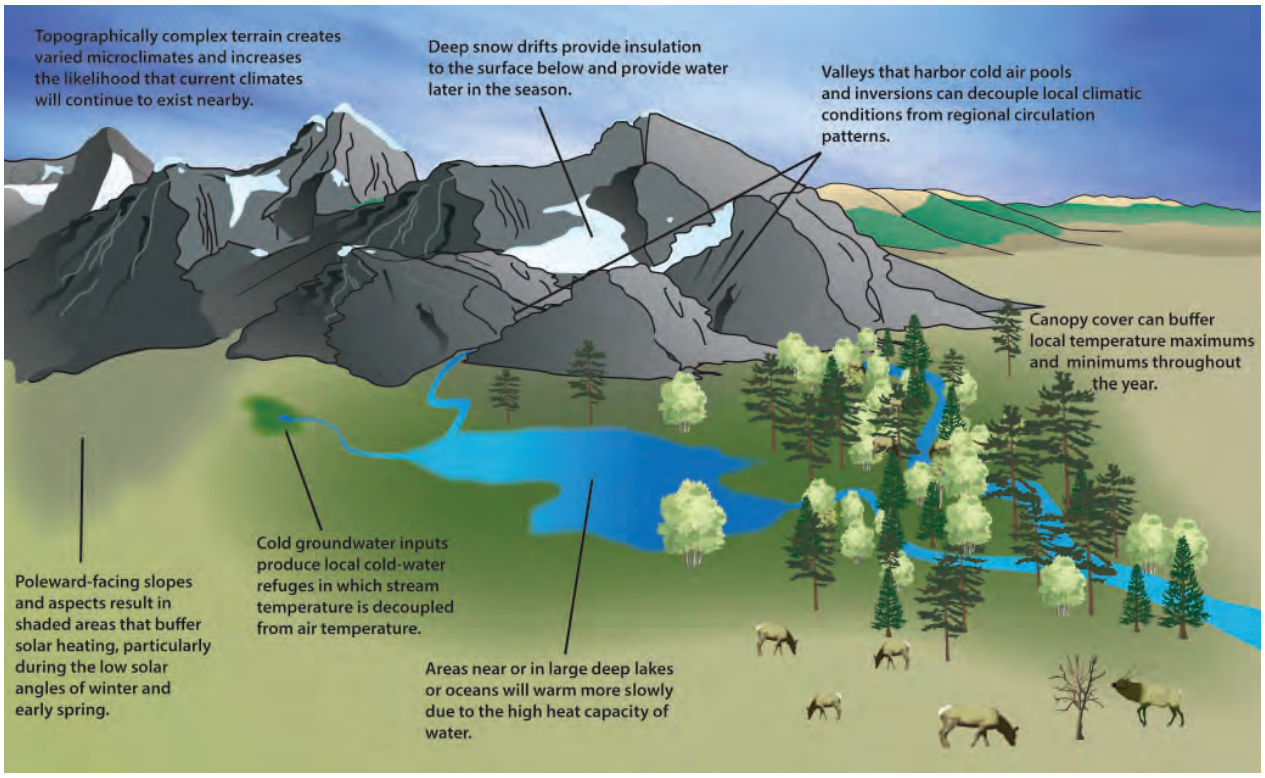

Figure 1. Examples of the different bio-physical criteria, discussed during the workshop, which will enable certain geographical locations to experience greater buffering from climate change. From Morelli et al. 2016.

e.g., (i) supporting wildlife corridors and (ii) facilitating resources for recovery for a broader region after a disturbance event.

Before the workshop, the workshop facilitators held a meeting with several co-authors of the Morelli et al. (2016) study, who were present at the conference, to discuss the concept of climate refugia within the context of natural resource management in the Upper Gunnison Basin, and identify opportunities for future research and applications regarding this topic.

The Workshop

The workshop had both an indoor (1.5 hours) and a field trip (2.5 hours) component. The indoor component involved several short presentations to introduce the attendees to the SECR project (by Marcie Bidwell, Mountain Studies Institute) and the bio-climate niche modeling carried out to identify potential climate refugia on the landscape (by Suzanne Marchetti, US Forest Service). Koren Nydick (Rocky Mountain National Park) provided an overview of the "climate refugia" approach to natural resource management as discussed in Morelli et al. 2016, and finally Matt Vasquez (District Wildlife Biologist, Gunnison Ranger District, US Forest Service) offered a local manager's perspective on the opportunities and challenges to incorporating science into decision making.

The second and longer part of the workshop was in the field where workshop participants used both the bio-climate niche model maps and observed presence or absence of a feature to identify and discuss potential climate refugia sites. The field trip started right at RMBL and headed northeast to join the Copper Creek Basin trail, which involved a scenic walk through aspens in their prime fall splendor[1]. The intention of the outdoor activity was to stop at a few different sites in the basin and identify relevant features to characterize climate refugia. The outdoor activity also facilitated several unstructured but pertinent discussions both broad and specific to the workshop topic. This report is an attempt to capture important highlights from these discussions (in the next section) and to inform future land-management practices and promote actionable science.[2]

Highlights from the Workshop Discussions

Why conserve climate refugia?

- One of the leading climate change adaptation strategies identified in the SECR project was to identify, conserve, and manage climate refugia sites.
- Conserving and managing climate refugia sites are among the most cost-effective actions managers can take (i.e., highest rate of return on your investment; Morelli



This young subalpine fir seedling is evidence of regeneration under current climate. Photo: Imtiaz Rangwala

et al., 2016). While conserving refugia is a first critical step, intentional management of refugia (like seeding or restoration) is a longer term approach to promoting their success.

- Connecting climate refugia sites across a wider landscape through linkages may be critical for the future persistence of a wide-ranging wildlife species. For example, establishing habitat connectivity for lynx is of particular interest for the Grand Mesa Uncompaghre and Gunnison (GMUG) National Forests.

Characteristics of refugia

- Refugia are, and need to be thought of, as a dynamic system, which implies accepting variation in their characteristics from natural disturbances rather than a steady state.
  - o Workshop leaders and land managers worked to identify existing changes on the landscape that are likely related to climate change. Some of the things we saw included:
    - Bolting krummholz
    - Aspen and sage on the same hill slope
  - o Workshop leaders pointed to the following as evidence of potential refugia:
    - Regeneration in Engelmann spruce & subalpine fir in an open meadow—presence of young plants (<15 years old)
    - Species diversity, especially trees
    - Available migration "routes" (linkages for species migration)
    - Evidence of low or no mortality from recent climate events, e.g., beetle killed trees from year 2002, an extreme drought year. Or evidence of resilience after a large disturbance, e.g., large regeneration pulses after high tree mortality.

Developing a strategy

- Defining and contextualizing climate refugia within specific decision-making situations is important.
  - o Land managers need to ask themselves: climate refugia for what? And understand how to incorporate climate refugia management decisions with those made to protect other values.
  - o Workshop participants discussed the importance of documenting/cataloguing institutional knowledge that contributes to long-term understanding of species behavior (specifically discussed in the context of USFS) and heralds future "internal" champions of managing for varied climate futures.
  - o Distinctions between short, medium, and long-term resilience strategies:
    - For example, introductions of pulse disturbance events into the conversation. Workshop participants underlined the importance of understanding recovery times after pulse disturbances
  - o Importance of the presence of species that are likely to expand under future climate:
    - During the workshop, attendees discussed the likely shift in Douglas fir populations to higher elevations, which will only be possible in places where Douglas fir are already present. Similarly, expectations for expanded aspen and oak habitat will hinge on the established presence of that species. For land managers, this means identifying existing sources of aspen, oak, or other species and protecting them as seed sources in the case of species-shifting disturbance events.
  - o When it comes to identifying and promoting refugia, consider the genetics! Species that are able to survive are the ones learning the fastest, and within a species there may be genetic propensity for higher or lower elevation, and warmer or colder climates. For example, a high-elevation aspen stand may be more likely to persist and expand in future with a warmer climate than a lower elevation one.
  - o As further support for the need to ground-truth scientific findings, participants discussed both the benefits and risks associated with layering models to identify refugia.



Workshop participants examining evidence of regeneration as a potential indicator of climate refugia sites. Photo: Imtiaz Rangwala

While layering models may help identify overlap and prioritize project areas or refugia sites, it also multiplies uncertainty.

- For U.S. Forest Service land managers
  - Workshop attendees highlighted that potential incorporation of climate refugia considerations into existing National Environmental Policy Act (NEPA) review processes could include:
    - Looking ahead to future threats (i.e., fish impacts post-fire) when preparing NEPAs
    - Streamlining NEPA for climate change: When deciding to implement strategies on the ground in a timely manner, how do land managers ensure they have the information (science) they need?
    - Identifying opportunities for the use of programmatic NEPA for spruce salvage sales. For example, if a spruce salvage site is likely to occur within a climate refugia site, additional safe guards could be applied to ensure habitat for regeneration
    - Using salvaging logging as a tool to improve resilience (in addition to the economic benefits)
    - Opportunity to guide fire suppression and let it burn areas
    - Identifying opportunities to utilize climate smart seed mixes and other restoration techniques after a disturbance, e.g., create natural snow fences and erosion control after a fire.
  - Some of the existing Forest Health guidelines may also be appropriate for determining climate refugia sites.
  - Develop a suite of characteristics that may help managers ground truth insights from bioclimate niche models.
  - Develop some additional indicators and tools, including maps and datasets to identify cold air drainages, cool species at lower elevations, geological substrates that hold the water, etc.

Conclusions

Identifying, conserving, and managing climate refugia sites are recognized as among the most efficient and least costly strategies for adapting to a changing climate. Many managers embrace this concept and want to use it to guide on-the-ground practices that can help conserve wildlife, carbon, groundwater and surface water resources as well as maintain livelihoods, tools for helping them to identify and prioritize relevant management strategies for their landscape are critical next steps in the process. At the same time, managers need to have high confidence when utilizing this concept in their specific day-to-day decisions. This managers' workshop attempted to move the needle on exactly that, and the value of sharing this concept by incorporating a field trip into

the session was evident for both scientists and managers. Future research and monitoring within potential climate refugia areas will expand our knowledge on this important strategy and offer increased opportunities for the development of indicators and tools that land managers can lean on in their decision-making.

Acknowledgements

We are very grateful to Suzanne Marchetti, Matt Vasquez, and Koren Nydick for their contribution in designing and facilitating the workshop. We thank all the workshop participants for their time and contributing to a valuable discussion, and to the several co-authors of the Morelli et al. (2016) paper for participating in a discussion prior to the workshop. We also want to especially thank RMBL scientists and staff for their assistance and participation in making this workshop successful. Finally, we acknowledge the support from North Central Climate Adaptation Science Center on the SECR project, and Western Water Assessment for IR's time on the project.

Footnotes

[1]During the conference, workshop facilitators (using guidance from resident scientists at RMBL) explored and scouted different options for the field trip component of the workshop.

[2]In the Spring 2018 issue of *Mountain Views Chronicle*, the "Voices in the Wind" section asked the following question about developing and implementing actionable science: "Actionable science is scholarship designed to inform and support resource decision-making, improve evaluation of risks and impacts, and assist in development and implementation of public policies…If you are a user of science information, what topics do you feel are most urgent for actionable science in your mountain context?"

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Workshop participants consider the value of environmental diversity for mountain climate refugia.

Western Mountain Field Stations

Rocky Mountain Biological Laboratory, Gothic CO
Ecology of Place: Making Ecology and Evolutionary Biology Spatially Explicit

Ian Billick[1], Ian Breckheimer[1,2], David Inouye[1],
Ken Williams[1,3], Joshua Lynn[1,4], and Jennifer Reithel[1]
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At the Rocky Mountain Biological Laboratory (RMBL) we are exploring how to harness the scientific value of environmental variability found in mountain ecosystems, an element of "unleashing the power of place". Since its inception in 1928 RMBL has been a springboard for botany and mammalogy courses that take advantage of the wide range of ecosystems and organisms that stretch between the bottom of the Black Canyon, elevation of 1160 m, to the top of Uncompaghre Peak, 4360 m. While this diversity is great for teaching, a scarcity of large homogenous areas can be a problem for experimentally-oriented field scientists. Topographic variation can increase natural variance in the response variable, overwhelming the ability of scientists to hone in on the effects of experimental factors of interest. Scientists may struggle to run experiments on a large enough scale, or to get enough replicates.

Habitat diversity, and the struggle to find just the right study area, highlights the fundamental challenge of "place" to generality in the field sciences (Billick and Price 2011). If it is hard to find just the right place for an experiment, do the experimental results have meaning beyond the location of the experimental plots?

Marketing research shows that people struggle with the idea that place-based research can be of general interest (RMBL unpub. data). A survey of different messages about RMBL found that the statement "Because biological processes are fundamentally the same everywhere, the work of RMBL is broadly applicable nationally, even globally, helping scientists and the public understand how the natural world works" motivates support, but is not something that donors understand.



Gothic townsite in the 1880s from north



Gothic Townsite in fall

Quite a bit of the work at RMBL in recent decades has focused on plant-insect interactions (e.g., pollinations and herbivory) or organismal behavior. These studies involve processes that happen on very small scales and for which it is possible to get large sample sizes with reasonable statistical power. Scientists can work at this scale in the mountains while also satisfying the general expectation, at least in ecology and evolutionary biology, that field work should include an experimental component.

This attitude also extends into sciences. We have seen scientifically-savvy managers struggle to accept that a study on pollination and road dust done in one part of Colorado (for example, Waser et al. 2016) might be relevant in another part of Colorado (Billick pers. obs).

But things are changing in interesting ways, at least for the ecological and evolutionary work done at RMBL where study sites have historically been "vaguely spatial". Historically, the

location of studies were identified in vague terms (e.g., the Upper East River Valley) that made it difficult to reconstruct the exact location. Nor has the spatial context of study sites in most studies been explicitly used to interpret the results. Furthermore, studies often treat variation in location as "blocking", or "random" effects, with an assumption that the sampled locations represent some poorly defined larger spatial distribution of sites, but not as "fixed effects", with a focus on investigating underlying mechanisms.

Starting 15 years ago RMBL received an NSF grant (DBI-0420910) to implement Global Positioning (mapping) and Geographic Information Systems (managing mapping data). This allowed RMBL scientists to map their research sites and associated data streams, including human-collected data as well as sensor-based data, with a high degree of precision. The initial mapping has supported management of 2,000+ active research plots/year, ensuring scientists have permissions, minimizing unnecessary intrusions on the research, and coordinating multiple projects.

As spatial data accumulate, and new computational resources expand the scope and power of spatially explicit environmental measurements, there are growing opportunities to interpret human-collected field data within a spatial context. ***Our geodatabase now allows us to do much more than know where data has been collected. It allows us to answer new kinds of questions***. Here are some examples of what is becoming possible. Beginning in 1973 Dr. David Inouye started regularly measuring the phenology of 120 plant species occurring in 30 permanent 2x2m plots in four habitats (Inouye 2008). This research has supported approximately 60 scientific papers and grown into one of the most comprehensive long-term studies of plant flowering times, providing insights into the effects of climate change (https://www.bio.fsu.edu/~nunderwood/homepage/RMBLphenologyproject.html).



David Inouye 2009



Attempts to protect plants from frost

Starting in 2010, these plots were instrumented with sensors that measure soil and temperatures and were geo-located with high precision. These data make it possible to embed Inouye's plots in an explicit spatial context and ask questions about the spatial patterns of flowering that might impact pollinators. In the summer of 2018 Dr. Ian Breckheimer began collecting high-resolution photos of the landscape around Dr. Inouye's plots with a drone. The goal is to use machine learning to automate the collection of plant phenology data across large landscapes.



3cm aerial capture by UAV 2

Simultaneous observations by Inouye's team and drone observations may make it possible to build a model for flowering times of the plant communities since 1972 for a much broader area than captured by Inouye's plots.

Another step forward involves site-specific estimates of climate data with interpolations. Lynn et al. (2018) took data on a series of climate variables including mean annual air temperature from 29 weather stations (RMBL, USDA Natural Resources Conservation Services, and the Southwest Climate and Environmental Information Collaborative) spread across Colorado's west slope. They built a regression model predicting the climate variables based upon elevation, aspect, and slope.

RMBL has LiDAR (Light Detection and Ranging Data) (Wainwright and William 2017) data that provide elevation, slope, and aspect data with a 6" resolution, and which can feed the regression model predictions. RMBL can now provide site-specific estimates of climate parameters for locations throughout the valley, including the research sites for all scientists.

While building climate regression models using data over such a large region, and then applying them to more local scale has its limitations, we expect the climate models will improve quickly as better data become available. For example, given the importance of snow melt date to many of the biological systems around RMBL (e.g. Boggs and Inouye 2012), the next step is to start creating high-resolution models of snow melt date. Several research groups are examining how to parameterize such models, potentially using a combination of ground-based time-lapse photography, soil temperature data loggers, and measurements from satellites.

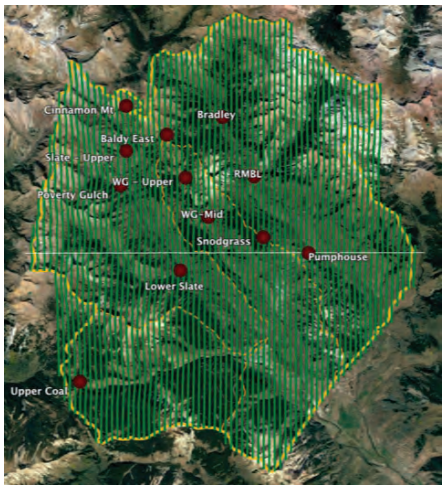
Climate models will continue to improve, as will our ability to understand biological processes driven by local climate. For example, as the cost of genomics has dropped dramatically, it is becoming possible to apply genome-wide association studies (GWAS) at large enough scales to link environmental variability to genes and evolution. Prasad et al (2012) examined evolutionary pathways of plant secondary compounds in the mustard plant *Boechera stricta* using environmental contrasts between Montana and Colorado populations (including populations in proximity to RMBL). Dr. Jill Anderson and her research team (e.g., Wadgymar et al. 2018) are growing plants of known genomic backgrounds in five gardens at different elevations to separate the role of environment and genes in controlling plant traits. However, rather than focusing on planted gardens, it is now becoming practical to apply GWAS to naturally growing plants, correlating traits and their genomic basis with spatially explicit measurements of the selective environments experienced by the plants.

The opportunities to use geodatabases to integrate different types of data are likely to increase quickly. The Watershed Function Scientific Focus Area, coordinated by Dr. Susan Hubbard and Dr. Ken Williams through the Lawrence Berkeley National Laboratory, is synthesizing a wide range of spatially explicit measurements of the ecological and hydrological function of the Upper East River Watershed, such as ground-truthed estimates of plant and soil chemistry derived from airborne hyperspectral imagery using NEON's Airborne Observation Platform (an effort led by Dr. Dana Chadwick). The team is also using helicopter borne electromagnetic sensors to create three-dimensional models of subsurface geology (led by USGS scientist Dr. Burke Minsley). Spatially and temporally extensive maps of snow distribution, snow water equivalent, and melt date are being generated in collaboration with NASA and its Airborne Snow Observatory (ASO).

So where is all this headed?

Field scientists have long used natural variability as a tool for probing how processes work. However, increasing computational power, growing sophistication of spatial analysis tools, and the enhanced ability to generate a large range of different types of data on large spatial scales and at high resolution means that spatial variability is becoming more of a tool than a barrier. The growing datasets related to water allow the watershed-scale predictive models describing seasonal water availability, surface runoff to streams, and groundwater recharge. Given the importance of water to biological processes, such data and associated models are another important means by which spatially explicit datasets are being used to link plot level observations, such as plant phenology in relationship to snow-driven hydrologic processes. This will allow ecology to be more explicitly woven into fine-scale hydrology models (e.g., Pribulick et al. 2016), eventually making it possible to downscale regional climate models to scales appropriate to meaningfully capture the heterogeneity of mountain environments.

Additionally, such modeling may make mechanistically-based ecological prediction possible. We have already seen scientists combining measurements over an elevational gradient with repeated measurements through time to assess the extent to which spatial variability can be used to accurately predict change through time (Petry et al. 2016). We're also finding that stream gage data can be used to reconstruct historical snowmelt dates, providing insights into how historical climate may have affected surrounding mountain ecosystems. Scientists have multiple tools to integrate spatial data with time series data to make predictions.



NEON flight

We expect to see more scientists using this approach and applying it on finer spatial scales.

Such spatially explicit predictions will not be limited to ecology, but in at least some circumstances, will also extend to evolutionary dynamics. Watt et al. (1996) have demonstrated that combining genetic data with spatial variability provides insight into evolutionary processes. This has provided opportunities to predict at the genetic level how populations will respond to climate change (MacLean et al. 2016).

Given the diversity and complexity of the Earth's ecosystems, we will rarely have the luxury of having a mechanistic, spatially explicit model when making environmental decisions. It is important to understand when and where these mechanistic models are necessary for making good predictions and management decisions. Spatially explicit, mechanistic models of ecological and evolutionary processes informed by decades of detailed field data, like the ones that are emerging at RMBL, can help us understand which shortcuts are reasonable. Moreover, the depth of understanding combined with the large collection of long-term datasets, makes the valleys around Gothic an important case study for understanding the predictability of ecological systems more generally.

