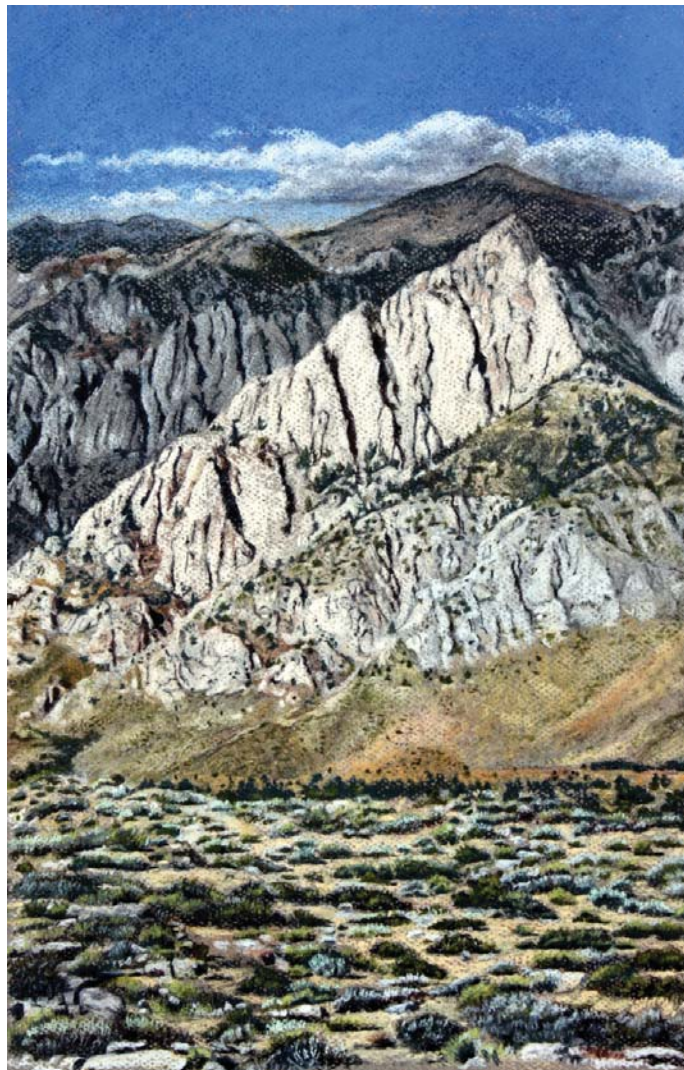


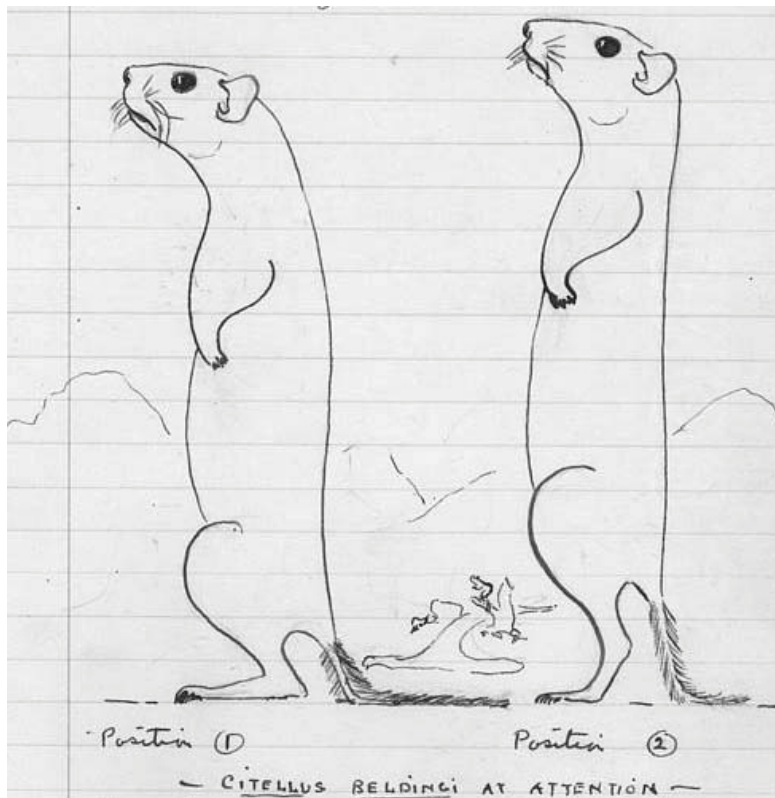
MOUNTAIN VIEWS

The Newsletter of the Consortium for Integrated
Climate Research in Western Mountains
CIRMOUNT



Informing the Mountain Research Community

VOL. 9, NO. 1
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Belding ground squirrel. Field notes of Charles Camp from the Archives of the Museum of Vertebrate Zoology, University of California, Berkeley (<http://bscit.berkeley.edu/mvz/volumes.html>; Volume 557, Section 3, 8 July 1915, page 151).

Front Cover: Wheeler Crest. Wally Woolfenden

Wheeler Crest is part of the eastern escarpment of the Sierra Nevada in California. It is a magnificent wall of quartz monzonite intruded primarily by younger Round Valley granodiorite, and attains an elevation of 4193 m at the summit of Mt. Morgan. From Owens Valley and the foothills it presents itself as a craggy series of overlapping rock shingles, isolated by clefts, that seem to have been formed from alluvial fans as the Sierra Nevada uplifted, exposing the triangular rock faces as they slipped upward, discarding their debris cover. One can see the sequence from bare rock down to more recent inactive fans dissected on both sides and modern fans extending from canyons and gorges. I was fascinated by the formation for many years as I drove past the crest on Rock Creek Road and eventually wanted to capture it with a painting. I chose a striking section of the escarpment and used pastels, which suited its sublimely stark quality. To provide a contrast with the upthrust granitics I included the desert shrublands stretching gently away from it.

—Wally Woolfenden, Swall Meadows, CA

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Back Cover: Alaskan tundra fieldnotes. Fred Paillet

Read about the contributing artists on page 68.