Making ecology spatially explicit also provides opportunities to make predictions in a looser, non-mechanistic sense. In the business world Courtney et al. (2013) argue that in the face of greatest uncertainty, when causal models are lacking, case-based decision-making is the best approach. Indeed, Tetlock and Gardner (2016) have demonstrated the ability of some people to accurately and consistently make accurate predictions, essentially using a Bayesian approach (Silver 2012), involving extremely complex human social, political, and economic systems. Even if the explosion in technology and mapping capabilities doesn't quickly yield highly predictive mechanistic ecological models, the information these techniques yield in the valleys around RMBL can be used as the basis for case studies to have the capacity to improve environmental decision-making around the world.

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The Valentine Eastern Sierra Reserves

Carol Blanchette
Valentine Eastern Sierra Reserves, Mammoth Lakes, California

The Valentine Eastern Sierra Reserves (VESR) consist of two separate sites, Valentine Camp and the Sierra Nevada Aquatic Research Laboratory (SNARL), located approximately eight miles apart (Fig. 1). They are situated in Mono County on the eastern slope of the Sierra Nevada, near the Town of Mammoth Lakes, CA. The reserves are part of the University of California Natural Reserve System, and administered though the University of California, Santa Barbara (UCSB).

Mrs. Edward R. Valentine donated Valentine Camp to the University in 1972 and provided a generous endowment fund for its support. The 154 acre Reserve sits below the Mammoth Lakes Basin at an elevation of approximately 8,000-ft (2,400-m) and contains an unusually diverse sample of Eastern Sierran habitats on the climatic ecotone between the sagebrush desert of the Great Basin and the coniferous forests of the Sierra Nevada. Mammoth Creek flows through the property, and numerous springs arise within its boundaries (Fig. 2). The terrain includes a variety of elevations, slopes, and aspects. Plant communities include Great Basin Sagebrush, Montane Chaparral, Sierran Upper Montane Forest, Meadow Vegetation, and Montane Riparian Vegetation. The facilities are open, as weather permits, from around the first of June through the middle of October, and on a limited basis for winter day use. Housing consists of three large cabins, which can accommodate a total of 16 persons. A system of foot trails provides access to all of the site's major habitats.



Figure 1. Map of the Valentine Eastern Sierra Reserves.

SNARL is a 55-acre field station site, which serves as is an ideal base for field research throughout the eastern Sierra and the Owens Valley. A former US Fish and Wildlife Research station since 1935, the facilities at SNARL were transferred to the University in 1973. SNARL provides a modern laboratory, which includes a molecular diagnostics facility, and experimental stream complex that promotes and encourages scientific research



Figure 2. The Valentine Camp is located along the climatic ecotone between the sagebrush desert of the Great Basin and the coniferous forests of the Sierra Nevada.

all year long. SNARL lies immediately at the base of the eastern slope of the Sierra Nevada, along the borderline that separates the montane environment of the Sierra from the arid Great Basin Desert to the east. The flora of SNARL includes species characteristic of mesic mountain habitats as well as xeric desert sites. Convict Creek provides a perennial water supply that contributes to SNARL's habitat diversity. Three major types of vegetation occur on the relatively uniform terrain found at SNARL. Each is characterized by floristic composition and accompanying physical features, including soil type, exposure, and water availability. The three vegetation types found at SNARL are: 1) Great Basin Sagebrush Vegetation 2) High Desert Riparian Woodland 3) Riparian Meadow Vegetation.

By utilizing the resources at both SNARL and Valentine Camp, VESR is well known in the region for its active outreach programs. The Spring Seminar Series at SNARL hosts visiting scientists who give presentations on scientific topics of interest to local and regional public audiences of approximately 75-100 people per week. The Outdoor Science Education program, which operates both at Valentine Camp and SNARL, provides hands-on science lessons for K-12 students from Inyo and Mono counties as well as remote locations of western Nevada. During the summer months, SNARL also offers one and two-week science day camps for K-12 students on a fee basis.

Capabilities for Supporting Scientific Research and Training

VESR has extensive facilities for research and teaching at both Valentine Camp and SNARL. Valentine Camp has housing for 16 in three renovated log cabins constructed in the 1920's, a small wet lab, and a classroom building that can hold classes of up to 30 students (Fig. 3). SNARL is home to a more extensive array of field and laboratory facilities. One of the most unique features of SNARL is the experimental stream channel system (Fig. 4). The original channels were established by US Fish and Wildlife researchers in the 1940's and divided Convict creek into four sections up to 400 meters in length, with individual water-control structures and moveable fish barriers. An array of new experimental stream channels was built in the 1990's, and consisted of nine identical stream sections, with identical patterns of riffles, pools, and meanders. Each channel is one meter wide and 50 meters long, with natural sediments and cobbles laid over a rigid concrete base. The new channels provide researchers with statistically meaningful replicates for controlled comparative studies. In addition to the experimental channels and divided stream sections, researchers have access to stretches of Convict Creek above and below the reserve, and to small channels flowing through the aquatic laboratory (Fig. 5).



Figure 3. Three large cabins at the Valentine Camp are available for visiting scientists and educators.



Figure 4. The experimental stream channel system at SNARL is a unique facility available for aquatic research.



Figure 5. In addition to the experimental channel system, SNARL researchers have access to wet meadows and naturally flowing Convict Creek.

An additional SNARL field facility, the Snow Science Laboratory, is located on the flanks of Mammoth Mountain at an elevation of 9,600 feet. The lab is buried partially underground with a tower and platform reaching up 25 feet. Stretching from the platform, a cable suspends a cart full of instruments above the undisturbed snowpack. Inside the lab, lysimeters collect snow meltwater at ground level, and dataloggers record meterological, electromagnatic, and physical (i.e. snow depth) parameters.

In 1995 a two-story building was moved to SNARL and fully refurbished to serve as the reserve's database center. It provides several offices, a collection room, a conference room, and serves as the center of operations for SNARL's growing data management and research coordination efforts. Offices and laboratories have dedicated Internet services, computers and peripherals available for researchers' use.

SNARL also is home to a recently updated and modernized laboratory which houses six wet labs, a chemistry lab, radioisotope lab, additional offices, and a library. The laboratory also has a state of the art molecular diagnostics facility including a new quantitative PCR laboratory, tissue homogenizer, micro centrifuge and -80º Celsius freezer. Additional research facilities include: lab equipment such as an analytical balance and high purity water system walk-in cold room, spectrophotometer, meteorological station, woodshop, assorted boats and motors, snowmobiles, backpack electrofisher, incubator, plant dryer, and other field equipment.

Eight storage units make it possible for researchers to store their equipment for long-term research use. An animal care facility, built to USDA standards, is available for holding and caring for wild terrestrial vertebrates. An additional facility for holding aquatic organisms provides tanks and water tables with flow-through stream water. SNARL's commitment to teaching and outreach is reflected in its accommodations for visiting classes and community events. Large visiting groups can stay in the dormitory, which has bunk beds for 25 people, bathrooms, showers, a large kitchen and meeting room. Researchers accommodations also include several small houses at SNARL, each with a kitchen, bathroom, and one or two bedrooms. A brand new state-of-the-art classroom and meeting space (The Page Center) is the newest addition to SNARL (Fig. 6). The Page Center can accommodate 200 people and is equipped with modular meeting and classroom furniture, high tech audio and video capabilities, as well as high-speed wireless internet.

Unique Aspects

Both Valentine Camp and SNARL enjoy unique aspects that provide valuable research opportunities. Valentine Camp is a small, pristine site that preserves a remnant of the diverse natural vegetation found in the immediate vicinity of the town of Mammoth Lakes, Mono County, California. For the past 25 years, this area has undergone rapid change as a result of the expansion of ski facilities on and near Mammoth Mountain and of commercial and residential development of the town. As a result, virtually all native vegetation within town limits and in adjacent areas has been removed, or has lost much of its native biological diversity as a result of development-related disturbances and the spread of introduced species. These losses highlight the fact that, as a preserve for native biological diversity, Valentine Camp is even more important today than when the Valentine Eastern Sierra Reserve was established in 1973.

SNARL is located at the foot of the eastern escarpment of the Sierra Nevada, and serves as a unique base from which to access a broad range of habitats for research and teaching. This includes the nearby Convict Creek, which traverses SNARL from west to east and drains a watershed containing alpine lakes and peaks rising to over 3,900 m. Three national parks (Sequoia, Kings Canyon, and Yosemite) protect large portions of the adjacent Sierra Nevada, and immediately surrounding SNARL are additional extensive public lands managed by the US Forest Service (USFS) and Bureau of Land Management (BLM). Ecosystems managed by the National Park Service (NPS), USFS, and BLM are the focus of many ongoing research efforts at SNARL. To the east lie the mountains and valleys of the Great Basin. In addition, SNARL is located on the flank of the Long Valley Caldera, and much younger volcanic formations lie a short distance to the north. Fifty kilometers north of SNARL lies Mono Lake, a large saline water body that has been the subject of intensive study by SNARL-based researchers for the last thirty years.

Planning for the Future

VESR was recently awarded an NSF planning grant to develop a ten-year strategic plan to articulate a scientific vision for research and educational use, and an evaluation of the programs, facility needs and resources necessary to support that vision. The goal of the strategic plan is to enhance research and education activities at VESR as well as the regional coordination of research, education and outreach activities across the Sierra Nevada region

through a network of regional agency, non-profit, academic and field station partners. The planning process at VESR involved engaging with key stakeholders through virtual and in-person workshops. The strategic plan will direct the prioritization of facilities and programs enhancements, and access for researchers, students, educators and natural resource managers in the eastern Sierra Nevada. As part of the planning process we have articulated VESR's mission, vision and six main goals in support of the VESR mission:

Mission

VESR's mission is to advance knowledge and promote stewardship of the Eastern Sierra region through science, education and outreach.

Vision

An environmentally sustainable Eastern Sierra region with an engaged and scientifically literate community of stewards.

Goals

Research excellence: VESR provides functional, safe and user-friendly facilities, technologies and expertise that support cutting-edge research for faculty and students from the University of California, and across the globe.

Field-based education: VESR facilitates programs that enhance university-level, field, experimental and laboratory-based teaching in the Eastern Sierra. VESR strives to create an environment of diversity and inclusion in its support of university level education.

Public Engagement: With an array of science communication and educational programs, VESR engages the surrounding communities on scientific issues of societal relevance, and provides science and outdoor learning opportunities for students of all ages and backgrounds.

Diversity & Inclusion: VESR maintains a socially responsible environment in support of a body of users that reflect the diverse population of the state of California and the communities that the University of California serves.

Land Stewardship: VESR utilizes the resources of the field-based research endeavors to steward the lands and natural resources owned or managed by the University of California. VESR seeks to achieve science-based and responsible stewardship of the regional biodiversity for the purposes of supporting both social and ecological well-being.

Sustainability: VESR works towards environmental sustainability by decreasing electricity usage, incorporating new technology to reduce the carbon footprint, and reducing consumption and waste of all resources (e.g., fuel, water, materials)

To achieve these goals, we are in the process of identifying priorities for strategic investments in the broad areas of Programs, People and Infrastructure. We plan to finalize our plan in the coming months and make it available on our website (http://vesr.nrs.ucsb.edu/).

Photos are from the VESR library.



Figure 6. The new Page Center

Mountain Studies Institute, Silverton, Colorado

Page Buono and Marcie Bidwell
Mountain Studies Institute, Silverton and Durango, Colorado

Mountain Studies Institute (MSI) has been providing science and education to San Juan Mountain communities since its inception in 2002. Based in Silverton, CO and with offices in both Silverton and Durango, MSI is an independent, not-for-profit research center.

Together with our partners, MSI develops science that people can use to address environmental issues facing the San Juan Mountains. We conduct and facilitate research, provide educational opportunities and internships, and monitor forest and watershed health. We take pride in our ability and commitment to connect scientists and stakeholders across the San Juan Mountain region to go beyond scientific inquiry to the meaningful application of knowledge that makes a difference in the quality of the environment and our communities.

What're We Up To? A 2018 Snapshot

While there have been a number of milestones that mark our growth and direction between 2002 and now, 2018 was a year that exemplified MSI's role in the community, connecting stakeholders with the science and the health of our mountain ecosystems. In all of our work, climate science informs management decisions and the San Juan Mountains remain the living classroom at the heart center of our geography.

Climate

MSI continues to invite outside scientists, monitor our climate stations, and engage area land managers with local climate science.

For the past three years, we have been part of an interdisciplinary team, including social, ecological and climate scientists, who collaborated with local stakeholders in the Upper Gunnison and San Juan Basins to develop and apply an innovative climate planning framework. Called the Social-Ecological Climate Resilience (SECR) Project, our team hosted stakeholder workshops, defined three plausible future climate scenarios, developed response models for ecological and social systems, and defined actionable strategies that each partner can implement within the context of their respective conservation goals. In particular, MSI played a key role in researching and defining actions for the seeps, springs and wetlands ecosystem in the San Juan Basin.

The results of the study were published this year and, at the 2018 MtnClim conference in Gothic, CO, played a central role in the Managers' Workshop aimed at identifying climate refugia and key strategies for their conservation and management. Read more about the workshop on page 6.

Also this year, MSI and partners launched a drought resilience planning effort in the Mancos Watershed. A BOR WaterSMART grant will empower MSI and partners to combine existing vulnerability assessments to further refine and map values most impacted by drought and climate change. Based on findings from these initial efforts, MSI and partners are developing a decision framework with prioritized, actionable drought resiliency measures to inform future drought planning efforts.



MSI's Dr. Rory Cowie monitors a climate station outside of Silverton, CO.



The American pika is an important indicator of climate change impacts to mountain to high alpine ecosystems.



A student from Escalante Middle School monitors post-burn water quality in the Animas River.

Forests and Watersheds

MSI carried the message about a changing climate into our forest and watershed work this summer as our community shifted their attention to severe droughts and fire risk. Recognizing that the 2018 water year hit record lows, we worked with land management partners to construct a series of events aimed at preparing and educating our community about the impacts of drought and climate change on our forest ecosystems, while connecting them with resources. The series touched on forest and fire ecology, smoke dynamics, insect infestations, fire mitigation resources and management strategies in the face of a shifting climate.

During the 416 Fire, which burned 54,000 acres in the San Juan National Forest in the Hermosa Creek drainage north of Durango, CO, MSI worked closely with USFS partners to share critical messages about both benefits and impacts of wildfire. We used science to inform land owners and managers about potential post-burn impacts on the Hermosa and Animas watersheds, and wrote articles about the ecological benefits of fire. By leading a field tour that compared the 416 Fire to one that burned 16 years ago on Missionary Ridge, we were able to show the public the great potential for recovery in the 416-burn area.

As soon as the first rains fell on the 416 burn, we expanded our existing water quality monitoring efforts to extend both up and downstream of the Hermosa Creek so that we could better understand the impacts of the 416 on water quality in the river. Our data became a crucial piece to explaining to the community how the increases in turbidity and metal concentrations, and decreases in dissolved oxygen and pH, led to a significant fish kill in our local streams. Most notably, our data illustrated that the debris flow from the fires were actually more harmful to the water quality than the Gold King Mine Spill that shocked the region with neon orange water three years earlier.

Further, MSI used the 416 as an opportunity to expand our education programs and engage local students with forest and watershed health. We took multiple middle school classes into the woods to study beetle kill on Molas Pass (unaffected by the burn), the burn's impacts on trees and soil, and the fire's biotic and abiotic impacts to water quality through assessments of benthic macroinvertebrate communities, pH, turbidity, dissolved oxygen and temperature.

Citizen Science and Stewardship

We know people love the San Juan Mountains, and we know that they learn more when they're immersed in them, their eyes sharp and hands dirty. That is why, this summer, we took our Mountain Discovery Center into the "living classroom" of the San Juan Mountains.

As part of a long-term effort to restore fens in the San Juan's, we invited the public to join us during eight stewardship days. We were joined in the field by 180 volunteers, including 126 youth for 823 service learning hours. Together with volunteers of all



MSI staff and volunteers restore the Chattanooga Fen just west of Silverton.

ages and backgrounds, we planted five species: *Carex microptera*, *C. utriculata*, *C. norvegica*, *C. aquatilis*, and *Calamagrostis canadensis* across Chattanooga and Ophir Fens. In total, our volunteers put 2,292 seedling plugs in the ground, including the greenhouse cultivated plugs and locally collected transplants. After 10 years, we are very pleased to see Chattanooga Fen functioning as an intact ecosystem. The restoration efforts at Ophir Fen will continue for several seasons until we can establish enough vegetation so the fen is fully functional.

Together with community stewards, we restored approximately 4.0 acres of wetlands, 3.62 acres of which were within the ecologically important and globally rare iron fens. We also monitored the effectiveness of our 2017 plantings and collected seeds to keep our revegetation efforts going. The summer of 2018 was an "exceptional drought," and we saw die-off of seedlings planted in July by August. We experimented with several new species of sedges in 2018 and will take these lessons forward as we continue our revegetation efforts.

Another popular citizen science initiative that we have supported for years now is PikaNET. PikaNet engages people of all ages to collect data on the American pika. This high alpine creature is considered an indicator species of climate change due to its high vulnerability to warming global temperatures. MSI teaches volunteers what species and indicators they are looking for, where to find them, how to collect data, and how to submit the data to a statewide online database. Participants "adopt" their own pika monitoring site to collect and submit this important data. Data that participants collect will become part of a larger effort to monitor pika populations in Colorado and across the Southern Rockies. The Rocky Mountain Wild and the Denver Zoo will offer sister trainings in the Front Range of Northern Colorado.

While we have expanded our organization, we remain true to our core value of "science and education in the San Juan's" and continue to rely heavily on the living classroom offered by the unique and awe-inspiring mountains we call home.

Learn more about MSI at www.mountainstudies.org

Or, if you're in the area, join us for our November 29th Jack Frost Friendraiser (4-6 pm, 679 E 2nd Ave, Suite #8, Durango CO)

All photos are credited to the Mountain Studies Institute

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Sometimes MSI staff get fancy (but usually only for our annual Jack Frost Friendraiser)

News from Niwot Ridge/CU Mountain Research Station

William Bowman
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Mountain Research Station, Nederland, Colorado

The Mountain Research Station (MRS) was founded in 1921 as an interdisciplinary facility of the Institute of Arctic and Alpine Research at CU Boulder. Located at 2900 m in the Front Range of the Colorado Rocky Mountains (Fig. 1), the MRS is devoted to the advancement of the study of mountain ecosystems and provides research and educational opportunities for scientists, students, and the general public. The mission of the MRS is to facilitate research and education to better understand the unique patterns and processes of biotic and physical systems in mountains, and how environmental changes may influence these patterns and processes. Research at the MRS is performed by a multitude of investigators from numerous organizations, including National Science Foundation sponsored programs such as the Niwot Ridge Long-Term Ecological Research (LTER) Program, the Boulder Creek Critical Zone Program, the National Ecological Observatory Network, and many individual investigators. The MRS is in charge of the Mountain Climate Program, established in 1952 to provide long-term climate data from the montane, subalpine, and alpine zones of the Colorado Front Range. Four main meteorological stations have been maintained continuously since the inception of the program

As with most mountain field sites across western North America recent summers on Niwot Ridge have been increasingly marked by smoky skies, but our region of the Front Range of the southern Rockies has been spared the onslaught of large fires common in many other western ranges. Accelerated snowmelt has trended toward earlier starts to the summer season, but overall trends in high elevation temperatures have not been as strong as warming in the lower portions of the surrounding mountains and plains. Mountain pine beetles have not killed as many trees in the past 5 years as what was observed 5 to 10 years ago, and we were spared the high mortality seen on the western slope of the Continental Divide. However western balsam bark beetles are showing up in greater numbers, and spruce beetles are also showing higher impacts in old-growth stands.

Phase VII of the Niwot Ridge LTER program began in the summer of 2017 under the leadership of Katie Suding (CU Boulder). Research is focused on the impacts of earlier and longer summers on alpine ecosystem responses, particularly how complex topography enhances or moderates changes in plant function and composition. Experiments initiated in the summer



Figure 1. The Niwot Ridge LTER/ CU Mountain Research Station straddles an elevational gradient from forest to alpine zones in the Colorado Front Range. Photo: Bill Bowman



Figure 2. In the summer of 2018 a new experiment started involved advanced snowmelt treatments using black sand, coupled with warming treatments using ITEX chambers. Photo: Bill Bowman

of 2018 include advanced snowmelt treatments using black sand, coupled with warming treatments using ITEX chambers (Fig. 2). Parallel manipulations in aquatic ecosystems will be initiated in the summer of 2019 using *in-situ* mesocosm tanks. Additionally a newly deployed microclimate sensor network in a small catchment will facilitate an effort to understand coupling between terrestrial and aquatic function, as well as how predictability of changes in the physical environment influence plant species composition and function. Additional ongoing work associated with the LTER program includes pika population dynamics, legacy effects of nitrogen deposition, and plant-microbial interactions influencing community dynamics in newly exposed talus soils.

The summer of 2017 also saw the first full research season for the National Ecological Observatory Network effort on Niwot Ridge, which is the core site for Domain 13 (southern Rockies and Colorado Plateau). This program, funded by NSF, monitors biodiversity, soils, surface water, and ecosystem function using ground observations and automated instruments to provide data for ecologists to understand how ecosystems respond to variability in the current physical environment as well as model potential future responses to climate change.

Courses and outreach remain important aspects for the Mountain Research Station. Most years we host the Guild of Rocky Mountain Ecologists and Evolutionary Biologists meeting (Fig. 3), which is focused on graduate student research (though not exclusively), with two keynote presentations and a combination of contributed talks and posters. Regular undergraduate field courses include winter ecology, mammalogy, vegetation ecology, and lake and stream ecology. Additionally we serve as a locus for non-CU field courses, including a graduate level flux course covering eddy-covariance techniques for measuring biosphere-atmosphere exchange of CO_2.



Figure 3. Niwot/MRS hosts the annual meeting of the Guild of Rocky Mountain Ecologists and Evolutionary Biologists. Photo: Bill Bowman

HJ Andrews Long-Term Ecological Research Program

Mark Schulze
HJ Andrews Experimental Forest
Blue River, Oregon

Tucked deep in the central Oregon Cascades, The HJ Andrews Experimental Forest has been the site of ongoing long-term ecological research for seventy years. Its 16,000 acres of lush native forests and delicate montane meadows blanket the steep walls of the Lookout Creek watershed (Fig. 1). Dozens of bird species and hundreds of varieties of plants call this wild place home, along with cutthroat trout, giant salamanders, flying squirrels, cougars, and myriad other living things, big and small.

Scientists have long studied the Andrews' ecosystem, rooted by its towering old-growth trees, in part because it represents the mountain forests that cover nearly a quarter of the land surfaces on Earth. Along with their rich biodiversity, these forests provide habitat for fish and game, store carbon and supply many of the resources upon which humans depend. However, they are also under pressure from climate change and growing demand for timber and agricultural land.



Figure 1. Forest-meadow transition in the HJ Andrews Forest, with the Three Sisters in the background. Photo: Lina DiGregorio

Researchers at the HJ Andrews study how these global forces play out on local scales as they cascade through complex topography and interconnected ecosystems. The US Forest Service set aside the watershed for study of forest management and hydrology in 1948 (Fig. 2). By 1969, the focus of research conducted at the Andrews had extended to forest and stream ecosystem dynamics. This work expanded when the Andrews became a charter member of the National Science Foundation's Long-Term Ecological Research Network in 1980.

The history of the Andrews forest includes both natural and human influences, and affords scientists and managers a unique opportunity to investigate the mechanisms at work in forested mountain ecosystems. Long-term experiments and monitoring track the changes occurring at the Andrews and beyond, enabling scientists to distinguish short-term fluctuations from underlying trends, and to draw robust conclusions about gradual changes that often prove difficult to study (Fig 3).

For example, analysis of long-term climate records and more recent quantification of microclimate across the Andrews has revealed that while climate change has affected some aspects of the environment—like earlier springs and thinner snowpacks—local atmospheric processes and the old growth forest itself may



Figure 2. Lookout Creek with new log jam. Photo: Mark Schulze



Figure 3. Re-measuring Mack Creek permanent plot. Photo: Lina DiGregorio

buffer these effects in some parts of the landscape during some seasons (Daly et al. 2009, Frey et al. 2016a, Honzakova 2017, Sproles et al. 2018). Moreover, these complex microclimate patterns in space and time influence behavior, phenology and populations of forest species. Small-scale temperature variation is as important as vegetation structure in determining songbird occupancy and movement across the landscape during the breeding season (Frey et al. 2016b). The temperature buffering effect of old growth forest may reduce negative impacts of increasing summer temperatures on populations of temperature-sensitive songbird species in old-growth dominated landscapes (Betts et al. 2018). However, low snowpack and high frequencies of temperature inversions lead to homogenization of spring plant phenology across the mountain landscape, with potential implications for trophic interactions in a changing climate (Ward et al. 2018).

Management experiments conducted over the course of decades have illustrated how timber harvesting practices have a lasting impact on the flow of nutrients and water within the landscape and on aquatic communities (Kaylor and Warren 2017, Lajtha and Jones 2018, Perry and Jones 2017; Fig. 4). Recent work has shown that legacies of clearcutting extend to the surrounding



Figure 4. Watershed 1 gauging station. Photo: Lina DiGregorio

forest and for decades after harvest, resulting in significantly lower biomass in unlogged stands within 75 meters of an old harvest unit than similar-aged forest farther removed from these edges—a significant unintended consequence of harvest practices in the clearcutting era, which produced a highly fragmented landscape (Bell et al. 2017).

Future work at the Andrews will continue to investigate how global climate patterns manifest themselves in the mountainous terrain of the HJ Andrews and interact with natural disturbances and land management. Researchers are studying how fine-scale patterns of soil moisture relate to forest productivity, and trying to understand the relative importance of soil water and nutrient availability, temperature and vapor pressure in determining growing season stress in the increasingly pronounced dry season. Efforts continue to better understand terrestrial and aquatic food webs and how trophic interactions may be influenced by changes in microclimate patterns and hydrologic connectivity. There is a renewed focus on canopy ecology and vertical gradients in microclimate, pathogens, endophytes, secondary consumers and predators, which may influence forest resilience and vulnerability as much as gradients across the mountains. And a major emphasis will always be on maintaining, curating, and interpreting the long-term records of climate, hydrology, disturbance, vegetation and population dynamics that form the backbone of all new inquiry at the Andrews Forest (Fig. 5).



Figure 5. Upper Lookout Creek rain gauge, winter 2008. Photo: HJA Forest

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Southern Sierra Critical Zone Observatory

Michelle Gilmore and Roger Bales
Sierra Nevada Research Institute, University of California, Merced, California

The Southern Sierra Critical Zone Observatory (SSCZO) is an Earth and environmental research program investigating the living part of Earth where water, soil, rock, air, and biota interact to form land surfaces and the ecosystem found on them. Hydrologists, geomorphologists, soil scientists, and ecologists from six University of California campuses, University of Wyoming, and other institutions such as the USDA Forest Service Pacific Southwest Research Station and Lawrence Livermore National Laboratory collaborate to improve our understanding of water balance, nutrient cycling, weathering processes, and forest function in the Sierra Nevada. Interdisciplinary research and ongoing monitoring at our intensively studied sites allows us to research this living layer of Earth at spatial scales from water droplet to watershed, and temporal scales from minutes to millennia. Coordinated, linked activities enable us to explain and predict the properties and processes of southern Sierra landscapes and ecosystems, including water cycle responses to drought, fire, tree mortality, changing climate, and other disturbances to the landscape across space and time (Figs. 1, 2).

SSCZO's main field areas are located in the headwaters of the Kings River and foothills on the western slope of the southern Sierra Nevada with biomes ranging from oak savannah to subalpine forest, crossing the rain-snow transition zone. Research sites are located on federal lands including the Sierra National Forest, San Joaquin Experimental Range, and Sequoia National Park. Multiple sites are co-located with the USDA Forest Service Pacific Southwest Research Station's Kings River Experimental Watersheds. Sites span a range of elevation from 400 m to over 2100 m above sea level. As elevation increases, vegetation, temperature, and dominant precipitation phase also change.

We frequently engage with research communities, stakeholders, and public audiences in order to share our activities and findings, to promote informed decision-making and management of critical-zone and ecosystem services, and to increase public understanding and awareness of critical zone science and the importance of these sensitive mountain regions.



Figure 1. An illustration of Critical Zone Observatory measurements in a montane forested watershed. Photo: Jenny Parks



Figure 2. A strategically-placed network of solar-powered monitors capture variations in snow depth, soil moisture and temperature, air temperature and relative humidity, and solar radiation across the forest landscape every 15 minutes at Providence Creek Catchments site P301, Sierra National Forest, CA USA. Wireless-sensor networks based on these instrument clusters developed at the Southern Sierra Critical Zone Observatory have been deployed in multiple watershed headwaters in the state. Photo: Roger Wyan

One recent example of research with direct implications for ongoing and future forest restoration efforts is a recent study that quantified changes in runoff from forest thinning and fire (Fig. 3) (Roche et al. 2018). Researchers found that between 1990 and 2008, fire-thinned forests resulted in an additional 14 million m^3 of runoff annually in the Kings, and 64 million m3 in the American River. This builds off of prior work that showed the Kings River flow is highly sensitive to vegetation expansion and climate change, predicting large increases in evapotranspiration and decreases in mountain runoff and water supply as climate warms (Goulden and Bales 2018).

Other work has found links between mountain ecosystems, landscape evolution, and bedrock lithology (Hahm et al. 2014). Changes in canopy cover correlate with the ratio of mafic to felsic minerals in igneous intrusive bedrock of the Sierra Nevada. "Balder" forest areas that were sampled were found to have bedrock containing higher silica and felsic mineral content, while areas with higher forest cover were observed in areas with bedrock containing higher percentages of mafic minerals and higher concentrations of nutrients such as phosphorus, aluminum, calcium, and magnesium (Fig. 4). This finding suggests intricate feedbacks between mineralogy, weathering rates, soil production, bedrock nutrient availability, soil water-holding capacity, and ecosystem productivity in a region often delineated as a swath

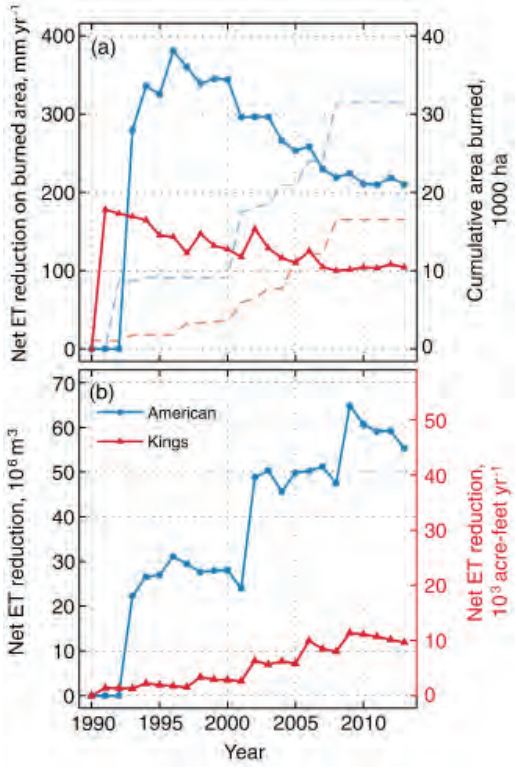

Figure 3. (A) Net annual evapotranspiration (ET) reduction depth on areas burned (bold lines) and cumulative area burned (dashed lines), and (B) net annual ET reduction volume resulting from fires in the American and Kings River watersheds 1990–2008. Note that only fires through 2008 were included in the analysis. From Roche et al. 2018.

of homogeneous granite on geologic maps. We continue to build off of this work to improve our understanding of soil and regolith production, depth, and structure; and how water cycling and ecosystem function vary with these properties.

We have also recently learned of the importance of dust as essentially a forest fertilizer, providing additional nutrients such as phosphorus from sources in the Central Valley and as far away as the Gobi Desert (Aciego et al. 2017). Vegetation in the southern Sierra uptake more nutrients from these dust sources than from bedrock sources (Arvin et al. 2017).

Advancing our knowledge of Sierra Nevada headwaters and forests—California's largest water tower—is vital to California and beyond. We and eight other Critical Zone Observatories (CZOs) in the U.S. CZO Network funded by the National Science Foundation strive to rapidly advance Earth-systems knowledge through our open sites, datasets, and other resources for researchers. Numerous international CZOs and hydrologic observatories are also working toward these goals.

Learn more about the Southern Sierra Critical Zone Observatory online at http://criticalzone.org/sierra

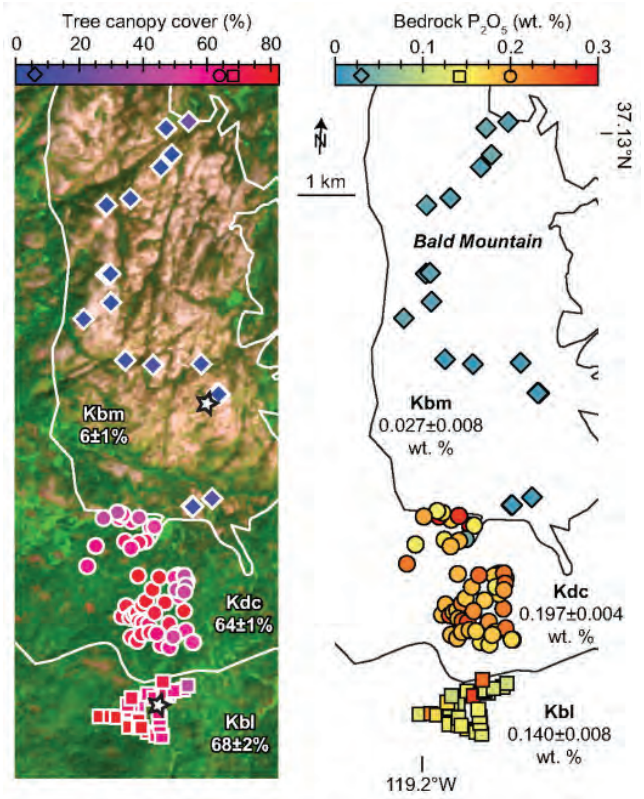

Figure 4. Distribution of vegetation across bedrock with differing phosphorus content. (Left) False-color Landsat image of CZO vicinity with georeferenced bedrock contacts from simplified geologic map shown at Right. Symbol colors match color-bar scales of Landsat-derived, remotely sensed tree-canopy cover, a proxy for primary productivity (Left), and bedrock P concentrations (Right). Vegetated–unvegetated ecotone coincides with boundary of Bald Mountain Granite (Kbm; diamonds), a desert in bedrock P relative to more heavily forested Dinkey Creek Granodiorite (Kdc; circles) and Bass Lake Tonalite (Kbl; squares). Labels show average (±SEM) tree-canopy cover (Left) and bedrock P concentration (Right) by rock type. Stars at Left pinpoint productivity surveys. From Hahm et al. 2014.

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Material for this article is adopted from the USGS "Glaciers and Climate Project" webpages

Benchmark Glacier Program

Scientists with the Glaciers and Climate Project study many of the pertinent impacts that glaciers present to society, such as altering hydrologic cycles, contributing to sea-level rise, and creating environmental hazards. Having progressed from early studies which focused on understanding where and why glaciers exist, and their primary response to climate, the Glaciers and Climate Project's objective today is to advance the quantitative understanding of glacier-climate interactions to best predict and prepare for local, regional, and global implications of changes to Earth's mountain glaciers and ice sheets. With a firm foundation of long-term records, the Glaciers and Climate Project continues to broaden its value and impact by incorporating new technologies and expertise over a diverse suite of glaciological challenges.

Benchmark Glacier Research

Since the late 1950s, USGS has maintained a long-term glacier mass-balance program at three North American glaciers. These 'Benchmark Glaciers' include Washington's South Cascade Glacier and Alaska's Gulkana and Wolverine glaciers. Results from this program form the longest continuous record of North American glacier mass balance. Similar measurements began at Sperry Glacier, MT in 2005 (Fig. 1)

In 2013, research at these independent sites was unified into a single project, with an ultimate goal of measuring changes in glacier mass across the principal North American climate zones that support them. Common field and analysis methodologies will

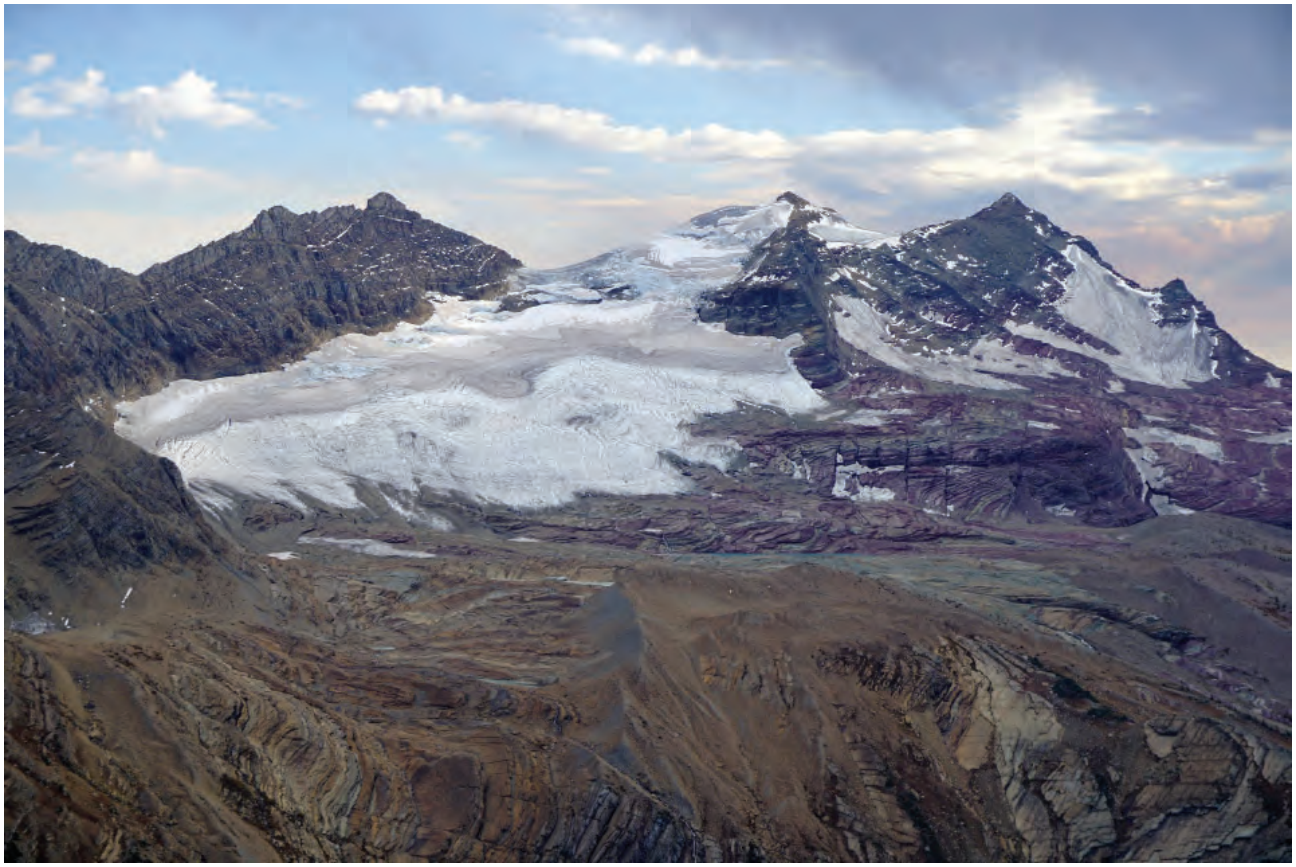

Figure 1. Panorama of Sperry Glacier.



Figure 2. Lisa McKeon using repeat photography to measure glacier recession.

enable comparison among the glaciers, and provide an improved understanding of both the causes and magnitudes of glacier change over long time periods at a continental scale (Fig. 2).

Each benchmark glacier is influenced by a unique climatology. In Alaska, the measurements capture changes in both continental and maritime climate zones. Alaska's maritime climate zone is characterized by relatively warm and wet weather while the continental climate zone is characterized by extreme winter cold, warm or even hot summers, and substantially less precipitation than along the coast. Washington's maritime climate zone includes some the highest precipitation recorded for the lower 48 states of the United States. Montana's intermountain climate zone reflects a blend of maritime influences from the west and continental influence from the Arctic and Great Plains, which meet along the continental divide.

Currently, historic data from the benchmark glaciers are being reanalyzed with consistent analysis techniques across the four glaciers. An emphasis on generalized algorithm development will allow other mass balance programs to be analyzed using the same algorithms (e.g., Taku Glacier in Alaska).

The fully unified USGS Benchmark Glacier project will allow mass balance records from different parts of North America to be directly compared to better understand the response of glaciers to climate changes (Fig. 3). The two Alaskan benchmark glaciers have already undergone this comparative reanalysis, which



Figure 3. Using a steam drill prior to installing ablation stakes.

revealed differences in variability and trends between the coastal and continental glaciers (O'Neel et al., 2014). For example, short-lived mass gains (positive slopes) occurred at Wolverine Glacier; in the 1980's the cumulative mass balance indicates gains since the 60s (positive values). These episodes of growth result from the abundant snow accumulation and cool summers that characterize Alaska's coastal climate zones. In contrast, the persistent mass loss at Gulkana glacier exemplifies the stronger dependence of continental glacier mass balance on summer temperature.

Additionally, as traditional field measurements are combined with remote sensing data, the short-lived remote sensing records can be linked to the longer field records. Just as geodesists have linked the tide gauge and satellite records to better understand sea level rise, glaciologists aim to link field and satellite records to gain regional insight into changing glaciers.

For further information on the project, contact Daniel Fagre, USGS Northern Rocky Mountain Science Center.

Photos are from the USGS archives.

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Looking down Sperry Glacier with crevasses in foreground and meltwater ponds at base of glacier.

FIRST PERSON

The Long Now Foundation and a Great Basin Mountain Observatory for Long Science

Laura Buszard-Welcher
The Long Now Foundation, San Francisco, California

About 15 years ago, my work unexpectedly collided with mountain climate science research when the nonprofit organization I work for, The Long Now Foundation, acquired Mt. Washington in eastern Nevada (Fig. 1). Not the whole mountain, but important parts of it, and also parts of the adjacent Spring Valley. Long Now had been looking for a site to build its flagship artifact for the future, the 10,000 Year Clock, and originally acquired the properties with this in mind. For various reasons, this turned out not to be where we are currently constructing the 10,000 Year Clock, which is now in the installation phase in a mountain in west Texas. What we might create on Mt. Washington that is Clock-related is not yet planned. Still, the Mt. Washington and Spring Valley properties remain close to the heart of Long Now, and we conjure what could happen there. One possibility is a long-term science station. More on this below.