Mountain Views

The Newsletter of the Consortium for Integrated
Climate Research in Western Mountains

CIRMOUNT

Volume 9, No 1, June 2015

www.fs.fed.us/psw/cirmount/

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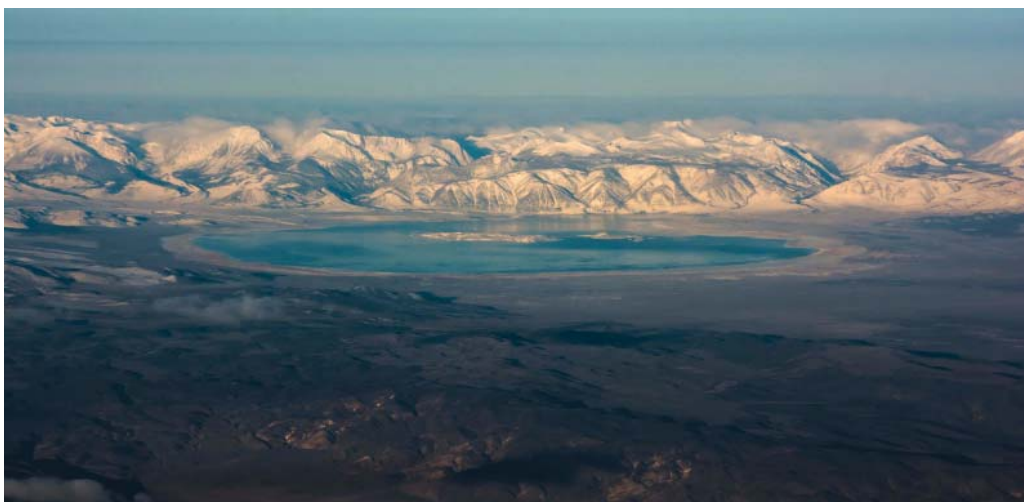
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Mono Basin and the Eastern Sierra Nevada escarpment.
Scotty Strachan, April 8, 2015

The Mountain Views Newsletter

Welcome to *Mountain Views*, the biannual newsletter of the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT, www.fs.fed.us/psw/cirmount/).

Gathered in these pages are reports on current mountain-climate and climate-response studies, *Brevia*, mountain climate news and announcements, and our seasonal round-up of mountain artwork.

With this issue, I am introducing several new sections. A *Guest Editorial* will feature short essays of topical interest. Leading this off is an editorial by Catherine Tucker, who continues the dialog on socio-ecological systems that started with the *MtnClim 2014* conference; her editorial is followed by an article on this topic that Greg Greenwood adapted from his 2014 AGU presentation. In that I have had trouble understanding how the socio-ecological system frameworks interact with traditional mountain sciences, I appreciate the patient efforts of our social-science colleagues as they help ecologists like me to better understand. I trust many of you will find these pieces useful as well.

Our articles and *Brevia* in this issue cover topics that range from Asian pikas to diatoms, dust to snow albedo feedbacks. Of particular interest is the developing evaluation of potential biases in mountain climate observatory data, in particular, the SNOTEL sites, and implications for climate spatial modeling. If you have, like me, wondered how atmospheric processes contribute to alpenglow, check out Ben Hatchett's informative article on the topic. For our interview, I was pleased to have a chance to talk with Tom Swetnam on the occasion of his nomination as AAAS Fellow and also recent retirement. Don't think that Tom is slowing down, though, as you can read in the interview.

Drought in the American West has been front and center in our minds and in the news. Despite a cool and wet May, impacts for snowpack, streamflow, and cascading effects to ecosystems and water use remain severe. With all the bad news, I thought to ask colleagues for our *Voices in the Wind* section whether they could find anything good to say about the drought. This was a hard assignment for those whom I asked, and the range of responses reflects the many ways in which climate affects our science and lives.

When drought and warm temperatures bring little or no snow, winter wildfires become an increasing likelihood. In one short afternoon, the Round Fire of February 2015 devastated 35 homes in the Swall Meadows community of the eastern Sierra Nevada, CA, including homes and property of several CIRMOUNT

scientists. I invited Jeff Holmquist, one of those unfortunate colleagues, to share his experience of this fire for the other new section in this issue, *First Person*.

Drought also reminds me of the fantastic PACLIM 2015 conference, which convened in March at Asilomar, CA and featured a special session on drought. Talks and posters from the meeting are posted on the CIRMOUNT meeting archive website. The PACLIM conferences alternate biennially with *MtnClim*, which will be held next in 2016 (likely autumn) and likely in eastern Washington. I appreciate the willingness of Andy Bunn and Scotty Strachan to take the organizing reins for *MtnClim*, just as Scott Mensing and Michelle Goman have done for PACLIM, relieving Scott Starratt. And speaking of conferences, I look forward to seeing many of you at the Perth III, *Mountains of our Future Earth* Conference in early October 2015 in Scotland. We have an updated announcement posted in this issue.

Artwork in this issues features field notebook drawings and other art that renders field observations graphically. Despite the prevalence and apparent ease of cameras, I am often reminded by my field-science mentors of the enormous value in taking time to draw what we see in the field. To do so encourages careful observation and deepens understanding and appreciation for the mountain landscapes, biota, and processes that we study.

—Connie Millar, Editor



AMERICAN GOLDEN PLOVER NEST
ADJACENT TO THE COOK TENT

Plover Nest, Cape Krusenstern, Alaska,
June 16, 2014. Fred Paillet

I'm pleased to introduce a new section for Mountain Views Newsletter, the Guest Editorial. Thanks to Catherine Tucker for launching this viewpoint, and as well for offering her perspectives on socio-ecological systems, which is the topic of a feature article in this issue. —Editor

Guest Editorial

Mountains as Complex Social-Ecological Systems

Catherine Tucker

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Researchers increasingly appreciate that mountain ecosystems exist as complex social-ecological systems. In the present era of climate change, we realize that biophysical conditions can be influenced by human activities occurring directly on mountains (as in mining operations and recreational activities) and indirectly (as in changing temperatures related to human-driven greenhouse

gas emissions). Interdisciplinary collaborations and exchanges provide opportunities to learn from each other and transcend the gaps produced by our training, which tends to categorize research into “natural” or “social” sciences, even when we realize that many critical research questions require expertise and perspective that synthesizes these realms. How do we move beyond our disciplinary constraints to conceptualize mountain social-ecological systems? How do we integrate holistic approaches for research, interpretation and dissemination of results, and translation of our findings into actions toward wiser policies and practices? I offer a few thoughts here, in hopes of furthering discussions that began at the *MtnClim 2014* conference in Utah in September 2014.

Conceptualizing mountains as social-ecological systems occurs as part of a broader trend in the sciences to recognize that humans are shaping ecological systems through many activities including natural resource exploitation, land use change, and industrial processes. As we know, our current geological era carries the moniker “anthropocene,” acknowledging humans as a (or the) major driver of global change. Several interrelated frameworks provide a foundation for thinking systematically about the interactions of biophysical (including climate, hydrology,

physical, biogeochemical and geologic) and social (including economic, political, cultural, institutional) dimensions that constitute complex social-ecological systems. An underlying concern is to improve understanding of complex social-ecological systems and circumstances conducive to effective governance toward sustainability.