The Big Here and The Long Now

Long Now was first established in 01996 with the mission of fostering long-term thinking in society.[1] We modern humans live longer than our ancestors, yet increasingly our tendency is to think and operate in ever shorter time frames—the four-year election cycle, two-year science grant, annual federal budget, or the quarterly return. This is to the detriment of observing longer trends that might impact us, or in strategizing solutions to problems that might take multiple generations, or even centuries to implement. The idea of the "Long Now" (coined by Long Now board member, artist, and musician Brian Eno) is to shift one's frame of reference, agency and responsibility from the local 'here' and short 'now' to the Big Here and Long Now—to thinking globally and long-term, and taking good care of one's civilization.[2]

To define an operating framework, Long Now looks back 10,000 years to the dawn of human civilization and projects this into the next 10,000 years. In total, this 20,000-year span of history, present, and future is the "Long Now." Rather than just taking this as an abstract concept, Long Now as an organization engages in projects that require us to take the Long Now seriously. One of these projects is the 10,000 Year Clock, designed to tick and keep time for 10,000 years. Another is The Rosetta Project, which is building an archive of all human languages and creating a backup that can last for thousands of years. Yet another is Long Bets, where you can lay down real money and make predictions



Figure 1. Mt. Washington in the Snake Range, NV, with bristlecone pines. Photo: Connie Millar

of societal consequence, but the bet might not be decided for hundreds or thousands of years (the stakes go to the charity of the winner's choice). Another project, Revive and Restore, recently spun off of Long Now, and is working on the de-extinction of species like the Passenger Pigeon and Woolly Mammoth. By taking the long-term seriously, we hope to inspire people and give them permission to think longer-term, even if that means ten years from now. We hope it also means 10,000 years from now.

A Clock and a Mountain

In many respects the 10,000 Year Clock is like an ordinary clock. It has a pendulum that 'ticks', it has chimes, it uses mechanical gears to track time. It is unusual in that it is built to reckon time for the next 10,000 years, is hundreds of feet tall, uses temperature differences between night and day as an energy source, and its siting requires a mountain (for more, see The Long Now Foundation 2018)

When Long Now was looking for a mountain for the Clock, the late Roger Kennedy was on the Board of Directors. He had been head of the National Park Service shortly after Great Basin National Park was established. The park and surrounding area in the Snake Range, Nevada, are home to the impressively long-lived bristlecone pine (*Pinus longaeva*), one of which, the ill-fated Prometheus Tree (Fig. 2), was felled by the U.S. Forest Service in 1964 at the request of a geomorphology graduate student undertaking research to date glacial moraines. It was posthumously dated at 4,862 years old; at the time it was the oldest known non-clonal organism on Earth. Roger thought that the beauty and remoteness of the area, along with the millennially-ancient bristlecone pine groves would provide an epic and inspirational siting for the 10,000 Year Clock.

Just outside the park boundary, south of the tallest peak in the range Mt. Wheeler, lies Mt. Washington. On Mt. Washington's western side is a gargantuan limestone cliff, reaching 11,657 feet in elevation at its summit. On its slopes, forests of pinyon pine (*Pinus monophylla*), juniper (*Juniperus osteosperma*) rise through limber pine (*Pinus flexilis*), Engelmann spruce (*Picea engelmannii*) and white fir (*Abies concolor*) culminating in open groves of stately bristlecone pine and alpine meadows, lush with flowers and pollinators on a midsummer's day. In winter, it is blanketed by many feet of snow, and icy storms buffet its peak and flanks (Fig. 3).

The property that Long Now purchased for the siting of the Clock is at the summit of Mt. Washington above the limestone escarpment. It was previously a sometimes-operating beryllium mine, and along with surface rights, Long Now acquired mineral rights to the property. Long Now has no interest in mining, but needed those rights in order to excavate inside the cliff, to create the chambers that would house the Clock and protect it from the elements. Long Now also acquired several patent mining claims heading south along the top of the cliff, and one non-patent claim known as the "Pole Adit" at about 7,800 feet on the western slope.

From atop the peak of Mt. Washington, looking westward the viewshed takes in Spring Valley (Fig. 4), a basin that at the time of Long Now's purchase was mostly home to alfalfa farmers, sagebrush, sheep and scientifically-significant stands of Rocky



Figure 2. The Prometheus Tree. Painting by Laura Welcher.



Figure 3. Late spring in the Snake Range, Scotty Strachan walks up Mt. Washington with Mt. Lincoln behind him.

Mountain junipers (*Juniperus scopulorum*, locally known as "Swamp Cedars", Charlet 2006). Hidden from view, but supporting life in the valley, is an ancient aquifer evidenced here and there where it percolates to the surface in artesian wells. With the help of local realtor Dave Tilford, Long Now purchased its mountain properties, as well as a valley property along Highway 894 with resident Swamp Cedars. A few years later, Long Now also acquired a property sold by the local school board along Highway 50 near Majors Place. This property is slightly higher in elevation from the Swamp Cedar property, and has a glorious view of southern Spring Valley, Mt. Washington, and the western face of the Snake Range (Fig. 5).



Figure 4. View from the crest of the Snake Range west to Spring Valley. Photo: Scotty Strachan

A Linguist and a Library

This is about where I enter the story. I came to The Long Now Foundation from an academic background in theoretical linguistics. My focus was on the documentation and description of certain indigenous languages of North America, which are today some of the most critically endangered languages on Earth (although many are also being revived as modern, spoken languages). I'd done my Ph.D. at UC Berkeley and was just wrapping up a year's postdoc in Michigan, when I was hired by Long Now to work on The Rosetta Project.

The Rosetta Project, which at the time was just getting off the ground, is an effort to build an archive of all spoken languages on Earth (there are around 7,000 of them) and to create a backup of this archive that can last and be readable for thousands of years, The Rosetta Disk (The Rosetta Project 2018). The Rosetta Project was conceived as part of the Long Now Library—a companion collection to the 10,000 Year Clock intended to provide a "wisdom line" for humanity, the knowledge to rebuild civilization if necessary, and the context to re-think and re-tool when inspired to do so (Brand 1999). The Rosetta Project was the first entry in the Library, created as a key to whatever information we may leave to the future in the form of our human languages.

The Rosetta Project is a good place for a linguist and budding long-term thinker to hang her proverbial hat. Our 7,000 modern spoken languages, in roughly one hundred and fifty different language families, are the product of millennia of differentiation and change through isolation of speakers as well as contact between them and its associated multilingualism. To study human language in its modern diversity is to peer back through at least 6,000-8,000 years of human history, since that is what we can reconstruct for the better-studied language families like Indo-European. It is also a poignant time to take an archival snapshot of human language, since the total number of languages is



Figure 5. The western escarpment of the Snake Range from Spring Valley. Mt. Washington on the left, and Mt. Lincoln on the right. Photo: Scotty Strachan

bound to be drastically reduced within a century. A massive loss of species is often used as a metaphor for explaining the magnitude of this linguistic change we are witnessing in our lifetimes.

While I have had the charge of The Rosetta Project for several years at Long Now, I have had many other roles and responsibilities there as well (this is common in small nonprofit organizations). Over the years I have carried the titles of Rosetta Project Director, Development Director, and most recently Director of Operations and The Long Now Library. (I can even add a section to my CV for helping open and run the Long Now bar/café The Interval! If you had told me that as a graduate student, I never would have believed it.) Pretty early on in my tenure at Long Now I took on the role of helping manage the properties in Eastern Nevada and this is where I was first introduced to mountain climate science.

A Mountain and a Transect

In 02007, researchers at several institutions within the Nevada System of Higher Education contacted Long Now about a proposal they were developing to submit to the National Science Foundation's EPSCoR (Established Program to Stimulate Competitive Research, National Science Foundation 2018a) grant competition. They wondered if Long Now might make its Spring Valley and Mt. Washington properties available for the siting of several semi-permanent environmental monitoring stations. The stations on Long Now properties would form a transect in various environments and elevations running roughly southwest to northeast across the Snake Range. Linked by radio, with relays to remote data centers, the whole system would define an area of data collection that could be used to study climate, ecology, and hydrology in this region of the Great Basin.

We listened with interest. Long Now had previously set up a small weather station of its own on Mt. Washington, but despite its remote and unadvertised location on the mountain, it was discovered and repeatedly vandalized (we did nevertheless manage to collect several years of data). This NSF project brought the possibility of a much more advanced set of instruments, with superior data collection through a linked data network that would be built and managed by climate scientists. Other than providing sites for the stations and access to them, Long Now would not be involved with their setup, operation or data collection.

Long Now said yes to the use of its properties. The proposal was successful, and in 02008 the Nevada Climate-ecohydrology Assessment Network (NevCAN for short) was created by a five-year, fifteen million dollar grant (National Science Foundation 2018b). Three of the seven planned observatory stations for the Snake Range were built on Long Now properties, one in the valley off Highway 894 (Fig. 6) and two on the upper elevations of Mt. Washington. Another monitoring station was added to the network when Long Now acquired additional Spring Valley property off of Highway 50 in 02013.

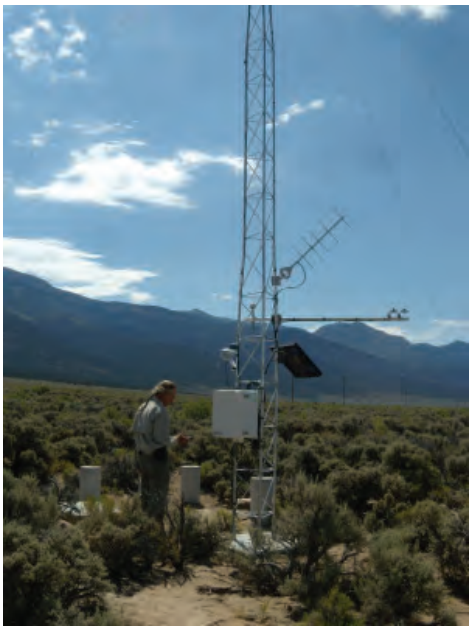

Figure 6. NevCAN weather station in Spring Valley, with David Charlet conducting vegetation plot assessments. Photo: Connie Millar

Deep Time and Long Science

I first had the delight of meeting Scotty Strachan when he was a graduate student at the University of Nevada Reno and had taken charge of the building and communications of all the weather stations in the NevCAN network. These included not just the stations around Spring Valley and Mt. Washington in the Snake Range, but also four stations in southern Nevada in the Sheep Range. Scotty also linked all of the stations by radio and relayed their collected data via repeaters back to his data center at UNR (I should add, using some serious ham radio skills, of which I maintain a merely hobby interest and ability). The use of the network was a critical part of his doctoral research.

All of this, frankly, impressed the socks off of me. Studying linguistics at Berkeley when I did my Ph.D. meant establishing a close relationship with your data. You cut your teeth as a linguist theorizing about data that you, yourself, had collected. This practice instills a strong understanding of the contextual dependence of collected data as well as a responsibility to the longevity of that data and its potential reuse in the future—which also means communicating that contextual dependence to future data users. To this day, Berkeley linguists rarely stray far from field research, and typically base the research of their scholarly careers on it. Given that linguists today are also typically collecting data about languages that are critically endangered means we have a deep responsibility to those communities we work with, as well as to the world, for we are working to document world heritage. But creating a culture of data stewardship through its entire life cycle from collection to its preservation, access and reuse is a problem that has plagued the discipline of linguistics, and we are just beginning to sort it out. Here was my first encounter with climate scientists in the field, and despite all of the challenges inherent in digital data creation and management, they seemed light-years ahead.

Scotty and I kept in contact and over the years had many opportunities to meet up, including when he made annual maintenance trips to work on the stations in Spring Valley and the Snake Range. Often trips were combined with picking juniper berries which we used to flavor the gin for the Long Now bar/café The Interval, or an ARRL ham radio field day atop Mt. Washington, and these all were a lot of fun. Many a night over a campfire we would talk about how fantastic it would be to build a science research station in Spring Valley. It could support resident scientists working on instrumentation and data collection using the NevCAN network. Building a cabin on Mt. Washington would enable researchers to stay at elevation while they did their work, and could provide shelter for winter field research as well.

What could set such a research station apart from other existing or proposed stations? To name a few, its focus on the Great Basin, and raising the profile of this important region for the study of climate science and human adaptation; its existing infrastructure with the NevCAN transect and the institutional relationship of the transect to the Nevada System of Higher Education; the scientifically important status of the Swamp Cedars and bristlecone pine populations to name just two species of interest. Doubtless there are many others.

Then, as an institutional partner of the research station, Long Now would bring an emphasis on "Long Science." Stewart Brand devoted a chapter in his book *The Clock of the Long Now* to this idea (Brand 1999:138). He observed that:

> "[t]he benefits of very long-term scientific studies are so obvious it is hard to understand why they are so rare…. Enormous, inexorable power is in the long trends, but we cannot measure them or even notice them without doing extremely patient science."

He continues (Brand 1999:142):

> "If a Long Now Library gets established, one useful role for it might be to broker ambitious longitudinal studies with deep-pocketed—or steady-pocketed—funding sources. It might also guarantee long-term oversight and archival backup for the studies. When they are abandoned by their original researchers, it could try to find new keepers of the work, or at least preserve the accumulated material for later review or revival. Such a Library could foster cross-pollination among the long-term projects: correlating data and spreading the word on new tools, new uses for old data, and newly evolved best practices."

So over twenty years ago, Stewart Brand saw a role for Long Science within the Long Now.

Why is Long Science especially valuable in Spring Valley? Right now, given there is a proposed project to build a pipeline and pump groundwater out of the valley, the obvious problem in need of a good long-term solution is basin groundwater access and use (Southern Nevada Water Authority 2018). Sustainable adaptations to a changing climate require long-term observation, analysis, planning and implementation. A Long Science research station in Spring Valley could potentially serve as public oversight to the proposed water pipeline project—if the pipeline is built, there will most certainly be defined triggers where mitigation plans must be put into effect. We will need third-party, robust data collection and analysis for monitoring.

Besides this need, there are good avenues for connecting long-term research across several disciplines to build a detailed, multi-faceted scientific chronology of the region. The climate record in multi-millennial bristlecones pines is one, also packrat middens (*Neotoma cinerea*; *N. lepida*) and their 40,000 years' record of fossilized plant material and pollen (Thompson 1990). Archaeology as well—as evidenced in the Baker, Nevada archaeological site, an agricultural community thrived in Snake Valley less than a millennium ago, in what today is an arid, dusty basin (Great Basin National Heritage Site 2018).

Long Now is a public-facing organization, and this is also important to its mission which is operating on the level of trying to change culture. We are always working to broaden our public engagement. So in addition to scientific residencies at the research station, we imagine resident artists and writers helping to open up the science to a broader audience. Stewart Brand observes that "science and art are always inspiring each other" (Brand 1999:142). Ideally, the resident scientists and artists would be in ongoing dialog with each other.

Then, our vision expands—with the more recently acquired property on Highway 50 we imagine a visitor center where people can come to learn about the work of the research station, and the importance of long-term thinking and science in the region. It would also be a great neighbor to the Great Basin National Park visitor centers on the east side of the Snake Range, and their growing emphasis on astronomy.[3]

Long Now and *The Long Now*

As I mentioned at the beginning, it isn't clear whether Long Now will build a Clock on Mt. Washington. While we have the means to purchase property in Spring Valley and on Mt. Washington, we don't have the funding to build the Clock itself. Mt. Washington also presents logistic challenges, not the least of which is a dirt access road that can't handle regular travel or heavy equipment, and an elevation significant enough that it requires acclimatization, at least for anyone used to living near sea level. Also, the potential impact of construction on the alpine environment and the bristlecones pines is a serious consideration (Fig. 7).

As board members have pointed out, we would be serving the Long Now mission by just holding the properties we have in Eastern Nevada, with their resident bristlecone pines and Swamp Cedars. But building *something* on Mt. Washington is certainly still on the table. Maybe it is some kind of a Clock. Maybe it is an observatory, as Danny Hillis, creator of the 10,000 Year Clock has mused. Maybe it is a library.

Maybe it is long-term science station.



Figure 7. Ancient bristlecone pine. Painting by Laura Welcher

Notes

[1]Long Now uses 5-digit dates to help prevent the Y10K bug.

[2]It is worth mentioning that in many ways the Long Now Foundation is a cultural successor of the Whole Earth Catalog, which Stewart Brand launched with the question to NASA "Why haven't we a photograph of the whole Earth yet?" When we did, he knew that would change everything, and he was right.

[3]In 02016, Great Basin National Park was designated an International Dark Sky park. Indeed, on a moonless night you can easily walk around there by the light of the Milky Way. Also in 02016, the Great Basin Observatory celebrated first-light for its new .7 meter, remote-operation telescope. It is the first research-grade telescope built within a national park, and it is especially intended for educational use. Dave Tilford, who is on the board of the Great Basin National Park Foundation that raised the funds for the telescope said that their dream is that school children who could access and use the telescope would grow up and be inspired to become astrophysicists.

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Mountain Observatories and a Return to Environmental Long Science

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Wind cutting across my cheek, I marched across a grey, sharp limestone slope at treeline in the Great Basin. The tinkle of rock under shoe and a light whistle of air though bristlecone pine krummholtz were the only sounds heard in a stark, seemingly timeless landscape. Oh, and labored breathing at 3500 m elevation. I was here at the summit of Mt. Washington, Great Basin, North America, to eavesdrop on an art project idea that would predict the slow advance of bristlecone growth over thousands of years (Fig. 1).

I caught up with the artist team downslope in a grove of live and long since expired trees, listening to brainstorming about how to demark growth extents of stems over millennia. It hit me as I reviewed the various strategies that even the artists seeking to communicate vast differences between human and tree timescales were struggling with the realities of nature's physics.

"Hey gang, let's put on our ten-thousand-year goggles. You need to view the eroding soil column more like a fluid on this slope."

"Wait, what?"

Science, as it turns out, is not very different in this regard—with the human element as the common denominator. Short-term demands of the mission, personal experience, economic drivers, and community dynamics often shape scientific work far more than we are willing to admit. As science continues to evolve from infancy into adolescence, it adopts the aggregate behavioral norms of the human participants (Fig. 2).

Looking at Western culture as an incubator of modern science, we can readily draw parallels in research with the societal cycles of fashion, entertainment, politics, finance, and international conflict. Alarmingly, as science becomes "mainstream", these short-term cycles increasingly impact how science is "done", and more importantly, how science is taught. These issues pervade all fields of inquiry, and mountain science is no exception.

At the recent *MtnClim 2018* conference, held at Rocky Mountain Biological Laboratory in Colorado, I was refreshed to see venerated attendees describing common measurement of physical processes taking place over decades of time. True "Long Science"



Figure 1. Bristlecone pines on Mt. Washington, Snake Range, NV.

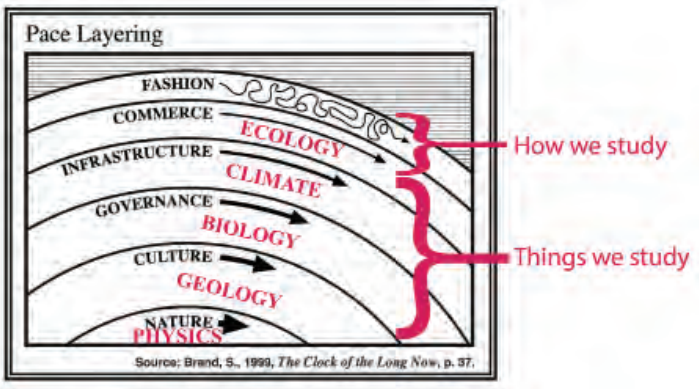

Figure 2. If we adapt the Long Now Foundation's Stewart Brand "Pace Layers" to environmental science, we get something like this. Research fashion changes like the weather.

being done in relatively simple ways like dedicated billy barr's weather observations, or in more elaborate schemes requiring electricity and endless counting mantras like Dr. John Harte's 28-year meadow warming experiment (Fig. 3).

This "observatory" or "Long Science" approach of establishing long-term, regular, repeated measurements that may be evaluated over time for bias, error, and repeatability is a mindset that goes far back into the evolution of scientific research itself. Particularly in the environmental sciences where strict laboratory control of variables and time is simply not possible. But one need only look at the stream of modern publication titles and abstracts to see that this approach is far from common in today's Research Economy.

Science-meets-unfettered-Capitalism is the order of the day in the race for bibliometrics, and "by any means necessary" is dangerously close to being normalized. For environmental science, the drivers are typically management or policy objectives as opposed to pure inquiry (true discovery science doesn't pay anymore), and landscape management or resource policy are generally focused on *conditions* (snapshot) as opposed to a layered, complex process (ain't nobody got time for that). The trends play out as we watch the budgets for *in-situ* environmental observations shrink across agencies and governments. Arguably, the technology for comprehensive remote sensing is still quite crude and we are far from scaling high-resolution tools in space and time to replace lost ground stations.

At the plot scale, we actually know very little. When listing the chain of critical processes to, say, account for the life of a bristlecone pine (microbiome, cellular physiology, phenological plasticity, soil hydrology and evolution, precipitation rate and phase, competitive interaction, radiation budget, vapor pressure deficit, and dozens of other key variables), we quickly run out of our knowledge comfort zone even at single timesteps! Environmental science is truly still in infancy, and we place our collective reliance increasingly on "modeling" using data collected with the research equivalent of stone tools in an afternoon. Rather, establishment of "Long Science" observatories in mountains offers a natural antidote to our default snapshot, tunnel-vision approach in environmental research (Fig. 4).

First of all, mountains represent those critical landscapes of process and change that in turn affect all things below them. Societal concern about water supply, hydroelectric power, weather, timber resources, recreation, wildfire, and so forth is inextricably linked with mountain environments. Thinking about, designing for, and communicating the links between mountains and populated lowlands force expanded views on all sides of the conversation. Science in mountains demands greater integration of cross-domain knowledge and expertise. It certainly brings with it a physical reality of long-term dynamism as well as rapid change across space. Single-species conservation focus, for example, becomes difficult to apply in this holistic spatio-temporal perspective (Fig. 5).

Secondly, it happens that direct monitoring of the environment decreases dramatically as elevation increases. Comprehensive observational science in mountains is comparatively rare. Those of us who work in these fields understand why: it is difficult, expensive, and complex—relative to performing the same work in more benign geography. Study design, activity planning, support logistics, equipment maintenance, replication, and data continuity all take on new dimensions when we bring science to

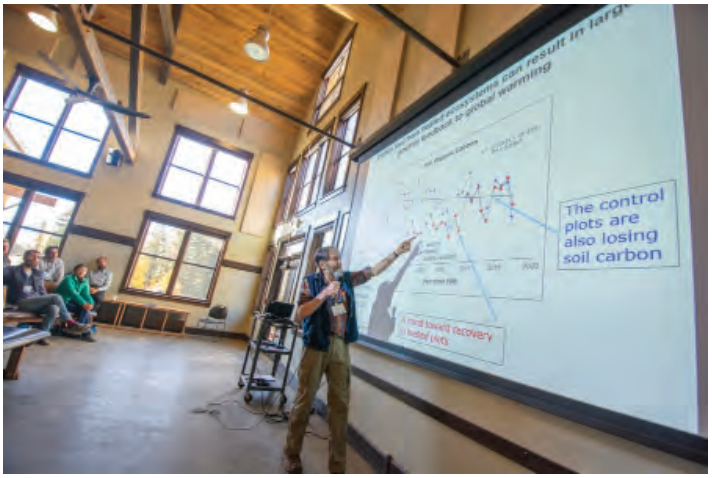

Figure 3. Professor John Harte giving a keynote talk at *MtnClim 2018* on his 28 years of meadow warming (#MtnClim2018).



Figure 4. Even with thousands of hours of embedded participation in field environments, many career field scientists will find it difficult to log more than a few years' equivalent over a lifetime. And how many researchers actually live in the field frequently? What do we know? What do we miss?

mountains. It forces us to think longer and harder about exactly what we are trying to accomplish, and how much we are willing to pay for or endure to meet rigorous standards of study. It also means we are still on a steep learning curve (Fig. 6).

Finally, it is that merging of applicability and cross-domain synthesis, combined with the functional challenges, which clearly builds the original wide-eyed mentality of observation and discovery. The mountain observatory approach is very much the scientific equivalent of making a difficult pilgrimage to sacred location, perhaps confronting demons along the way, to experience something that cannot be fully anticipated and requires much meditation to digest. A scientist dedicated to making observations in mountains over a continuous period must by necessity participate in the extremes of season; must plan for the decade-to-decade changes of soil, rock, vegetation, snow, ice, and weather; must face the realities of a dynamic environment that has few pre-existing records, and prepare to be surprised.



Figure 5. Even small high-elevation observatories, such as the one being serviced by the author here, are difficult and expensive to establish and maintain; it comes as no surprise that such activities are rare.

Humans, mountain art teams, and scientists of all disciplines avoid surprises out of habit, unless perhaps inside a dim movie theater or at a friendly birthday party. Surprise in the sciences can mean significant datasets reduced to uselessness, or, heaven forbid, years of assumption uncovered. This dichotomy of "surprise is necessary" for scientific progress certainly clashes with the human preference for security, but demands introspection.

Thus, the surprises, difficulties, and uncertainties of maintaining "Long Science" in mountains do not lend themselves well to the socio-economic demands of acceptance and tenure, of community consensus and funding, or even of frequent "groundbreaking" publication. Yet, the need/availability ratio of mountain observations remains higher than ever. It is research on the frontier of environmental knowledge, extending away from the trampled corridors of niche focus, aggregating assumption, and coveted publicity. A more poignant self-reflection by the community might be to determine how representative these trends are of evolution in scientific progress. But the mere fact that large and empty regions still exist on the map of earth systems knowledge, with rumors that "there be dragons", should stir the intentions of the historical von Humboldt or the fictional Maturin in all of us hoist the sails of the good ship *Surprise* for a Long Science adventure.

All photos by the author.

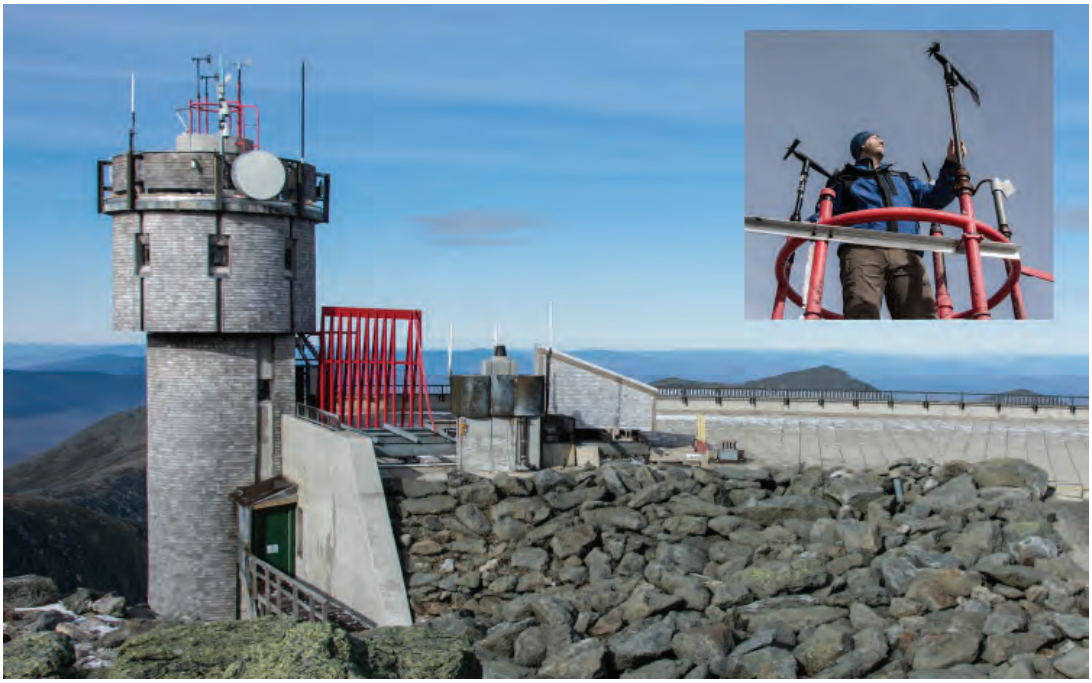

Figure 6. The platinum-standard Mount Washington (New Hampshire) Observatory, famous for its extreme weather, has precious little company even after 84 years of near-continuous operation. Dedicated private support from across populated New England has kept this vision alive.

H. J. Andrews Experimental Forest, Blue River, Oregon

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Translating Climate Change Policy into Forest Management Practice in a Multiple-Use Context: The Role of Ethics

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Batavia, C. and M.P. Nelson. 2018. Translating climate change policy into forest management practice in a multiple-use context: the role of ethics. Climatic Change, 148:81-94.

Summary

The scientific dimensions of forest management are well appreciated and highly researched, but its ethical dimensions receive comparatively little attention. In a recent paper, we illustrate how ethics are pertinent to the debates around federal forest management, carbon storage, and climate change mitigation, with the Pacific Northwest as a case study. Using a standard philosophical method called argument analysis, we show that policies predicated on the two overarching principles of federal forest management in the U.S.—the public good and multiple-use—do not in themselves suggest any specific management actions or objectives pertaining to carbon storage or sequestration. To arrive at a practical, actionable conclusion ("managers should do X") requires more explicit judgments about who counts and how much, both of which fall squarely in the ethical domain.

Background

As champions of carbon storage and sequestration, federal forests in the Pacific Northwest are critical allies in the national and international response to global climate change. These ecosystems, particularly in large-successional classes, rank among the world's highest capacity forests for carbon sequestration and storage. Throughout most of the 20th century the Pacific Northwest was a net carbon source, resulting from widespread, high-intensity harvest across the landscape. The situation changed with the implementation of the 1994 Northwest Forest Plan, which placed large tracts of federal forest in reserve and established limitations on harvest intensity. Over nearly 25 years the region's federal forests have seen a steady increase in carbon stocks, but management of these lands continues to generate lively and often heated debate.

As public lands, federal forests are supposed to be managed in the interest of the public. More specifically, federal agencies are charged with a multiple-use mandate, first codified under the 1960 Multiple-Use Sustained Yield Act and affirmed under the 2012 Planning Rule, whereby federal forest managers are tasked to balance a wide array of objectives ranging from timber provision to recreation to wildlife habitat. Over the past decade, national policy directives such as the Strategic Framework for Responding to Climate Change (2008) and President Obama's Executive Order 13653 (2013) have also put carbon sequestration and storage on the agenda as part of the suite of public benefits federal forests should provide. These policy directives justify carbon management objectives by appealing to the two management principles mentioned above: the public good and multiple-use.

National policy does not specify when, why, how, to what extent, or under what circumstances carbon sequestration and storage for climate change mitigation should be operationalized (or not) in management practice. It is perhaps this lack of specificity that explains why, by and large, climate change mitigation has not materialized as a management objective in most federal forests. We set out to investigate whether forest managers have adequate direction to balance carbon storage and sequestration with other objectives, given only the public good and a mandate to manage for multiple uses as guidance. Rather than taking an empirical approach, we used a philosophical method called argument analysis to consider whether, logically, the public good and/or multiple-use lead to specific conclusions about what managers should do on the ground. We call these "actionable conclusions."

Argument Analysis

Arguments are basic building blocks of philosophy, including the philosophical sub-discipline of ethics. Formally, an argument is composed of a series of premises (P) leading to a conclusion (C). According to the rules of deductive logic, if a conclusion necessarily follows from its premises, the argument is *valid*. If an

argument is valid and all its premises are true or appropriate, the argument is *sound*. Consider the following simple argument:

P1. All trees are plants.
P2. All plants have flowers.
C. Therefore, all trees have flowers.

Here the chain of inference is valid because the conclusion must be true if both P1 and P2 are true. However, P2 is untrue, so the argument is not sound. Most arguments supporting practical management decisions are prescriptive or normative, i.e., they suggest we should or ought to pursue some strategy or objective. As a basic rule of logic, normative conclusions cannot follow from descriptive premises alone. It would be impossible to argue, for example,

P1. Old-growth forests store large amounts of carbon.
C. Therefore, old-growth forests should be preserved.

This is an example of the "is-ought" fallacy, so named because it is logically impossible, or fallacious, to conclude something ought to be the case solely on the basis of what is the case. There must be a normative premise to justify the normative judgment reached in the conclusion. For example,

P1. Old-growth forests store large amounts of carbon.
P2. Forests that store large amounts of carbon should be preserved.
C. Therefore, old-growth forests should be preserved.

By articulating ideas formally as arguments, philosophers can examine, assess, and critique underlying values, beliefs, and assumptions. This mode of analysis can also be used to assess the reasoning behind natural resource management. Any practical management recommendation or action can be stated formally as an argument, a useful exercise that renders both the scientific and normative claims embedded in management decisions open for examination.

The Public Good Argument

As dictated by national policy, federal forest management should somehow respond to global climate change because doing so is in the interest of the public. In argument form, the policy mandate can be formulated as follows (Box 1):

BOX 1: THE PUBLIC GOOD ARGUMENT

P1. PNW federal forest management should serve the public good.
P2. Addressing global climate change serves the public good.
C. Therefore, PNW federal forest management should address global climate change. **NOT ACTIONABLE**

Though the argument is generally sound, the conclusion does not suggest any particular management action. An actionable conclusion requires a more explicit objective than "addressing" global climate change (which, as stated, could mean adaptation, mitigation, acknowledgement, or even dismissal, among other things). But understanding how "addressing" climate change will best serve the public good requires us to first determine who the relevant public is, and unfortunately the answer is far from obvious. Federal forests have countless stakeholders at multiple spatial and temporal scales. Only by defining a public of interest can we arrive at an actionable conclusion. Below are three arguments predicated on three different publics (one global and two local), each leading to a different prescription for action on the ground (Box 2).

BOX 2: THE "BROADEST PUBLIC GOOD" ARGUMENT

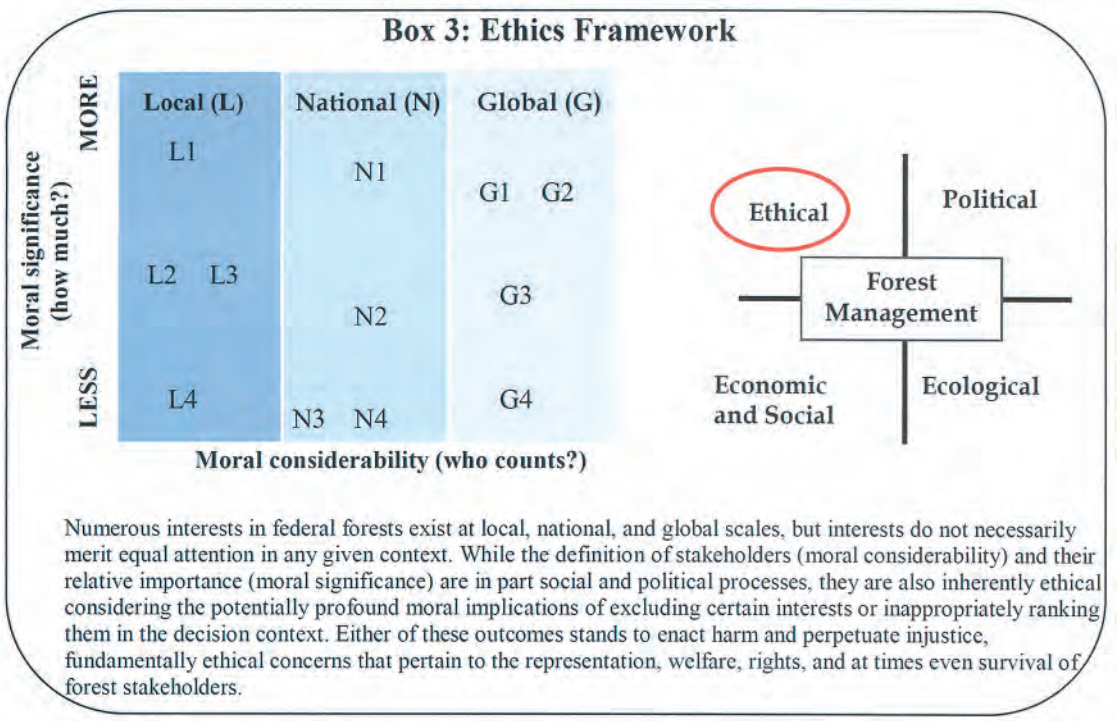
P1. PNW federal forests should be managed to serve the broadest public good.
P2. PNW federal forest management prioritizing global climate change mitigation serves the broadest public good.
C1. Therefore, PNW federal forest management should prioritize global climate change mitigation.
P3. Carbon sequestration and storage in forests mitigates global climate change.
C2. Therefore, management of PNW federal forests should prioritize carbon sequestration and storage.
P4. Prioritizing carbon sequestration and storage in PNW federal forests means doing X.
C3. Therefore, PNW federal forest management should do X. **ACTIONABLE**

THE "PROXIMATE PUBLIC GOOD" ARGUMENT (EXAMPLE 1: WALLOWA COUNTY)

P1. PNW federal forests should be managed to serve the proximate public good.
P2. Management enhancing fire resilience serves the proximate (Wallowa County) public good.
P3. Y enhances forest fire resilience.
C. Therefore, federal forest management in Wallowa County should do Y. **ACTIONABLE**

THE "PROXIMATE PUBLIC GOOD" ARGUMENT (EXAMPLE 2: DOUGLAS COUNTY)

P1. PNW federal forests should be managed to serve the proximate public good.
P2. Managing PNW federal forests sustainably for a higher yield of timber serves the proximate (Douglas County) public good.
P3. Z sustainably yields a higher level of timber.
C. Therefore, federal forest management in Douglas County should do Z. **ACTIONABLE**



Where do ethics come in?

The meaning and scope of "the public" are not given, but defined by a judgment about who counts in the decision context. Ethicists refer to this basic judgment as "moral consideration." Only the selected public(s) and their values are invited to the table, while others are effectively silenced and excluded from representation. In this sense, although "the public" and "the public good" may be partially descriptive social or political terms, they also have important ethical connotations (Box 3).

The Multiple-Use Argument

Perhaps the public good argument sets up a straw man since forest managers are not, after all, supposed to manage exclusively for any single value or any single public. Indeed, policy dictates that, as one of a suite of public benefits, carbon storage and sequestration should be balanced against all the other management objectives for federal forests. This reflects a mandate first expressed in the Multiple-Use Sustained Yield Act (1960), which stipulates, "coordinated management of the various resources…with consideration being given to the relative values of the various resources" (Sec. 5, 10-4). In argument form, the multiple-use charge could be formulated as follows (Box 4a):

BOX 4A: THE MULTIPLE-USE ARGUMENT

P1. PNW federal forests should be managed for multiple uses in a combination that best meets the needs of the American public.

P2. Multiple-use management best meets the needs of the American public when it reflects the relative values at stake.

C1. Therefore, PNW federal forests should be managed for multiple uses in a combination that reflects the relative values at stake. **NOT ACTIONABLE**

Once again, this conclusion does not suggest any particular management action. To arrive at an actionable conclusion requires further specification of any number of values, from carbon storage to fire resilience to timber provision, and their relative importance. In generic form (Box 4b):

BOX 4B: THE MULTIPLE-USE ARGUMENT (CONTINUED)

P3. The values at stake are A, B, and C.

P4. In importance, A > B > C.

C2. Therefore, we should manage for A, B, and C in a combination that reflects the relative importance A > B > C.

P5. By doing X we manage for A, B, and C in a combination that reflects the relative importance A > B > C.

C3. Therefore, we should do X. **ACTIONABLE**

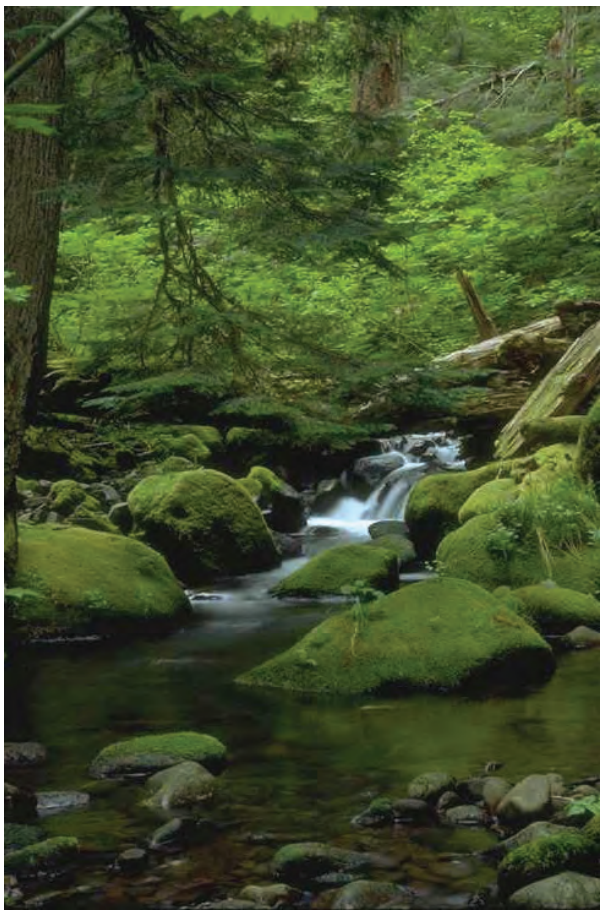
Where do ethics come in?

To grant consideration is to recognize an interest, but mere recognition says nothing about where that interest stands relative to all others in the decision context. Ethicists refer to the relative importance of morally considerable interests (how much they count) as their "moral significance." In management contexts, judgments of moral significance entail weighing, comparing, ranking, and/or prioritizing stakeholder values. These judgments, again, have important ethical implications (Box 3).

Conclusions

Managing competing demands of the long-term, global interest against the short-term, local good is deeply challenging, and there may be powerful reasons why humans tend to prioritize the latter by default. It is critical that ethical questions about when and

why it is (or is not) appropriate to manage multiple-use forests for climate change mitigation should receive more concerted attention from the research and forest management communities. Although management decisions reflect social, political, and economic conditions and constraints, explicit attention should also be granted to their ethical dimensions. Ethics is not a science, and we should not expect to discover any obvious or unequivocally "right" way to balance diverse stakeholder interests across multiple scales. But if ethical quandaries cannot be cleanly resolved they can be appropriately handled by granting ethical considerations explicit attention in open, participatory processes. Argument analysis could be integrated into established processes of stakeholder engagement or multi-criteria decision support protocols, to help decision-makers pursue actions and objectives that are both scientifically and ethically defensible. By rendering transparent the normative premises underpinning management decisions, argument analysis can provide a platform for participatory processes representing diverse public interests, and also focalize key ethical questions for further scrutiny and discussion.