Perhaps the most influential framework is the Social-Ecological System (SES) Framework (Ostrom 2009), which emerged as a synthesis and advance on the Institutional Analysis and Development Framework (McGinnis 2011, Ostrom 2011), the Robustness Framework (Anderies 2004), and research on common-pool resources and resilience/robustness of social-ecological systems (e.g., work by the Resilience Alliance). The SES Framework identifies four core subsystems—the resource system, resource units, the users, and the governance system—that interact to directly shape a SES. The framework points to interactions of variables and processes that lead to outcomes, which feedback to ongoing transformations in a given SES. In turn, a SES and its subsystems are located within overarching social, economic and political settings that interact with or impact as SES’s subsystems. Any SES also exists in relationship with other ecosystems, geological, climatological and biogeochemical systems. Thus the SES Framework encourages an integrative, interdisciplinary approach for examining any SES within and across scales of analysis.

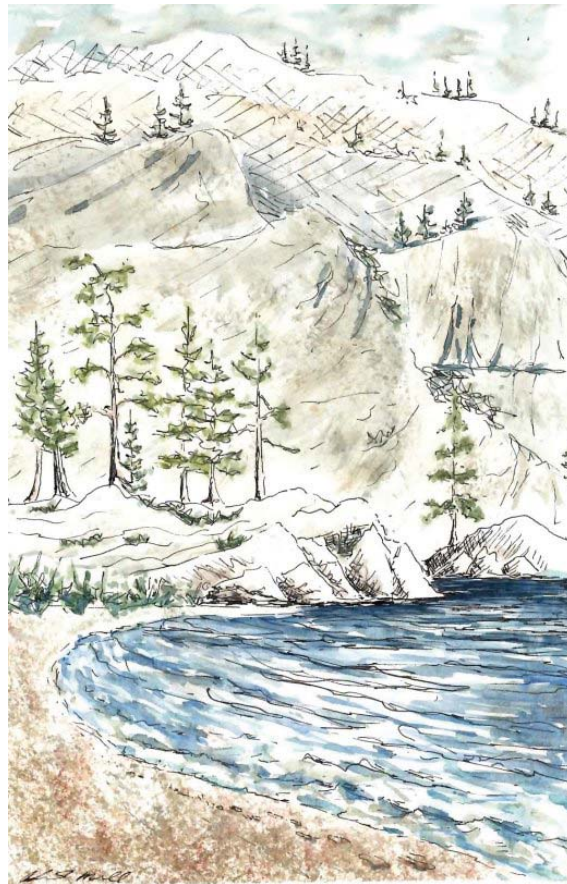
Researchers can use the SES framework as a tool to think about all components of a SES—variables that are not directly influenced by humans (e.g., geological characteristics), interactions of biophysical and social processes (e.g., land cover change), and human dimensions (e.g., institutional arrangements of a society that influence SESs through policy and practice). Applying the framework creates certain challenges due to its abstraction and intent to accommodate the full diversity and complexity of SESs. Therefore current work addresses operationalizing the SES framework. For example, Leslie et

al. (2015) develop a spatially explicit, quantitative approach for comparative analysis of multiple localities, and apply it for research on small-scale fisheries in Mexico.

Conceptually, the framework encourages researchers to consider their specific research questions and findings within their broader context. Through recognizing how our work carries SES level implications, perhaps we can enhance our attempts to reach beyond our own communities of knowledge. While there is much to learn in each of our fields of inquiry, perhaps we have even more to learn about sharing knowledge broadly and making it accessible to actors on the ground and with policy-makers. By thinking in terms of social-ecological systems and moving toward synthetic, integrative knowledge, we may work together more effectively to inform research, practice, and policy toward sustainability.

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Benson Lake, Sierra Nevada, California, August 9, 2014.
Adrienne Marshall

Social-Ecological Systems: A Core Concept for the Mountain Research Initiative

Greg Greenwood

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While there is much lip service paid to the concept of “coupled human-natural systems” or its twin, “social-ecological systems”, many in the Mountain Research Initiative (MRI) community may not understand exactly what those terms mean and more importantly what they suggest for future research. My goal is to unpack these notions and to show their utility.

We all live within social-ecological systems, and we all know that they can be complex. I drew Fig. 1 during a workshop that MRI and IGBP held in 2012 to look at the impacts of drivers, shown in brown, including but not limited to climate change, on the cryosphere, shown in magenta, and subsequently on hydro and ecological systems, shown in dark blue, through to geomorphic features and processes in light blue and finally on human values and systems. Such a “spaghetti” diagram, while technically correct, can seem quite ad hoc. We could presumably draw other such diagrams for other situations and end up with a collection of incommensurate “just so” stories, with no emerging patterns.

Thus we need a more organized approach to understanding causality within these systems. To give some order to this web of causality, MRI uses Fig. 2 taken from the Global Land Project (GLP 2005). This figure is now more than a decade old and while there are other conceptualizations, this figure is still very useful.

On the outside we see the earth system, those planetary systems such as the atmosphere, the oceans but also social institutions, such as global market, that establish the context within which we find land systems, the home for us and all terrestrial beings.

Land systems are themselves composed of social systems (on the left) and ecological systems (on the right). These two systems are in constant interaction through what the GLP termed “land use and management” but which we can generalize to “resource use and management”. Via resource use and management, social systems apply practices but also emit pollutants to ecological systems. Ecological systems respond to use and pollutants,