The H.J. Andrews Forest. Photo: Al Levno

Climate Warming Drives Local Extinction in a Subalpine Meadow

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[4]*Department of Environmental Science, Policy, and Management, University of California, Berkeley, California*

Panetta, A.M., M.L. Stanton, and J. Harte. 2018. Climate warming drives local extinction: Evidence from observation and experimentation. Science Advances 4:eaaq1819

Summary

Understanding if and how climate warming may drive local extinction is critical to our ability to better predict, prepare for, and ultimately mitigate the loss of biodiversity as global temperatures rise. Toward this goal, we examined the effects of both experimental and contemporary climate warming on *Androsace septentrionalis* (Fig. 1), a widespread mountain wildflower. Coupling 25 years of experimental warming (Fig. 2) with experimental seed introductions and both historical and current plant surveys (Fig. 3), we found that climate warming drives precipitous declines in population size (Fig. 4) by reducing fecundity and survival across multiple life stages (Fig. 5). We also found that climate warming limits the potential for future recovery of at-risk populations by purging belowground,



Figure 1. *Androsace septentrionalis* (Primulaceae). Also known as northern rock jasmine, *A. septentrionalis* is native to high elevation and high latitude regions of the Northern Hemisphere. Photo credits: A. M. Panetta (left) and J. B. Curtis (right).

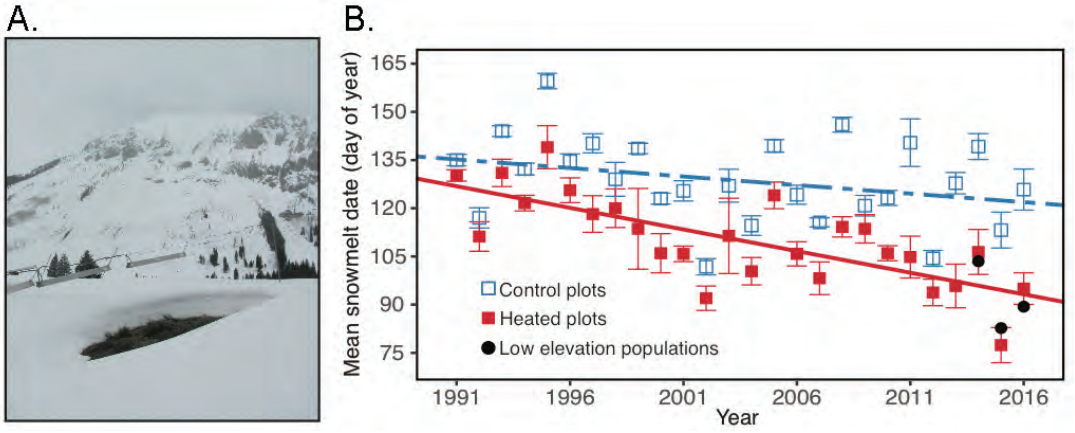

Figure 2. Experimental warming accelerates advancing spring snowmelt. (A) Infrared radiators suspended above heated plots cause earlier snowmelt, higher temperatures, and drier soils than in adjacent control plots. Photo credit: A. M. Panetta. (B) Experimental warming accelerates rates of advancing spring snowmelt caused by contemporary climate change. Over the past 2.5 decades, spring snowmelt in control plots has advanced by ~0.5 days per year, where as spring snowmelt in heated plots has advanced by ~1.3 days per year. Experimental warming also simulates the timing of spring snowmelt in warmer, drier populations of *A. septentrionalis* that occur naturally at lower elevations. Means indicate average yearly snowmelt date (n_{heated} = 5, $n_{control}$ = 5, $n_{low\ elevation}$ = 2), and error bars indicate ±1SE.

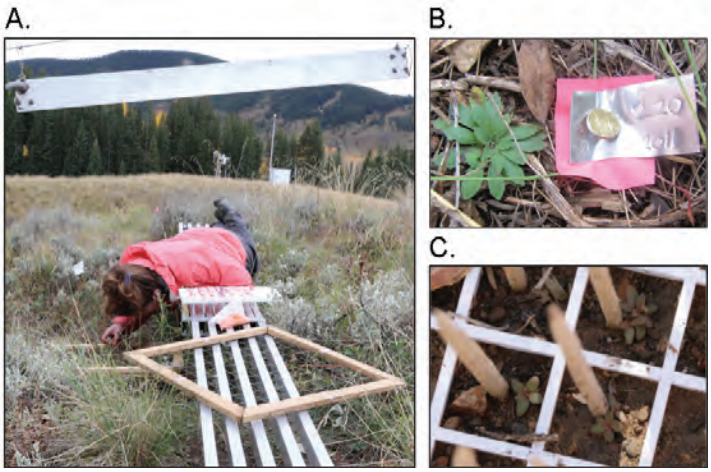

Figure 3. We monitored the abundance and performance of *A. septentrionalis* under both contemporary and experimentally warmed conditions. (A) Each fall from 2013-2016 we conducted annual surveys of naturally occurring *A. septentrionalis* in heated and control plots to assess the effect of experimental warming on (i) abundance, (ii) fecundity, (iii) survival from the fall seedling stage through senescence, and (iv) yearly deposits into seed banks. (B) To monitor the performance of individuals across years, we marked all naturally occurring plants with homemade plant tags. (C) To estimate the effects of warming on rates of emergence from seed banks and on early-life stage survival, we introduced *A. septentrionalis* seeds from nearby natural populations into experimental grids within each heated and control plot. We planted two seeds into each cell, using toothpicks to mark the specific location of introduced seeds so that we could distinguish between individuals that we planted and individuals emerging from the natural seed bank. Photo credits: (A, C) J. B. Curtis and (B) A. M. Panetta

extinction-buffering seed banks (Fig. 6). These results, which confirm causal, mechanistic links between climate warming and local extinction, warn of potentially widespread reductions in biodiversity across subalpine meadow communities as climate warming continues.

Remarks

When environmental change results in local conditions that surpass tolerance limits, natural plant and animal populations have three possible general responses—they may adapt to their locally changing conditions, they may migrate to track shifting suitable habitats, or, if they are unable to adapt or migrate quickly enough, they may go extinct. This study adds to a growing body of evidence that predicts that population and species extinctions are likely to occur across the taxonomic tree (1) as current rapid rates of climate warming (2) outpace contemporary rates of adaptation and migration (3-5). As such, it is increasingly important for the preservation of biodiversity that ecologists, evolutionary biologists, and land managers work together to empirically test how, and under what conditions, we may help natural populations adapt to warmer conditions via evolutionary rescue (6, 7) and track suitable habitat via assisted migration (8-10).

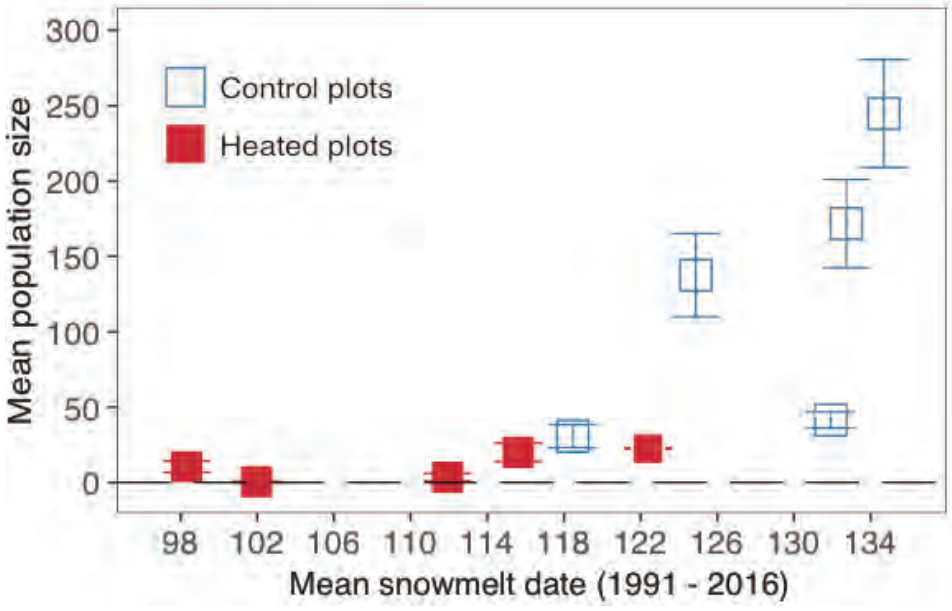

Figure 4. Experimental warming drives population sizes of *A. septentrionalis* toward zero. After 25 years of experimental warming, heated-plot population sizes are either at or near absolute local extinction (indicated by the dotted black line). Furthermore, earlier snowmelt across all meadow plots and both treatments is strongly associated with smaller population sizes. Means indicate average abundance in each of the ten warming meadow plots from 2013-2016 (n = 4 per plot). Error bars indicate ± 1SE.

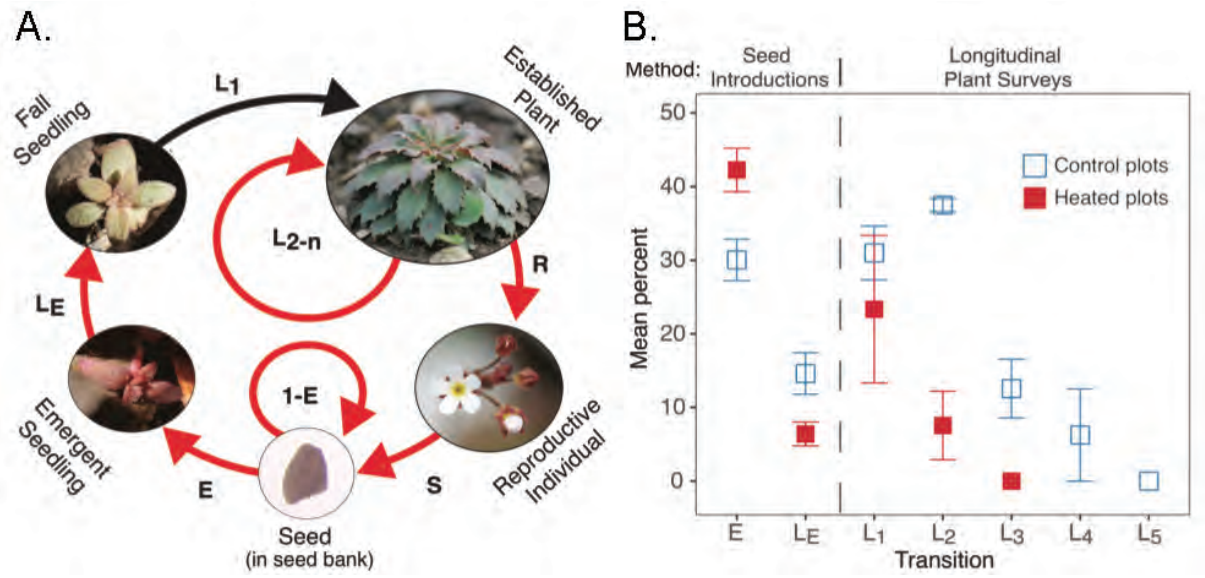

Figure 5. Experimental warming affects performance across multiple life stages. (A) The life cycle of *A. septentrionalis*. Emergence (E) from seed occurs from late-summer through early-fall in late season monsoonal moisture. Emergent individuals are highly susceptible to drought stress, thus their survival (L_E) to become fall seedlings depends on the timing and amount of rainfall. Fall seedlings that survive under winter's snowpack and through their first growing season (L_1) become established plants at age 1. Established plants may survive a second (L_2), third (L_3), and in rare cases fourth (L_4) year. Individuals typically become reproductive (R) in their second year of life, producing white flowers, each of which develops into a small fruit containing seeds (S). Red arrows indicate life stages affected by experimental warming. Photo credit: J. B. Curtis. (B) The effects of experimental warming on emergence and survival throughout the life cycle of A. septentrionalis. Experimental seed introductions demonstrate that warming increases seedling emergence (E) but decreases fall survival of those that emerge (L_E). Longitudinal plant surveys reveal that while warming has no significant effect on the survival of fall seedlings to age one (L_1), it substantially reduces the survival of established plants to age two (L_2) and beyond. Data indicate average percent emergence (E) and average percent survival (L_E-L_5); error bars indicate ± 1SE.

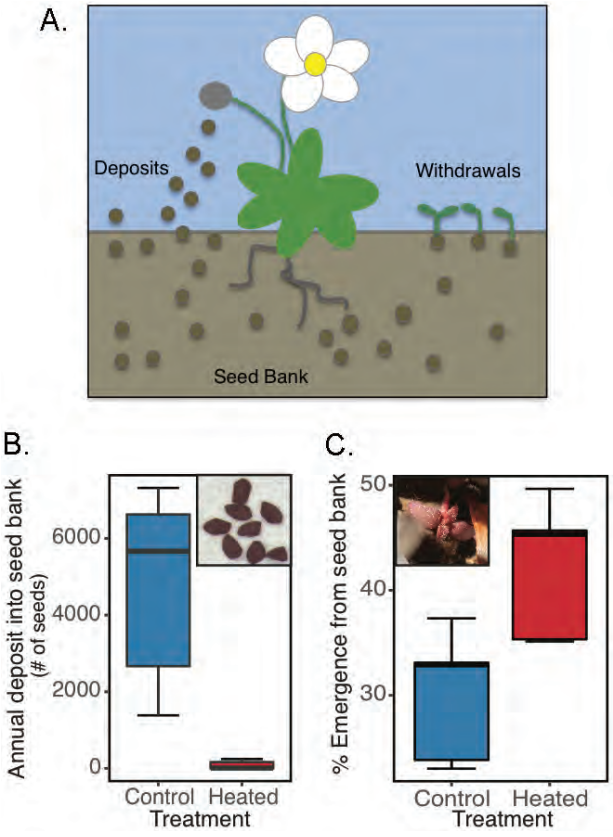

Figure 6. Experimental warming depletes seed banks by reducing deposits and increasing withdrawals. (A) Seed banks, which consist of viable, dormant seeds, grow by deposits made by reproductive individuals and decline by yearly withdrawals in the form of emerging seedlings. (B) Warming reduces annual seed deposits into belowground seed reservoirs by ~98%. Data represent the average number of seeds produced per plot from 2013-2016 ($n_{control}$ = 5, n_{heated} = 5). (C) Warming reduces seed dormancy, stimulating emergence by ~41%. Data indicate average percent emergence from experimental seed banks introduced into each Warming Meadow plot ($n_{control}$ = 5, n_{heated} = 5). Photo credits: (B) A. M. Panetta and (C) J. B. Curtis.

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Sierra Nevada Aquatic Research Lab, Mammoth Lakes, CA

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Riffles and Pools of Sierra Nevada Mountain Streams

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Herbst, D.B., S.D. Cooper, R.B. Medhurst, S.W. Wiseman, and C.T. Hunsaker. 2018. A comparison of the taxonomic and trait structure of macroinvertebrate communities between the riffles and pools of montane headwater streams. Hydrobiologia 820:115–133.

As water flows down from mountains it does not follow a straight path. It both meanders side to side and undulates from shallow to deep. Picks up and puts down what is on the stream bottom, receives what comes off the land and carries downstream what it can, leaving behind what is more than it can lift. These flows and forces form characteristic habitats of shallow riffles in rocky turbulent zones and deeper pools where deposits of debris and sediments often accumulate. Even though riffles and pools are foundational habitat features we are still learning about the aquatic life living on the bed of the stream in these zones.

New research (Herbst et al. 2018) shows these processes also sort and select for differing assemblages of bottom-dwelling or benthic stream life. Benthic macroinvertebrates, mainly the larval or immature stages of aquatic insects, number in the many hundreds of species in the Sierra Nevada (290 in 12 streams of this study alone). These diverse organisms also have varied life cycles, food preferences, and sensitivities to changing environmental conditions. The denizens of riffles are primarily mayflies, stoneflies and caddisflies, collectively known as the EPT (Fig. 1), for the Latin names of the orders to which they belong (Ephemeroptera, Plecoptera, Trichoptera, respectively). The EPT are often larger, long-lived species with requirements for clean cold flowing water. In contrast, the inhabitants of pools are dominated by midge flies (family Chironomidae), also a diverse group, but generally small, living short life cycles on and in sediments, with more tolerance of poor water quality.

Although the new research supports much of the conventional wisdom about riffles and pools, there were also new revelations. As stream ecologists, the biology of these habitats was thought to be something of a settled science but at least for the mountain



Figure 1. *Ironodes* – a mayfly denizen of riffle habitats. Photo: Bruce Medhurst



Figure 2. Pool below the waterfall, riffle below that, and so on downstream. Photo: David Herbst

streams that were studied, we found that these are dynamic features of streams, changing with time and flow (Fig. 2). Not surprisingly, we found that streams contract during low flows, but we also observed that pools become more prominent features at these times. High flows by contrast transform the channel bed overall to more erosional riffle features. As a consequence, the entire stream community at these low and high flow extremes are comprised of a benthic invertebrate fauna that are primarily either midges when there is less water, or EPT when flows are higher. Stream food webs often involve fish feeding below productive riffle habitats on the larger EPT, and riparian birds consuming them when they emerge as winged adults. Food web connections therefore are altered by the changing riffle and pool configurations with flow. The dynamic nature of the extent of riffle-pool habitat and changing inhabitation by benthic invertebrates may be the most intriguing revelation of the research. Riffles and pools have the least difference in species composition when pools are less common at high flows or riffles are less common low flows (Fig. 3).

Long-held notions of which species live in the erosional riffle and deposition pool types of habitats were also found to be inconsistent with results from these Sierra Nevada stream studies. Almost half of the species assigned to lists of habitat preference did not conform to findings, highlighting the need for more careful studies of where benthic invertebrates live and under what conditions.

The study also has important implications for water quality monitoring. Most programs that use benthic invertebrates as stream health indicators use a sampling approach that combines

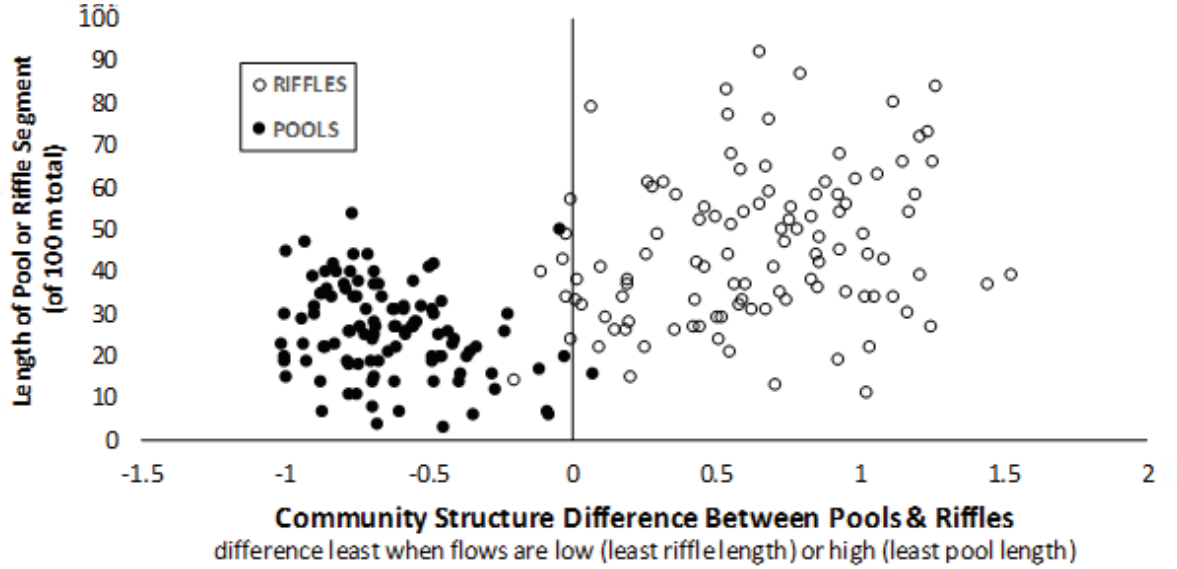

Figure 3. Community structure difference between pools and riffles.

riffles and pools. Although this gives an appraisal of the entire stream, we now know that the proportions of these habitats can change over time and often between sites, so assessments intended to evaluate pollutant impacts or status of ecological health of waterbodies might instead simply be a reflection of differences in flows and the relative cover of these two major habitat types.

These studies were conducted over nearly 15 years, highlighting the importance of prolonged intensive studies. Only through long-term research and monitoring was it possible to reveal both how stream habitats differ in space between riffles and pools, but over time as runoff varied between the extremes of drought and flood. Follow-up research from these studies is being prepared for publication soon and examines the effects of drought and climate change on the loss of habitats and biodiversity in these headwater stream environments.

Our studies also beg the question, how do pool-riffle differences change along a downstream continuum? An important organizing principle in stream ecology has been the notion that there are gradual changes in the structure and function of food webs and productivity as stream habitats change from mountain headwater areas into lower river valleys. We know this depends of geographic setting and on interruptions created by dams and reservoirs, and where tributaries enter, but riffles and pools also clearly punctuate these transitions with their own local-scale differences. How these habitat units change along the downstream course of watersheds would add another important insight to stream ecosystem structure and function.

Stream and river control along roads and in areas where flooding has occurred often includes dredging and channelization. These uniform and straightened channels remove the natural ecological variety of streams. That meandering, undulating natural snakiness, or sinuousity that rivers and streams have contribute to the mix of slow, fast, deep, shallow, rocky and muddy areas that form patches for different algae, plants, insects, leaf litter. This diversity is lost in these confined channels, as is connection to the surrounding land.

Surveys of the places and local conditions where life thrives are important for the conservation of species and habitats, so it is essential to look everywhere. To turn over every stone, so to speak, in being able to evaluate what organisms live where and be able to account for all of them so that we better understand where organisms live and what their requirements are. This is especially true of mountain regions where accessing and sampling in small headwaters is difficult and limited in representing how much of the branching network of upper watersheds can be covered. The joy and reward though come with the exploration.

Sagehen Creek Field Station, Truckee, CA and Valentine Eastern Sierra Reserves, Mammoth Lakes, CA

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Communication between Sagebrush Plants and Induced Resistance Against Insects

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Karban, R. and J.L. Orrock. 2018. A judgment and decision-making model for plant behavior. Ecology 99:1909-1919.

It is now well established that most plants respond to feeding by herbivorous insects by changing in many ways that increase their resistance to future attacks. Plants sense and respond to many cues that reliably predict a high risk of attack (Karban 2015). The most common and probably the most reliable cue is actual herbivory. Unlike animals, plants can tolerate some loss of their tissue since the organs that sense and respond to environmental cues are widely dispersed and redundant. However, plants also sense and respond to diverse cues that reliably predict impending attack before. In some instances leaf hairs sense insect footsteps (Peiffer et al. 2009), leaves sense the acoustic vibrations associated with chewing insects (Appel and Cocroft 2014), and plants perceive volatile cues that are released when neighboring leaves are damaged by herbivores.

My colleagues and I have been studying the abilities of sagebrush plants to sense and respond to the volatile cues emitted by damaged neighbors for more than 20 years at two field stations run by the University of California, Valentine Eastern Sierra Reserve near Mammoth Lakes and Sagehen Creek Field Station north of Truckee (Fig. 1). We have found that sagebrush plants near experimentally clipped neighbors experienced less damage by chewing herbivores (grasshoppers, caterpillars, beetles) than plants near unclipped control neighbors (Figure 2) (Karban et al. 2006). We don't yet understand the language of this communication although it includes both general cues and those that are highly specific. For example, when sagebrush is experimentally clipped neighboring wild tobacco plants increase their defenses and suffer less damage over the growing season (Karban et al. 2000). This suggests that many species share some conserved elements in their respective 'languages'. However, other elements show remarkable specificity. For



Figure 1. Sagebrush plants at Sagehen Creek Field Station following snowmelt, when plants grow most rapidly and are also most responsive to volatile cues from damaged neighbors.

example, sagebrush plants respond more effectively when the cues originate from genetically identical tissue compared to other individuals (Karban and Shiojiri 2009). They respond more effectively when cues come from close kin compared to strangers (Karban et al. 2013). Neighboring plants differ in the most abundant constituent of their volatile blends and can be grouped into distinct 'chemotypes', somewhat analogous to human blood types (Karban et al. 2014). Plants from different locations (e.g., Sagehen vs. Valentine) also appear to use different local 'dialects' and they respond more effectively to local cues (Karban et al. 2016).

Responding appropriately to reliable cues is associated with increased rates of survival and reproduction for these plants. Sagebrush plants that were provided with volatile cues were more likely to survive as seedlings and added more new branches and inflorescences than did controls without volatile cues (Karban et al. 2012). However, induced plants probably add less vertical growth (Karban 2017). Similarly, wild tobacco plants that were provided with volatile cues from neighboring sagebrush produced more inflorescences although they became more sensitive to frost (Karban and Maron 2002).

In attempting to understand plant communication and resistance, plant biologists may do well to borrow insights from psychologists and animal biologists who have been studying related phenomena for much longer. Recently psychologists have argued that behaviors in response to stimuli can best be understood as two discrete processes—judgment and decision-making (Mendelson et al. 2016). For plants judgment involves perceiving informative cues and decision-making involves choosing among several options based on their relative costs and benefits, ultimately leading to action (Karban and Orrock 2018). Judgment can be evaluated empirically by monitoring signaling associated with electrical, calcium, or hormonal fluxes, as has been done for animals. Decision-making can be evaluated empirically by monitoring gene expression or the differential allocation of resources.

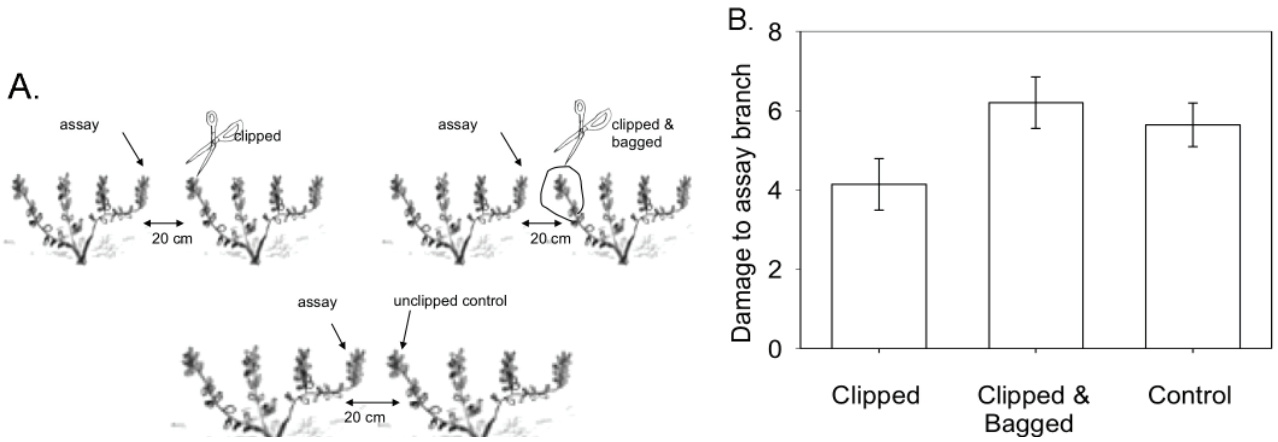

Figure 2. Cartoon showing the experimental design with three treatments: Top, left—leaves of one branch were experimentally clipped with scissors and damage by herbivores was measured on an undamaged assay branch located on a neighboring plant; Top, right—leaves of one branch were experimentally clipped with scissors and immediately enclosed in a plastic bag; damage by herbivores was measured on an undamaged assay branch located on a neighboring plant; Bottom—control in which leaves were not clipped and damage by herbivores was measured on an undamaged assay branch located on a neighboring plant. B. The percentage of leaves on assay branches of the three treatments that were damaged by chewing herbivores over the growing season. Only branches in the 'clipped' treatment that were exposed to the volatiles from experimentally clipped neighbors showed a reduction in damage.

This framework that separates plant behavior into judgment and decision-making may provide useful insights into many situations and problems (Karban and Orrock 2018). Plants are likely to experience new environments and interactions caused by climate change. This framework predicts that those novel situations that are similar to ones that plants have evolved with, in terms of the cues that plants recognize or the decisions that lead to effective responses, will be better positioned to survive novel anthropogenic environments. Plants that rely on general stress cues are predicted to fare better than those that use highly specific judgment cues.

These results with sagebrush indicate that plants are capable of far more sophisticated behaviors than we had imagined a few decades ago. Understanding how plants coordinate their systems that acquire information and ultimately provide defense against antagonists will allow us to manage plants more sustainably. Our work on plant communication would not be possible if we weren't able to return to individual plants for which we know the genetic relatedness and chemical responses. Having a protected work environment and accompanying infrastructure available at these field stations has been essential.

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10th World Dendro Conference, Thimphu, Bhutan

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Today I sit looking out at the mountain forests around me in the Pacific Northwest of the United States. The steep terrain, evergreen overstory, and fern-filled understory are as familiar to me as any ecosystem on earth. Being in a temperate forest with *Abies, Pinus*, and *Tsuga* gives me a deep sense of connection to the natural world and nothing is homier than the forest community of the North Cascades. When I was asked by Lamont's Ed Cook to assist in teaching at the field week for the 10th World Dendro conference in the Bhutan's remote Bumthang Valley, I looked forward to traveling to one of the most exotic places on the planet and enjoying the thrill of being in a new mountain ecosystem. After nearly a week of travel and accompanied by some of the giants in dendrochronology I arrived at a remarkable field station near the town of Jakar. Of all of the culture shock that traveling to Bhutan entailed, I was most surprised by being in the forests around the station. I could have been in my backyard. The forests of *Abies, Pinus*, and *Tsuga* felt as familiar to me as any forest I have worked in. It was remarkable to have found ecological common ground in a location and culture that is a world apart from my home. Given the way that spirituality and nature infuse every aspect of Bhutanese life this felt like a great deal more than chance. The Bhutanese often refer to things as "auspicious," which connotes something more subtle than the way that word is used in the west. The similarity of the landscapes felt auspicious.

The field week activities went well. Graduate and undergraduate students from around the world participated in courses on dendrochronology including ecological methods, ways of improving density measurements of tree-rings, and reconstructing extreme events. However, the most important and most meaningful aspect of the field week at the Ugyen Wangchuck Institute for Conservation and Environmental Research was working with Bhutanese forestry students, a majority of whom were women, to teach basic dendrochronology. This class, led by Bethany Coulthard of University of Las Vegas and Dan Griffin of the University of Minnesota exemplified the spirit of science and education. These students were able to share their knowledge of the landscape and in turn were taught the basics of tree-ring science by two of the best young dendrochronologists in the field. The training of so many young woman in a culture that puts conservation at the forefront of national policy felt great. Auspicious even.

More:

Ugyen Wangchuck Institute for Conservation and Environmental Research: https://www.facebook.com/UWICER/

WorldDendro2018
https://www.geog.cam.ac.uk/events/worlddendro2018/





February 17-20th, 2019
Paclim 2019
Extreme Events

The theme for Paclim2019 will focus on the weather and climate of Extreme Events. The past year has been marked by extreme heat, wildfires, landslide and flooding events. These events are related to immediate weather conditions as well as recent historic drought conditions. The workshop encourages participation from climate scientists who are examining the climate dynamics behind extreme events and paleoclimatologists reconstructing past extreme events and connections. We also encourage the participation of archaeologists and historians who examine the impact of such events on society as well as current policy and emergency preparedness managers.

We welcome oral and poster presentations on this year's theme of Extreme Events and as always welcome presentations (oral and poster) related to the general theme of climate and the Pacific.

Confirmed Keynote speakers include:

- Amir AghaKouchak, University of California, Irvine – Hydrometeorology (Extremes)
- Kevin Anchukaitis, University of Arizona – Dendroclimatology (Drought)
- Craig Clements, San Jose State University – Microclimatology (Wind and Fire)
- Bethany Coulthard, University of Arizona – Dendroclimatology (Western US Snow Extremes)
- Ingrid Hendy, University of Michigan, Oceanography (Atmospheric Rivers and Floods)
- Cary Mock, University of South Carolina – Historical climatology (Drought/Flood)
- Scott Stephens, University of California, Berkeley – Environmental Science (Wildland Fire climate change)
- Tony Westerling, University of California, Merced – Climate Modeling (Fire)
- Erika Wise, University of North Carolina – Climatology (Drought)

For more information please go to paclim.org and join the paclim listserv.

We hope to see you at Asilomar!

With best wishes

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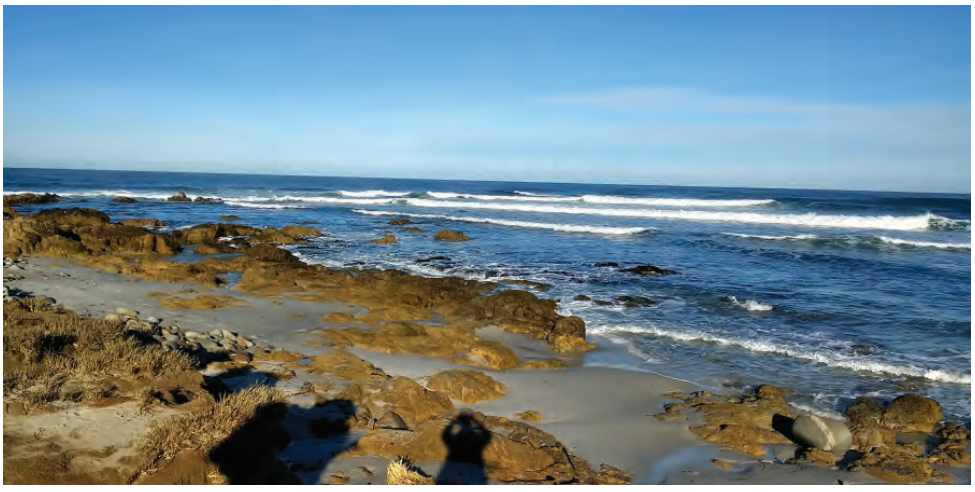


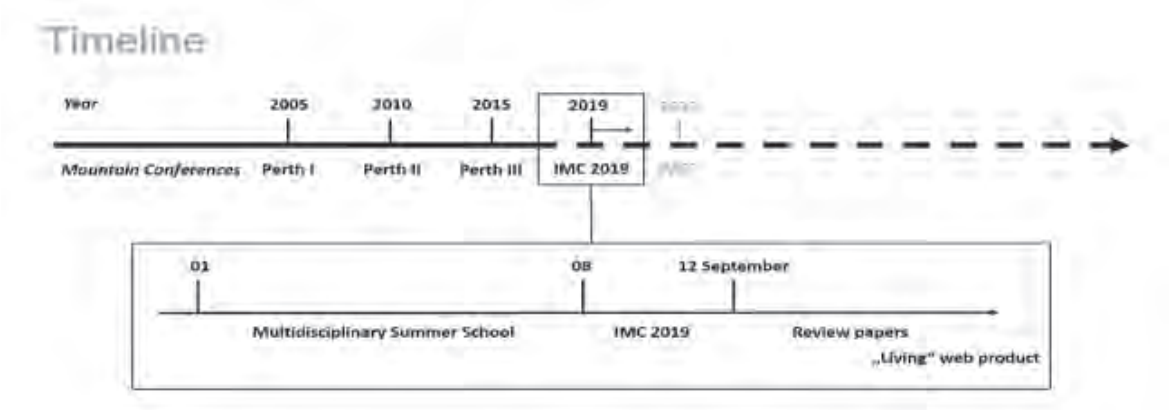


International Mountain Conference
September 8-12, 2019
University of Innsbruck, Innsbruck, Austria

About the Conference

Evaluating the responses of mountains to climate and other changes, and their resilience as social-ecological systems, requires the consideration of multiple and mutually interacting stressors. The IMC 2019 aims to encourage in-depth cross-disciplinary discussions towards a new understanding of mountain systems, their responses and resiliencies.

The IMC 2019 will take place 08 - 12 September 2019 in Innsbruck, Austria. It aims to build upon the three previous mountain conferences that took place in Perth, Scotland, continuing this special scientific conference series with a focus on mountain-specific topics. Hosted in the Alps, the IMC 2019 will provide an excellent opportunity for experts from different disciplines to come together and discuss mountain-related issues.



VOICES IN THE WIND

In this section, I query members of the CIRMOUNT community for their perspective on a topic of current interest. — Editor

Question: Each of you has conducted research projects at one or more western mountain field research stations. Can you describe the aspects that attracted you to work at a field station rather than elsewhere—and, in particular, the one(s) you use? As a researcher, what do you consider highest priority for field stations to offer? Are there things that are missing from field stations that you would like to see included? Anything else about your experiences at field stations that gives insight to their value?"



John Harte, Energy & Resources Group, College of Natural Resources, University of California, Berkeley, CA

I first came to the Rocky Mountain Biological Laboratory (RMBL) in the summer of 1977 to participate in the teaching of an undergraduate course called "Biology and the Human Predicament". The course introduced students to the role that biologists could play in understanding and addressing critical environmental issues such as climate change, acid deposition, extinction of biological diversity, and human population growth. In addition to lecturing, I took the students on field trips to show them how these global issues played out in the Upper Gunnison Basin. From the moment I saw the "Mexican Cut" Nature Conservancy Preserve that first summer I was hooked and decided to redirect to RMBL the core of my field research in ecology.

I have now spent the past 42 summers at RMBL, most recently investigating climate-ecosystem dynamics and feedbacks, making use of elevational gradients, interannual variability, and an ecosystem warming experiment that is now in its 29th year.

The RMBL community is a source of lasting friendships, intellectual buzz, and scientific collaboration. RMBL is somewhat unusual among field stations in the many ways it nurtures its community. For example, RMBL is a fine place to rear free-range children in the summer! Moreover, we are really part of what ecologists call a meta-community, with all of the great people and activities in the nearby town of Crested Butte and indeed all of Gunnison County comprising a critical piece of the action.

Field stations are scientific base camps, providing a secure place to keep coming back to so that one can explore ecosystems from a supportive base. RMBL provides a terrific opportunity to carry out long-term research that can actually influence environmental policy. My research at the Mexican Cut in the 1980's, which identified harm to aquatic life arising from coal-fired power plant emissions in the Western US, had a direct impact on the passage and provisions of the 1990 Federal Clean Air Act Amendments. And our ongoing research on effects of climate warming is informing both the scientific community and the public about the ways in which ecosystem responses to global warming are likely to greatly exacerbate the warming.



David Inouye, Department of Biology, University of Maryland, College Park, MD (emeritus) and Rocky Mountain Biological Laboratory, Crested Butte, CO

I've had the good fortune to spend most of my career working at the Rocky Mountain Biological Laboratory, but also spent two summers at the Mountain Research Station. My education as as graduate student benefited greatly from the opportunity to participate in seminars at RMBL, and to interact with faculty and students from universities around the country each summer. The logistical support provided by RMBL was critical, and the community that it provided, both intellectually and socially, was important for my training and to make it an inviting place for my family to accompany me each summer. It paid off in the long run for RMBL, as one of my sons and his wife are now also summer residents/researchers in Gothic. The combination of logical support and opportunities for intellectual collaborations should be a top priority for field stations to offer. The contrast between RMBL and the MRS was

instructive, as at the latter many researchers are just commuters, traveling to Niwot Ridge from homes and labs in Boulder for the day, so there isn't as much of a sense of community or as many opportunities for collaboration. The difference in research focus also differs, with RMBL researchers primarily addressing questions at the population level, while MRS focuses more on ecosystem-level questions. I worry some about the expense of working at mountain research stations, which have a short field season in which to generate income, while trying to support a year-round administration.

Molly Cross, WCS Americas Program, Wildlife Conservation Society, Bozeman, MT



Early in my graduate degree program at the University of California, Berkeley, I found myself slipping and sliding along the steep, soaking wet slopes of a tropical forest in Costa Rica, scooping up soil samples into small, ziplock bags. I was there to scope out a possible research study site for my PhD. An acquaintance of my PhD advisor had plans to build a scientific research station/ecotourism retreat on the side of this beautiful, biodiverse rainforest. But at the time, those plans only existed on paper. As I tried (unsuccessfully) to make an international call to my advisor from a tiny pulpería in a small nearby town, to seek his advice on the preliminary data collection I was doing, I began to question whether this was really where I wanted to do my research. I loved being in Costa Rica, speaking Spanish, and befriending my host family and their neighbors. The setting was stunning, and the research questions were important and interesting. But the truth is that I'm not really *that* adventurous. And I knew just enough about getting a PhD to know that it was going to be hard....very hard.

The next summer, I had a chance to explore a very different study site option at the Rocky Mountain Biological Laboratory (RMBL - pronounced "rumble") in the abandoned mining town of Gothic, Colorado. I realized pretty quickly that RMBL was going to be a much better fit for me. There were several benefits to working at a long-term, well-established field station. For one, my advisor and several of my labmates also worked at RMBL, so I had easy access to technical advice (and cheerleading), which was especially helpful when things went wrong (which will inevitably happen!). I also was surrounded by a community of researchers from other universities, working on a wide range of ecosystems and disciplines that made for a vibrant and intellectually engaging environment in which to live and work. Since my project directly built off several studies that my advisor and his students conducted in earlier years, I benefitted from the longer-term, historical perspective that an established research site offered. Working at a field station with other researchers also had the advantage of there being people at the field site during times of the year when I was not there; one of those colleagues offered to track the date at which snow on my research plots melted out, allowing me to gather important information that I was unable to collect myself. Lastly, I appreciated the lab space that was available at RMBL, allowing me to not only collect samples at my field site but also to do some basic analyses (which I preferred to do in the shadow of Gothic Mountain, rather than the urban jungle of Berkeley). In addition to all of these practical reasons, working at the RMBL field station was also just plain fun because there were lots of interesting and enjoyable people to spend time with, when the muddy boots, soil sampling gear, and field notebooks were put away for the day.

I can't say that working at RMBL made my PhD work easy...but I believe that it made it easier. It also wasn't always perfect—the main downside to working at a busy field station that I experienced was that it was sometimes hard to find a site that wasn't already part of someone else's project, and it can be tricky to come up with research questions that haven't already been asked by someone, at some point, at that location. But for me, it was a great fit. I never had second thoughts about my decision to work at RMBL, and to save the Latin American traveling adventures for my time off.