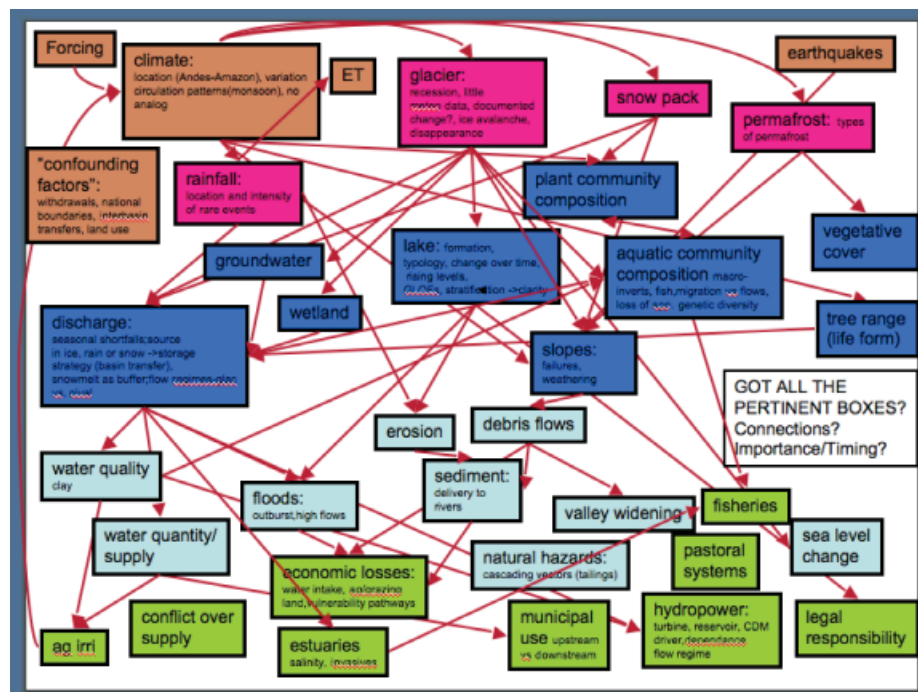


Figure 1. A plausible causal chain from climate change to human impacts via the cryosphere.

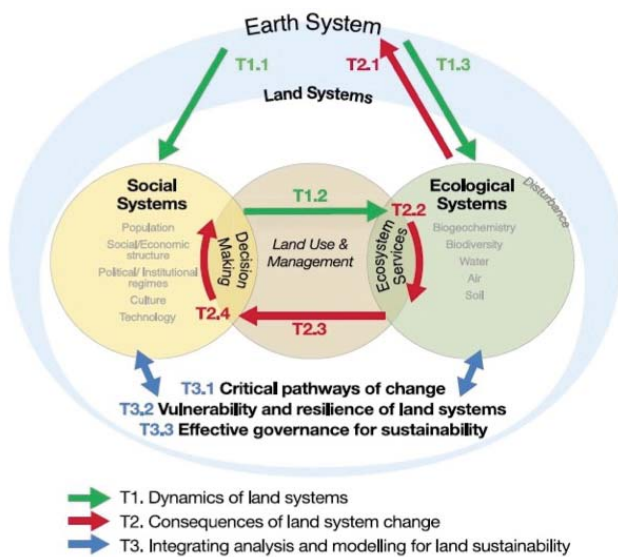


Figure 2. The world according to the Global Land Project (GLP 2005).

usually in the context of other, larger global drivers, influencing in the end the production of ecosystem goods and services, including hazards. Ecosystem goods and service translate into well-being for at least some within the social system, though for whom remains a major question. The social system in turn and in response to ecosystem goods and services, global drivers and its own internal functioning makes decision regarding use, management and pollution.

A vast majority of research focuses on elements on the right side of the figure (Bjørnsen et al. 2012). Obviously a lot of us are interested in ecological systems! Why should we zoom out and make the whole system our research interest?

First, the whole system is intrinsically interesting. Many of us want to know how the world, in all its complexity, works. Some might believe that there are no commonalities between different social systems, that all human arrangements are unique. The same might have been said with respect to ecological systems a century ago and yet we have since found concepts – evolution and selection, energy flow, material cycles – that provide a unifying and useful framework for understanding ecological function. A similar systemic understanding of social systems will likely one day emerge.

Second, an understanding of the whole system could help us anticipate catastrophes. There are clearly outcomes that most of us would consider outside the boundaries of the acceptable (aka “bad”, however normative that may be) – civil war, economic depression, ecological collapse. To the degree that we understand

how social-ecological systems operate, we might be able to stay within bounds of the acceptable, or more poetically, to avoid the plagues.

Third, understanding how the whole system works also opens the possibility for changing the systems trajectory through informed decisions. Should it become possible to define not just states that we wish to avoid, but also states we wish to achieve, then a sufficient knowledge of the whole system would help us nudge it in the right direction.

The Global Land Project saw three major research themes with this scheme (Fig. 2). The first, shown with green arrows, involves *the dynamics of land systems*. The second, shown with red arrows, involves *the consequences of land system change*. And finally, the third, shown with blue arrows, involves *resource sustainability*.

The first question related to the dynamics of land systems is: how do globalization and population change affect regional and local resource use decisions and practices? A good example might be how trade liberalization and on-going infrastructure development affects the economic opportunities in mountains of the developing world. For instance, Mount Kenya is now a center of flower production with exports to Europe and elsewhere. Another example might be the current uptick in large-scale land acquisition projects in the developing world (e.g. <http://www.landmatrix.org/en/>).

The second question, how do changes in land management decisions and practices affect biogeochemistry, biodiversity, biophysical properties and disturbance regimes of terrestrial and freshwater ecosystems, is the classic question of the impact of human activity on the environment. A good example might be how production of flowers on Mount Kenya has changed (or not) the structure and function of ecosystems on the mountain.

The third question, how do the atmospheric, biogeochemical and biophysical dimensions of global change affect ecosystem structure and function, is the classic question of the impact of global environmental change, with climate change as the canonic form, on local ecological systems. Following our Mount Kenya example, a good instance of this question would be the impact of glacier loss and changes in hydroclimate on the mountain ecosystems.

The second GLP theme interrogates the consequence of land system change.

The first question, what are the critical feedbacks to the coupled earth system from ecosystem changes, asks about reciprocal effects on the global system from changes in the land system, with as an excellent example, the impact of changes in the land surface albedo on regional and global climate.

The second question, how do changes in ecosystem structure and functioning affect the delivery of ecosystem services, refers to the translation of ecosystem change into features that are valued by humans. Leaving aside Mount Kenya, a good example here might be how a younger forest in the mountains of southwestern China, attributable to a combination of intensive harvesting and a warmer and drier climate, will affect mushroom production, a key non-timber resources of the mountains.

Following on, the third question is: how are ecosystem services linked to human well-being? Pursuing our mushroom example, we would want to know how changing mushroom abundance affects the well-being of different classes of residents, their food security, their income, and their culture.

The final question under the theme of consequences is: how do people respond at various scales and in different contexts to changes in ecosystem service provision? Continuing the previous reasoning, how do people respond to a shortage of mushrooms? Do they limit access of “foreigners” to the resource? Do they attempt to cultivate the mushrooms? Do they abandon mushroom harvest and instead start new resource-based enterprises that in turn affect the ecological system in some new way? Or do they leave the area for non-resource dependent jobs elsewhere?