Roland Knapp, Sierra Nevada Aquatic Research Laboratory, University of California-Santa Barbara, Mammoth Lakes, CA



My research focuses on mountain lakes, ecosystems that are generally remote from a university campus or agency office. As such, the presence of a field station located in the mountains or nearby that can serve as a base of operations is often critically important. For me, that field station is the Sierra Nevada Aquatic Research Laboratory (SNARL), managed by the University of California Natural Reserve System. Its location at the eastern base of the Sierra Nevada makes SNARL a unique resource for me and a host of other scientists. However, unlike most researchers, who might visit a field station for a few weeks per year (e.g., during summer field seasons), early in my career

I chose to work at a SNARL year-round. Although that decision complicates my research effort considerably due to the "soft money" nature of my position, the ability to live in mountains that I study has made all the difference in ensuring that scientific results generated by my research are quickly translated into on-the-ground management actions. That rapid translation is largely a consequence of the relationships with agency scientists and managers that my proximity allows. The ability to meet regularly and on short notice and to assist on each other's projects has produced a degree of trust, camaraderie, and collaboration that would have been much more difficult to establish had I been located on a university campus hundreds or thousands of miles away.

For those field stations that can accommodate resident researchers, directors should consider steps to encourage the critical mass of scientists necessary to make a field station more of a mini-campus instead of an isolated outpost. Although the necessary investments might be substantial, for example in adequate housing and fellowships for graduate students and postdoctoral researchers, such investments can bring increased scientific productivity, financial sustainability of the facility, and community engagement, and ultimately better management of the ecosystems that a field station provides access to. In that light, investing in field stations seems a small price to pay.



Jutta Schmidt-Gengenbach, White Mountain Research Center, University of California-Los Angeles, Bishop, CA

I feel very fortunate to have been able to live near and work at UCLA's White Mountain Research Center (WMRC) year round, for several reasons. The main attraction of a field station is, of course, "the field", and most natural scientists I know prefer their study habitat to a city or even a large campus. The mountains are what lured me here, and being steeped in the environment in which I both conduct research and recreate, I get to observe the study sites year round, and not just during a short field season. A field station is often isolated, similar to a ship at sea, fostering a special camaraderie among the small staff and users. I like the casual atmosphere, the diversity of the visiting researchers, and the impromptu discussions at a picnic table or on the front porch swing. We also get to see students at their highest level of enthusiasm and engagement—they are so jazzed to be learning hands-on in this awesome environment. WMRC is just an idyllic place to work, and when the microscope work gets tedious, the view out of my windows makes up for it!



McKenzie Skiles, Department of Geography University of Utah, Salt Lake City, UT

I first visited the San Juan Mountains in 2007 for a backcountry ski trip, and immediately fell in love with that remote southwestern corner of Colorado. I had a hard time believing my good fortune when two years later it would be my job to return, to start my graduate research at Senator Beck Basin Study Area (SBB). Field sites like SBB are few and far between, especially in the Western US; it a well instrumented, mountain observatory with two snow energy balance plots and stream gauge at the basin pour point. Its maintained by the Center for Snow and Avalanche Studies in Silverton, which also collects regular snow observations. While it was established in 2003 to study the hydrologic impacts of dust on snow, the terrain, remote location, and instrumentation make it an ideal mountain field site, and over the last 15 years SBB has hosted a range of researchers looking at snow and mountain processes.

But it is more than just the data quality; it is a beautiful place to do research, and because it is only accessible by foot, you have the time to appreciate it. On my first ski tour around the basin I found myself at the basin high point, looking around at the surrounding peaks, and knew I had found my calling. That trip showed me I could combine my love of snow and the outdoors with my love of science, and I've never looked back. When I moved to get my PhD at UCLA I continued to do fieldwork at SBB, and honestly spending every spring digging snowpits in the mountains might have been the only way I got through four years in LA. The blood (literally, I took a bad spill on my skis once), sweat, and occasional tear that came with field work has not only made me tougher, but also a better scientist.

This year will mark a decade of fieldwork in SBB, and last season I brought my graduate students there for the first time. I'm honored to play a role in mentoring and inspiring the next generation of snow scientists, thought I'll admit it's pretty easy with SBB as the field site and the San Juan Mountains as the backdrop.



Mark Raleigh, Cooperative Institute for Research in Environmental Sciences and the Department of Geological Sciences, University of Colorado, Boulder, CO

Over the past five years, I have been studying how forests influence seasonal snow processes at the Niwot Ridge Long Term Ecological Research (Niwot-LTER) site northwest of Boulder, Colorado. More specifically, my work there has focused on snow interception in the subalpine forest and landscape influences on bulk snowpack properties (like density and depth). I was attracted to work at the Niwot-LTER for many reasons, including the long legacy of data collection and the confluence of diverse researchers and monitoring infrastructure (more about that below). As a snow scientist, there are many benefits to working at the Niwot-LTER given the wealth of past and ongoing snow research from the University of Colorado and other institutes. This concentration of snow researchers provides opportunities for leveraging the data we collect and advancing our collective understanding of this natural system. I was also attracted to conduct some of my research at Niwot because it can be a very windy place in the winter. This has been ideal in my recent experimental work to relate changes in wind-driven tree sway to the amount of snow intercepted in the forest canopy, work which I presented at *MtnClim 2018* in Gothic this past September. Honestly, it is hard to beat the proximity of the Niwot-LTER because as a Boulder-based researcher, I can travel to the Niwot-LTER within an hour drive. So, field trips can be done on the fly, planned easily and strategically around weather, and with minimal expense—that all makes field work a bit easier.

Based on my experiences at the Niwot-LTER, I see tremendous value in field stations that prioritize a long-term vision and support a platform for interdisciplinary research. At the Niwot-LTER, there is a multi-decadal legacy of research at the site on snow, hydrology, and ecological processes; these provide valuable context for the data that I collect both in terms of snow and connected systems. For instance, I can compare my recent two winters of snow pit measurements to annual records that go back to the early 1990s; this obviously would not be possible if I were starting a new research site. A convergence of researchers from different fields and infrastructure from different networks provides opportunities for richer collaborations and interdisciplinary research. The monitoring infrastructure at the Niwot-LTER is quite unique and diverse—the LTER domain includes stations from Ameriflux, NRCS SNOTEL, NOAA, and NEON to name a few. The Boulder Creek Critical Zone Observatory (CZO) is also just downhill in the Gordon Gulch drainage, so in tandem with the LTER it is possible to study the connected snow, hydrology, and ecological systems along a wide elevation gradient. There is clearly incredible value in concentrating researchers and monitoring systems in a single area, as evident at the Niwot-LTER and other areas. However, as unique as these places are in terms of infrastructure and scientific synergies, I have also long wondered about the physical uniqueness of these places. “To what degree do the lessons we learn at these field stations transfer to other locations?” is a question worth asking for all LTERs, CZOs, and field stations.



Lara Kueppers, Energy & Resources Group, College of Natural Resources, University of California, Berkeley, CA

I was introduced to work at field stations as an undergrad, when I worked at the Sabana USFS field station in Puerto Rico and at Jasper Ridge Biological Preserve. Since then, I've worked at the Rocky Mountain Biological Laboratory, the University of Colorado Mountain Research Station and the University of California Natural Reserve System Yosemite Field Station. I also collaborate with scientists at Barro Colorado Island in Panama, who have collected and made available a treasure trove of diverse datasets. I continue to leverage these amazing research facilities because they provide physical infrastructure (lab space, basic equipment, electricity, wifi), professional infrastructure (permit MOUs for research on public land, data from past studies), and communities of scientists focused on diverse questions. Each place I've worked has had its own strengths, but I've come to value the community of scientists most, as these colleagues challenge and support me, and form an extended network that benefits my students and postdocs. I've tried to do field work independent of field stations over the years, and have found that permit processes in particular are getting more difficult to navigate as an independent researcher. Finally, in my land surface and vegetation modeling research, long-term datasets that field stations foster, archive, and make available are invaluable resources. The staff that make field stations the research hubs that they are deserve recognition for the important work that they do!

Joe Sapp, Department of Ecology and Evolutionary Biology, University of California-Santa Cruz, Santa Cruz, CA



I conducted 100% of the field work for my Ph.D. at Sagehen Creek Field Station (which I will lovingly refer to as "Sagehen" from here on). What originally attracted me to the place was a tip I received from a senior graduate student that the specific ants I was looking for occurred at Sagehen. This tip was confirmed in the first 30 minutes of my first arrival at Sagehen when the station manager Jeff Brown dropped what he was doing and personally led me to the five relevant ant nests he knew of, marking them with chalk paint for my benefit as he went. I now know I could likely have found an abundance of my study organism at countless other locations in California and beyond, but I also know I was wise to make Sagehen my research home. I will concede some of the credit for my "wisdom" to Jeff, for making it abundantly obvious what a great place Sagehen is to live and work. Jeff and Faerthen Felix (the assistant manager at Sagehen), have created and are actively maintaining a fertile and productive natural laboratory that is a singular resource for environmental researchers and students at all stages of their lives and careers. Sagehen is a lively place to meet other like-minded colleagues. It is an ideal place to set up long term experiments (as I did), because you know Jeff and Faerthen will be two fierce advocates and defenders of your work in your absence. They will protect it from mechanical tree thinnings and prescribed burns, and advise you if inclement weather or anything else threatens your work. I believe the highest priority for field stations is to provide a stable, secure natural laboratory that is both financially and logistically accessible for the greatest diversity of researchers possible. I have first-hand knowledge that the leadership at Sagehen is committed to that belief, and I hope they continue to defend this valuable resource and magical place long into the future.

Meagan Oldfather, Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, CO



For my dissertation research, I worked out of the Barcroft Research Station, one of the three stations associated the White Mountain Research Center (WMRC) in eastern California and part of the University of California Natural Reserve System. Previously I also worked for multiple summers at the Mountain Research Station outside of Boulder CO. I greatly appreciate working at research stations for three reasons – the availability of previous research and knowledge of the area, the opportunity to meet other scientists in a space that encourages open, curious scientific discussion, and the potential for logistical help during strenuous field campaigns. My work at WMRC was a great example of all three of these things. The alpine plant I worked on was also the main study organism for a doctoral dissertation by Dr. Oren Pollak approximately 25 years prior. The work by Dr. Pollak not only gave me a great starting-off point for understanding the natural history in that specific area, but also allowed me to make interesting observations about how the population characteristics of this species has changed over the last quarter century in the White Mountains. I enjoyed many great conversations with both other visiting scientists and staff over delicious dinners over the past 6 summers and meet life-long friends and collaborators. The staff at WMRC also always took care of me like I was family, which was very appreciated and got me through the cold (windy!) field days. For my post-doctoral research, I will continue to work at a University of California Natural Reserve (Jepson Prairie) and look forward to the academic and logistics support that provides. However, as there are no structures to stay at this reserve (and it is close enough to town for this not to be necessary), I know I will deeply miss the opportunity for lively scientific discussion over dinner after a long field day. The one thing that I feel really facilitates these benefits of a field station is a staff that is engaged. I think well managed facilities, biotic and abiotic historical data, and knowledgeable staff are really important in getting the most out of field stations. I believe in this so much that my career goal is to someday direct work at research stations!

DID YOU SEE IT?

Mountain Vortices

Connie Millar
USDA Forest Service, Pacific Southwest Research Station
Albany, California

"Close your eyes and mouth and keep your head down!" Scotty's voice was firm as he forced me to the ground with a hand on my shoulder. Scotty was not being rude—he was protecting me from a vortex.

I had come to the Diamond Mountains in Nevada with my Great Basin buddies, Scotty Strachan (UNR) and David Charlet (CSN), to look for limber pines (found them), bristlecone pines (nope), and pikas (none, but honestly, I didn't expect them, despite great habitat). On this tumultuous day in June last summer, Scotty and I had pushed northward along the narrow crest of the fault-tilted range, hopping from westside to east as we neared the high point of the range, Diamond Peak (there are two widely separated, identically named, Diamond Peaks in the range; Fig. 1). The wind had been fierce as we camped on a treeless high pass at the south end of the range the night before. David and my tents had flapped ceaselessly in the night, keeping me restless, while Scotty's hammock swung in a violent pendulum that seemed to lull him to sleep.

As Scotty and I walked along the crest in the morning past Diamond-Peak-the-Southern-One, the westerly winds ramped up, and temperatures dropped. To the west, above the ever-receding flotilla of Great Basin mountain ranges, black clouds loomed, built, and drew closer (Fig. 2). The wind took my breath and I struggled to stay upright. East of the crest blue sky beckoned and warm winds lofted from the basin far below (Fig. 3).

Satisfied that only limber pines grew in this part of the range (Fig. 4), we retraced our steps back as the winds and clouds mounted. Nearing the summit of Diamond Peak the vortex caught us (Fig. 5). Scotty had been walking on the eastside of the crest behind me, and had seen the gravel-entrained whirlwind spinning toward us. That is when he jumped over the crest toward me, issued his command, and we braced for several minutes while chaotic winds and debris hurled around us.

OK, I'm making it sound worse than it was. But whirlwind it was, and I have to confess that although I've seen hundreds



Figure 1. Hiking toward Diamond Peak. Photo: Scotty Strachan



Figure 2. A storm growing in the west, moving toward us.

(thousands?) of dust-devils in hot, dry Great Basin playas I hadn't until that day seen a mountain vortex wind. Probably I have *experienced* them—maybe you, too, have—but I had not understood them as whirlwinds in that it takes dust or snow or debris to reveal them.

This got me interested in funnel winds, what causes them, and their effects. From the literature I've reviewed, vertically circling winds in the vicinity of mountains are common, have multiple causes—many spurious and not well known—are not tornadoes, nor are they closely related to dust-devils, although some similar processes can be involved. Unlike tornadoes, they are not connected to, nor propagate from, cloud masses. Although usually short-lived and harmless, some vortex winds can be dangerous, especially to airplanes, and in certain cases to downwind structures and communities. Following are brief descriptions of vortex winds most commonly described for mountain areas and their environs. In that I am new to these phenomena, it is highly possible that my summaries are outdated: please let me know if this is the case!

Gustnadoes (e.g., Forbes and Wakimoto 1983, Doswell and Burgess 1993, Agee et al. 2009). These transient and shallow whirlwinds form at the ground surface from processes somewhat related to tornado build-up, but on a micro-scale and with transient and mostly benign effects. They are part of a category of funnel winds developing from localized convective and shear winds. Gustnadoes occur from turbulent wind events in the proximity of thunderstorm build-up. Severe and cold downdrafts (gusts) in the front of advancing strong (but not super-cell) storms create inertial instability that can lead to transient vortex eddies. Clouds at the boundary layer develop bulges and lobes, "with cyclonic circulations at the cusps created by these lobes. Sometimes, for reasons that essentially are not known, those circulations become quite intense" (Doswell and Burgess 1993).



Figure 3. Clearer skies and warmer winds to the east.



Figure 4. Scotty roaming into a stand of limber pines north of Diamond Peak.

Many situations of short-lived vortex winds in high mountains have been described that appear to fall under the category of gustnadoes. For example, Blanchard (1986) observed "ash devils"—mountain vortex winds that developed on Windy Ridge near Mt. St. Helens in the Washington Cascades. The author noted near-surface lapse rates of 8-12 °C at the time as potentially related to the cause of these vortices, with the ultra-fine ash on the ridge surface revealing the winds. Notably, as in our case on Diamond Peak, Blanchard observed ash devils below the ridge crest and on the windward (not lee) side, becoming more developed as they moved onto the top of the ridge.

Gustnadoes appear more likely when the cool outflow from turbulent high air masses meets warm air moving from low elevations. What Scotty and I experienced on Diamond Peak seems most likely to have been a gustnado.

Mountainadoes (e.g., Idso 1975, Bergen 1976, Schlatter 1992, Doswell and Burgess 1993). When strong laminar winds flow perpendicular to a mountain axis, with conditions that promote wave circulation and lee waves to form, several kinds of turbulence are well known to develop on the downwind (lee) side of the crest. These are famously known to pilots to be extremely dangerous for their shear effects. They can form on relatively clear sky days, and surface winds do not need to be strong. On both upper and lower sides of the laminar flow downwind from the mountain crest, wave winds can "break out" and form eddies. The most common become rotor winds that form in the lee and below the crest of the mountain. These can develop into long horizontal rollers, like ocean breakers on a beach. A vertical vortex can occur if a topographic barrier (an outcrop or small topographic high) breaches or otherwise disrupts the roller, tilting it from horizontal to an upright whirlwind. The effect is referred to as vortex twinning when a roller is symmetrically broken by an obstacle or blows around one, wherein the roller splits, each side gets diverted upward, and oppositely spinning vortices develop in the lee on both sides of the obstacle.

Vortex Shedding (Bergen 1976, King 1977, Schär and Durran 1997). In fluid dynamics, vortex shedding is an oscillating flow that develops when a fluid such as air or water flows past an abrupt obstacle. In this flow, vortices are created behind the obstacle (downstream/downwind) and detach periodically from either side of the body. Vortex shedding is an explanation favored by Bergen (1976) for the cause of strong vortex winds that develop in the vicinity of Boulder, Colorado, downwind of the Rocky Mountain Front. These can have quite large rotational velocity, even when prevailing winds are mild or moderate, and develop on storm-free days. Vortices formed this way appear to be translated by prevailing winds from the point of shedding (near the obstacle), and thus can occur quite far from a mountain crest. In the case for Boulder, vortices cause significant cumulative damage to homes and communities.



Figure 5. Nearing Diamond Peak, enroute south, just before the vortex. Photo: Scotty Strachan

Dust Devils (Rennó et al. 1988, Balme and Greeley 2006). These common whirlwinds are less likely to be encountered in mountainous areas of high topographic relief than the phenomena summarized above. Dust devils are strong, well-formed, and relatively long-lived vortices that develop on clear, hot days over flat land, such as deserts or playas (where entrained dust makes them visible), with otherwise still air (Fig. 6). They are especially likely to form in regions of low humidity where strong thermal gradients between the ground (hot) and air aloft (cool) can develop rapidly. When pockets of hot air near the surface rise through cooler air above, an updraft is formed, which, under certain conditions, begins to rotate. As the air rises, the column of hot air stretches vertically, moving mass closer to the axis of rotation, which increases the rotational velocity, as in an ice skater pulling her arms in to her body. Dust devils grow by hot air that is drawn in horizontally to the bottom of the vortex, and the hot air moves up in a funnel-like vortex. Spinning of the dust devil can produce forward momentum, such that the whirlwind can travel quickly across flat ground, especially if the surface is hot.

Although dust devils commonly form over flat, dry, and hot ground, thermal gradients are indicated as partly responsible for the intensification of some of the mountain vortex winds described. Further, situations might arise high in mountain ranges where flat, sandy plateaus exist, and where intense thermal gradients can spin up mountain dust devils. These have been described as gypsum gravel devils in the high Andes (Benison 2017) where the crystals are entrained off a saline pan surface in northern Chile. In that case, the whirlwinds transported sediments up to 5 km distant, where they formed unusual deposit formations of hitherto unexplained origin.

Photos by the author unless noted.



Figure 6. Two dust devils near Tonopah, Nevada.

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CONTRIBUTING ARTISTS

Bob Coats is a research hydrologist with the UC Davis Tahoe Environmental Research Center. He has been studying climatic, hydrologic, and ecological processes in the Lake Tahoe Basin—and writing poetry—for more than 40 years. His poems have appeared in *Orion, Zone 3, Windfall, The Acorn,* the Pudding House anthology, *Fresh Water: Poems from the Rivers, Lakes and Streams*, and in his book *The Harsh Green World*, published by Sugartown Publishing.

Adrienne Marshall's research interests are in hydrology, watershed studies, and mountain systems, with primary focus on effects of climate change on snow and water in mountain systems. She is currently pursuing a PhD in Water Resources at the University of Idaho, Moscow, ID. Adrienne is an avid mountain walker, and has logged many miles in the Sierra Nevada of California (among many other ranges), where she sketches mountains, lakes, skies, trees, and animals. You can view paintings on her gallery site at: https://adriennehikes.wordpress.com/

Stu Weiss is Chief Scientist and co-founder of The Creekside Center for Earth Observation, Menlo Park, CA, whose mission is to apply the latest science and technology to address challenging conservation problems. Stu's research interests include conservation biology, landscape ecology, microclimatology, restoration ecology, GIS analysis, statistical analysis and experimental design, nitrogen deposition, and policy development. His camera and photography skills are always employed as he works in coastal or mountain ecosystems.

Jeff Wyneken is a production editor with Stanford University Press, University of California Press, and others. He is an avid mountain wanderer and observer of nature, and traveled to Colorado with me (CIM) for *MtnClim 2018*.



Briones Regional Park Park, East Bay Area, California by Adrienne Marshall

In Praise of Rain

Sing down the rain from clotted gray sky
in sizzling drops that roar on the roof,
or a whispering mist that beads the bare trees.
Let it flood worm burrows ‘til water
spurts from every hillside,
every meadow springs a lake, roiling
with sex-crazed frogs.

Murmur high tide into the marshes.
Let it surge the sloughs,
sneak into saltgrass,
sweep away wrack and debris,
mocking the sodden wave-gnawed levees
until the bay reclaims its own.

Cry the wind through clattering branches.
Let it keen with the grief of a thousand
mothers of drowned children,
fling huge drops like a torrent
of tears from shuddering firs,
topple old giants rooted in soggy soil.

Howl the clouds from the northern sea.
Cirrus, stratocumulus, nimbus
streaming in great arcs from the Aleutians.
Let them scud across the sky,
blot sun, shroud mountains.
Bring on the rain.

–Robert Coats, February 1998



Roosevelt Lake in Yosemite National Park by Adrienne Marshall

FIELD FRAMES



Photo: Nigel Golden



In June 2018 I traveled to Denali National Park, to the shadow of the continent's tallest mountain, to study the impact of climate change on arctic wildlife living there. Here I am about to take a DNA sample from an Arctic ground squirrel.

Toni Lyn Morelli
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