The third theme of integrated analysis and modeling for land

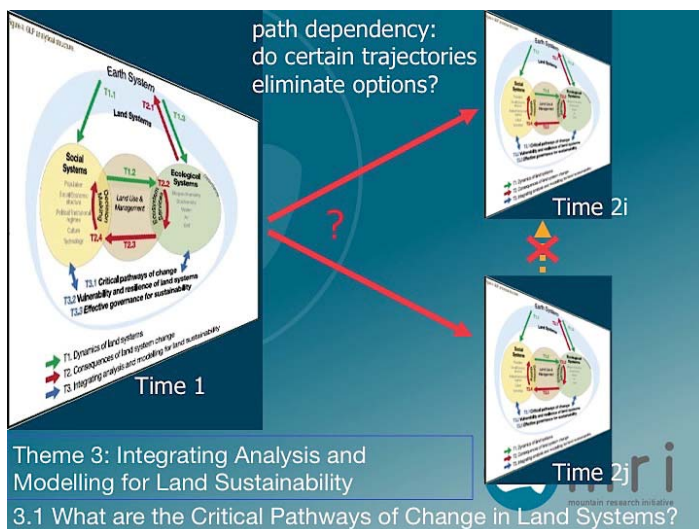


Figure 3. Path dependency: some trajectories render other states unattainable.

sustainability focuses on how the system evolves over time.

The first question under the third theme, what are the critical pathways of change in land systems, addresses path dependencies with the system, specifically if certain trajectories eliminate future options. Fig. 3 shows the idealized land system as it follows two different trajectories over time. Imagine that a certain set of practices, for instance, a strong soil conservation program, leads the system from its initial condition at time 1 to a future condition i , characterized by a thick soil mantle at time 2. Imagine too that the absence of such a program leads to severe soil erosion with a resultant condition j . Once the system has arrived at condition j it is nearly impossible within a human timeframe to return to a thick soil mantle. Thus the system exhibits path dependency: some future states become unattainable if the system follows certain trajectories. Just this example indicated a path dependency arising from an irreversible erosion of natural capital, one can imagine other path dependencies arising from the erosion of economic or social capital.

The second question, how do the vulnerability and resilience of land systems to hazards and disturbances vary in response to changes in human–environment interactions, involves the inner loop of human–environment interaction at the heart of Fig. 2. In Fig. 4, from left to right, one can imagine a forested land system that receives a shock, let’s say a forest fire. It is possible that the inner loop of human–environment interactions, including for instance, the way people reinvest in their forest via restocking and protection, might allow the system to recover. However, should there be a bigger shock or perhaps a different set of human–environment interactions, one in which there is no incentive for reinvestment, the shock might drive the system toward complete deforestation and subsequent desertification. Thus, depending on the mechanisms embodied in the human–environment interactions, the system might recover, or it might stabilize at a new, different and perhaps less productive condition.

The third and final question of the third theme, which institutions enhance decision making and governance for the sustainability of land systems, focuses on a very specific part within the social system, those institutions that people use to regulate their behaviors as part of the human–environment interaction. In fact, the example I just gave, which evoked institutions regulating reinvestment in ecosystems, serves as well here. We want to know how institutional arrangements make the difference between trajectories that are sustainable and those that are not.

Fig. 2 is a very high-level abstraction and leaves a lot of detail to be filled in by the user. For instance, the laundry list of features associated with the ecological system in Fig. 2 is more

3.2: How Do the Vulnerability and Resilience of Land Systems to Hazards and Disturbances Vary in Response to Changes in Human-Environment Interactions?

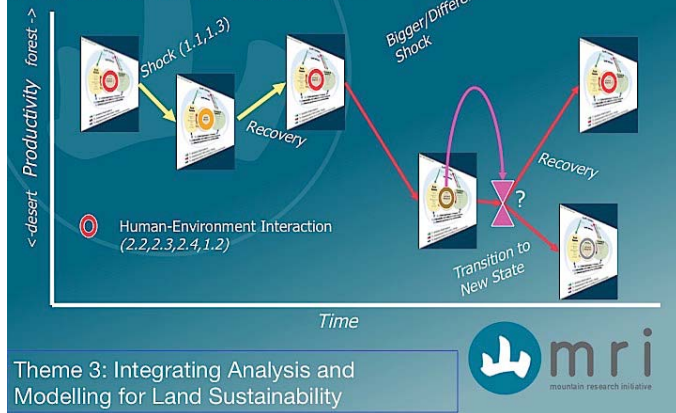


Figure 4. Human-environment interactions and especially institutions can strongly influence the response of the land system to drivers.

emblematic than accurate. That said, I suggest that ecologists have a pretty good idea of what's inside the ecological system. Over past decades, ecologists have developed increasingly complex models of how external drivers modulate the flow of energy, matter and information through ecological systems. Just as an example, the USGS Western Mountain Initiative used RHESSys, the Regional Hydro.Ecological Simulation System, as a platform for capturing ecological processes at multiple but demonstrably different sites throughout the western USA. While all places are at some level unique, there are enough similarities to allow the adaptation of a single ecological modeling framework to fit a variety of different sites.

I do not believe that we can say quite the same for the social system. On one hand there is the sentiment, held not so much by social scientists, that human affairs are just so complicated that all situations are idiosyncratic. The natural world must certainly have appeared that way too prior to Linnaeus but the legacy of centuries of observation has been a slowly accreting sense that there is order in the ecological world.

On the other hand, there is a growing field of agent-based modeling (ABM), (Rounsevell et al. 2012), which posits that human affairs can be characterized by the interaction of agents, people or social entities who act according to some set of rules. This is in some way like stating that the physical world is result of the interaction of atoms. It is certainly true, but simply pushes most of the unknowns into a different bin. Nevertheless agent-based modeling provides a starting point for a systematic approach to social systems.

The trick, of course, is in understanding the rules by which actors act. A moment's reflection by each of us regarding that which governs our own actions — biological needs, economic challenges, issues of status, congruence with moral codes — will show that this is not a trivial question. Social scientists are nonetheless intent on understanding what Courtney Flint characterized to me as “structure and agency”, that is, the impetus for actors to act versus the constraints placed on their actions. While in the end, not all or even many social science researchers may see the value of compressing their knowledge into an ABM framework, I expect that their understanding of “structure and agency” will eventually be formalized into something that looks like a model.

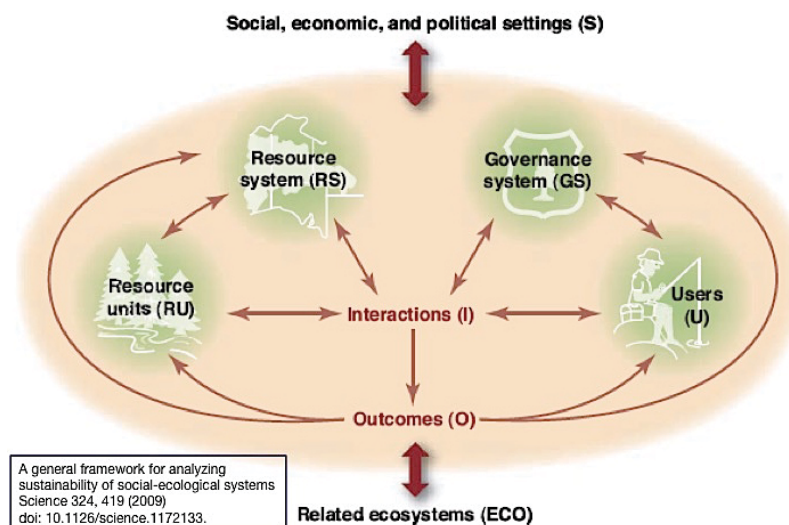


Figure 5. Social-ecological systems as conceived by Elinor Ostrom (Ostrom 2009).

Table 1. Examples of second-level variables under first-level core subsystems (S, RS, GS, RU, U, I, O and ECO) in a framework for analyzing social-ecological systems. The framework does not list variables in an order of importance, because their importance varies in different studies. [Adapted from (12)]

<i>Social, economic, and political settings (S)</i> S1 Economic development. S2 Demographic trends. S3 Political stability. S4 Government resource policies. S5 Market incentives. S6 Media organization.	
<i>Resource systems (RS)</i> RS1 Sector (e.g., water, forests, pasture, fish) RS2 Clarity of system boundaries RS3 Size of resource system* RS4 Human-constructed facilities RS5 Productivity of system* RS6 Equilibrium properties RS7 Predictability of system dynamics* RS8 Storage characteristics RS9 Location	<i>Governance systems (GS)</i> GS1 Government organizations GS2 Nongovernment organizations GS3 Network structure GS4 Property-rights systems GS5 Operational rules GS6 Collective-choice rules* GS7 Constitutional rules GS8 Monitoring and sanctioning processes
<i>Resource units (RU)</i> RU1 Resource unit mobility* RU2 Growth or replacement rate RU3 Interaction among resource units RU4 Economic value RU5 Number of units RU6 Distinctive markings RU7 Spatial and temporal distribution	<i>Users (U)</i> U1 Number of users* U2 Socioeconomic attributes of users U3 History of use U4 Location U5 Leadership/entrepreneurship* U6 Norms/social capital* U7 Knowledge of SES/mental models* U8 Importance of resource* U9 Technology used
<i>Institutions (I) → outcomes (O)</i> I1 Harvesting levels of diverse users I2 Information sharing among users I3 Deliberation processes I4 Conflicts among users I5 Investment activities I6 Lobbying activities I7 Self-organizing activities I8 Networking activities	<i>Outcomes (O)</i> O1 Social performance measures (e.g., efficiency, equity, accountability, sustainability) O2 Ecological performance measures (e.g., overharvested, resilience, bio-diversity, sustainability) O3 Externalities to other SESs
<i>Resolved ecosystems (ECO)</i> ECO1 Climate patterns. ECO2 Pollution patterns. ECO3 Flows into and out of focal SES.	

*Subset of variables found to be associated with self-organization.

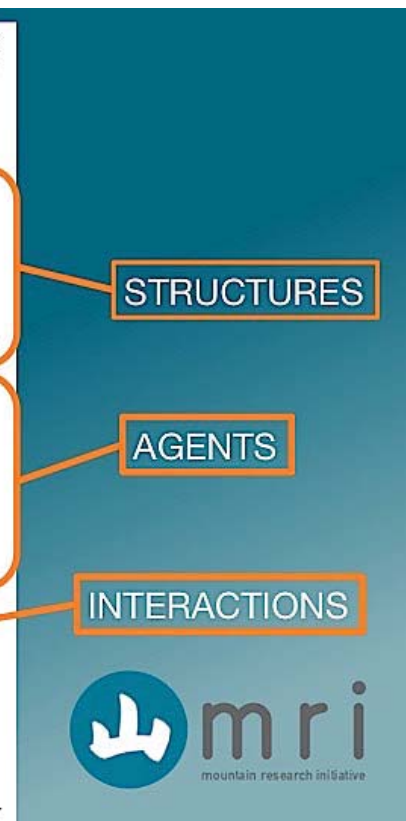


Figure 6. Features of social-ecological systems shown by case studies as important to understanding their sustainability.

Fig. 4 isn't the only way to think of coupled human-natural systems. Fig. 5 portrays Elinor Ostrom's, the Nobel Prize laureate conception of SESs (Ostrom 2009). She unpacks both the ecological and social systems in the light of understanding the development of sustainable natural resource systems (Fig 6) For biophysical scientists, especially those who work close to agencies, her list of the features central to understanding social systems—the characteristics of the agents themselves, the structure and institutions that channel agency and the interactions that result—is eye-opening and at the same time familiar. She showed the way toward a more systematic characterization of social-ecological systems that could serve as the basis for observatories and eventually for models that could be hooked to ecological models to understand the functioning and even the evolution of social-ecological systems.

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Big Data Are All the Rage—For Mountains, Too

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Big data. For some, it's a vaguely apocalyptic word; for others, it represents a new era of understanding our environment and ourselves. Today, big data are being harnessed in ever more innovative ways that simply were not possible when we only had small sets of data to work with. Although mountain system research doesn't yet produce the vast quantities of data that are now common to other fields, there are nevertheless a lot of data that, if pooled, could provide new insights into how mountain socio-ecological systems function. As the Mountain Research Initiative's (MRI) Concerted Efforts progress (Greenwood 2013), it becomes clear that it is time for the mountain research community to harness the lessons and power of at least "medium data" to develop a stronger, evidence-based understanding of both the generalities and the specificities of mountain systems.

Creating Big Data from Mountain Observations

The growing recognition of the power of data is probably partially responsible for the traction that MRI's Concerted Effort on mountain observatories has gained over the past year. MRI's campaign to mobilize a network of mountain observatories is based on the premise that, while a more comprehensive international system of mountain observatories is needed, there is no single entity with the authority to organize it or the budget to fund it (Greenwood 2013). The best way to mobilize a global observation network is to piece one together from the many existing but disparate observation efforts. By linking environmental and socio-economic observations across whole regions, we can start using data to make evidence-based comparisons, inform decisions and shape policies. More data don't just let us see more, they allow us to see in a new, better, and different way (Cukier 2014).

In July 2014, over 175 researchers working with existing observation sites met in Reno, Nevada, USA for "Mountain Observatories: A Global Fair and Workshop on Socio-ecological

Systems" to exchange ideas, identify priority topics and sites, and develop common programs. Experts identified a core set of indicators and the challenges of monitoring them. A key conclusion of the conference was that understanding the history of a system and its connections across spatial scales is extremely useful for understanding the operation of the system as shown by monitoring data. In addition, we need to find ways to juxtapose quantitative and qualitative data such that the qualitative information, e.g. the history of a place, informs our interpretation of current quantitative data. Similarly, a more effective integration of remotely sensed data, ground measurements, and spatial models is needed to ensure that highly precise but spatially limited site data can be placed in a broader spatial context.

To read more about the outcomes of this conference, visit <http://www.mountainobservatories.net/> or watch conference talks here: <https://cast.switch.ch/vod/channels/11f4ova8qa>.

Although the mountain research community is light-years from assembling the sort of big datasets that NASA works with, we are nevertheless entering an era of at least medium-sized data. The mountain research community now needs to identify what has already been done, focus on and enumerate actual variables, develop references and protocols, or pool existing protocols (e.g., climate data standards from WMO) in one place. Over the next year, the MRI will invite a set of mountain observing sites to constitute the core of a global observation network. These core sites will provide a real-world framework by which to establish protocols and standards for global observations, introduce novel data collection methods and pioneer new ways to integrate qualitative and quantitative data from a wide range of disciplines.

Elevation-Dependent Warming

Although it is well-known that global warming is more pronounced at high northern latitudes, there is some evidence that warming is also amplified by elevation. The question of where



Figure 1. One of four flux towers installed at different altitudes between 405 and 2700 m by the Southern Sierra Critical Zone Observatory, California, USA. Instruments collect information about climate and fluxes of carbon dioxide and water vapor with the objective of gaining new knowledge on how water, soils, and climate interact. Photo: Claudia Drexler

and why global warming is indeed occurring at a faster rate at high elevations is at the heart of MRI's second Concerted Effort, Elevation-Dependent Warming (EDW). Considerable scientific theory exists about EDW, but mixed observational evidence makes it difficult to know if this is a global phenomenon. If it is, we may be strongly underestimating the magnitude of impacts, particularly with regard to the water cycle.

From 22 to 25 April 2014, a group of 16 MRI experts met in Payerbach, Austria to review the evidence related to accelerated climate warming at high elevations and to design a campaign to assess if, where, to what extent and why mountains and other high elevation regions of the world are warming more rapidly than other portions of the planet. A large part of the workshop was dedicated to identifying the mechanisms that could produce EDW, such as changes in albedo and condensation levels, as well as changes in the energy balance due to changes in water vapor, incoming and outgoing radiation, and aerosols. The group also spent a good deal of time discussing what needs to be done to increase our confidence in the location and magnitude of EDW. Improving existing datasets, bringing in new datasets and linking station data with remote sensing data will be key to answering the EDW question. The next step of the EDW campaign will be to identify a project or projects that implement the lines of research outlined by experts at Payerbach.

EDW takes a very different approach to the subject of observations. In contrast to the bottom-up approach of Mountain Observatories, which integrates existing data and asks what insights the sum of these data support, EDW takes

an intellectually top-down approach centered around a single question. This approach prompts us to ask, "what other sort of observational networks do we need to really be able to answer this question?"

For more information about the campaign, visit <http://mri.scnatweb.ch/en/projects/global-campaign-to-understanding-elevation-dependent-warming>.

It's All About the Data

The MRI's other two Concerted Efforts, "Agency and Governance" and "Assessing Sustainable Mountain Development", are also strongly data-driven and closely linked with the concept of developing global observation datasets. MRI's Agency and Governance (A&G) campaign has focused on stimulating a conversation (without dictating the form or structure) between diverse social science disciplines about the interplay between human agency (an acting force) and governance (a constraining structure) in mountain regions.

During the 2014 Global Fair and Workshop in Reno, it was clear that while there are many different theoretical approaches to understanding social-ecological systems, data are central to all of them. To address Agency and Governance, we need information about both the observable behavior and institutions and the unobservable but certainly reportable interior states that underlie behavior. Answering this question will require the collaboration of a diverse range of social science disciplines, from anthropologists and sociologists to political scientists and legal scholars. At the Global Fair and Workshop, it was clear that

data form the basis of a discourse linking all these disciplines.

MRI's fourth concerted effort, Assessing Sustainable Mountain Development (SMD), was conceived around the idea that good policy is based on evidence—which again means data. Sustainability encompasses measures of environmental, economic and social capital. To assess sustainable mountain development, it is necessary to define the dimensions of each of these capitals and the space that these dimensions create, as well as the surface that conceptually separates that space into sustainable and unsustainable domains. The definition of these spaces and the surface that bisects them depend on data and their trends over time, not rhetorical arguments. Thus, the assessment of SMD will depend on yet more data, much of which will probably also be common to the other three Concerted Efforts.

Assembling and homogenizing existing, disparate datasets into a global set of observations will certainly provide new insights into how mountain socio-ecological systems function, how climate warming affects high elevation environments, and how mountain communities exercise agency and via what forms of governance. However, none of these questions are just about what variables to measure. As the mountain community embraces the era of medium-sized data, it will be necessary to identify new ways to ensure data quality, to manage global datasets and to create repositories that are accessible and that allow researchers to understand global change in mountains in new and better ways.

As a parting thought, consider that our world is now rich with

data-collecting devices, from mouse clicks to cell phones. The mountains are crawling with people armed with GPS-tracking, photo-taking, instant-uploading cell phones—what sort of information might they provide that could really change our understanding of mountain systems?

The Mountain Research Initiative (MRI) is an international networking project for global change research in mountain regions that has worked assiduously for more than 10 years to develop a community of researchers and to synthesize and publicize knowledge about global change in mountain regions. The MRI is funded by the Swiss National Science Foundation and was founded under the auspices of the International Geosphere–Biosphere Project, the International Human Dimensions Projects and the Global Terrestrial Observing System (IGBP, IHDP, GTOS).

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Figure 2. Photos can be an important source of knowledge about the dynamics of socioecological systems in mountains. A plant ecologist from Ecuador documents the scattered flora on Mount Rose (NV) USA, in July 2014. Photo: Claudia Drexler

Holocene Diatom-Derived Climate History of Medicine Lake, Northern California, USA

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It is often said that mountains make their own weather, and for the isolated volcanoes of the Cascade Range, this is abundantly clear. Evidence of the long-term connection between these volcanoes and the weather they generate is difficult to obtain due to the lack of sediment repositories.

Numerous climate records from moderate and high elevation sites in northern and central California and southern Oregon have identified a significant connection to regional coastal conditions (Barron et al. 2003, Barron and Bukry 2007). These terrestrial records have used pollen (Davis et al. 1985, Smith and Anderson 1992, Hakala and Adam 2004), tree rings (Graumlich 1993, Lloyd and Graumlich 1997), chironomids (Porinchu et al. 2003), charcoal (Brunelle and Anderson 2003, Whitlock et al. 2004, Briles et al. 2005), and glacial geomorphology (Clark and Gillespie 1997, Konrad and Clark 1998). While a few low elevation diatom records exist for the region (Bradbury 1991, 1992, Bradbury et al. 2004a, b), studies that used diatoms as a proxy for changes in effective moisture and limnological conditions at moderate and high elevations are limited (Holmes et al. 1989, Whiting et al. 1989, Bloom et al. 2003) and these studies do not extend north of the central Sierra Nevada.

Medicine Lake volcano is a large Quaternary shield volcano located about 50 km northeast of Mount Shasta, in northern California. The volcano began erupting about 500,000 years ago (Donnelly-Nolan and Ramsey 2001). At least 17 eruptions have occurred during the past 12,900 calendar years (cal yr B.P.). Anderson (1941) noted both geomorphological and sedimentological evidence for higher lake levels during the Quaternary. This evidence includes abandoned shorelines north of the lake and diatomaceous deposits to the south.

Medicine Lake is a small (165 ha), relatively shallow (average 7.3 m) mid-elevation (2036 m) lake that occupies a portion of the summit caldera of Medicine Lake volcano (Fig. 1). The lake is a cold polymictic lake with a strong seasonal thermocline. The strength, duration, and timing of seasonal overturn vary with the date of lake thaw, which normally occurs between May and July. Late summer surface temperature is around 15 °C and decreases to 4 °C at a depth of 25 m (Schneider and McFarland 1996). The thermocline is between 12 and 15 m deep. The specific conductivity (20 $\mu\text{S}/\text{cm}$) and nutrient levels (oligotrophic) are low. The pH of the water is near neutral at the surface and becomes slightly acidic at the bottom, probably due to the increased concentration of humic acids.

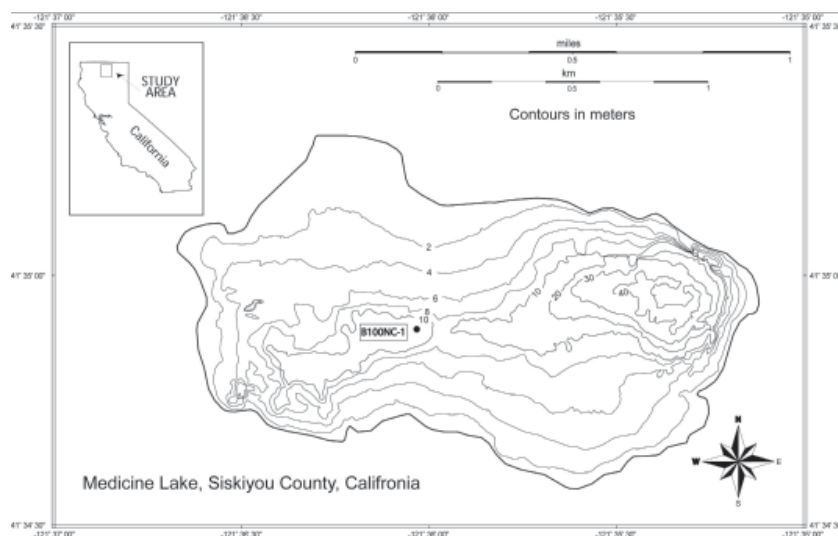


Figure 1. Map showing the location of Medicine Lake.

The lake lies within a semi-arid winter-rainfall climate (Shinker 2010, Shinker and Bartlein 2010). The 30-year normal PRISM data (www.prism.oregonstate.edu; accessed 5/2/15; Fig. 2) show that Medicine Lake volcano lies near the boundary between the wetter Klamath Mountains to the west and the arid Modoc Plateau and northern Great Basin to the east. More than 75% of the annual precipitation falls during the period from October to March. Although summer thunderstorms occasionally occur, more than 75% of the annual precipitation falls during the period from October through March. Precipitation is highly variable both locally and interannually. El Niño years tend to have greater than average precipitation. Warm summer temperatures and low precipitation, coupled with high evapotranspiration, lead to a low effective moisture for the region (Colman et al. 2004).

The modern forest surrounding Medicine Lake is dominated by lodgepole pine (*Pinus contorta*). Other pine species in the area include ponderosa (*P. ponderosa*), Jeffrey (*P. jeffreyi*), sugar (*P. lambertiana*), and western white (*P. monticola*) pines. Red (*Abies magnifica*) and white fir (*A. concolor*) are found at higher elevations and on shaded north-facing slopes. Incense cedar (*Calocedrus decurrens*) and western juniper (*Juniperus occidentalis*) are present in small numbers on dry slopes and at lower elevations. Sagebrush (*Artemisia tridentata*) is common in open areas at lower elevations throughout the Modoc Plateau. Oaks are represented by the huckleberry oak (*Quercus*

vaccinifolia). Several species of grass (Poaceae) and bracken fern (*Pteridium* spp.) are common in forest clearings.

Diatoms (Division Bacillariophyta) are one of the most useful indicators of aquatic conditions in lacustrine systems. The preservation potential of the siliceous frustule (shell) makes them valuable proxies for past environmental conditions. They are sensitive to changes in water and air temperature, lake level, and ice cover. These factors, in turn, have an effect on specific conductivity, nutrient concentrations (nitrogen, phosphorous, and silicic acid), and pH.

The bathymetry of Medicine Lake is important for two reasons, both of which are related to the amount of habitat available for colonization by benthic diatoms. The first is how the lake responds to seasonal variations in lake level. During periods of decreased precipitation and/or increased rates of evaporation, lakes with a wide, shallow shelf, only have water in the deepest part of the lake, which limits the abundance of species that colonize the littoral zone. During the drought of the 1930s, most of the shallow shelf in Medicine Lake was exposed (anonymous personal communication). Water level changes in deep, steep-sided lakes cause smaller changes in colonizable space, and the diatom assemblages may show little variation with these shifts in lake level. The thickness and duration of ice cover affects the amount of light available to benthic diatoms and the development of water column characteristics that affect the development of

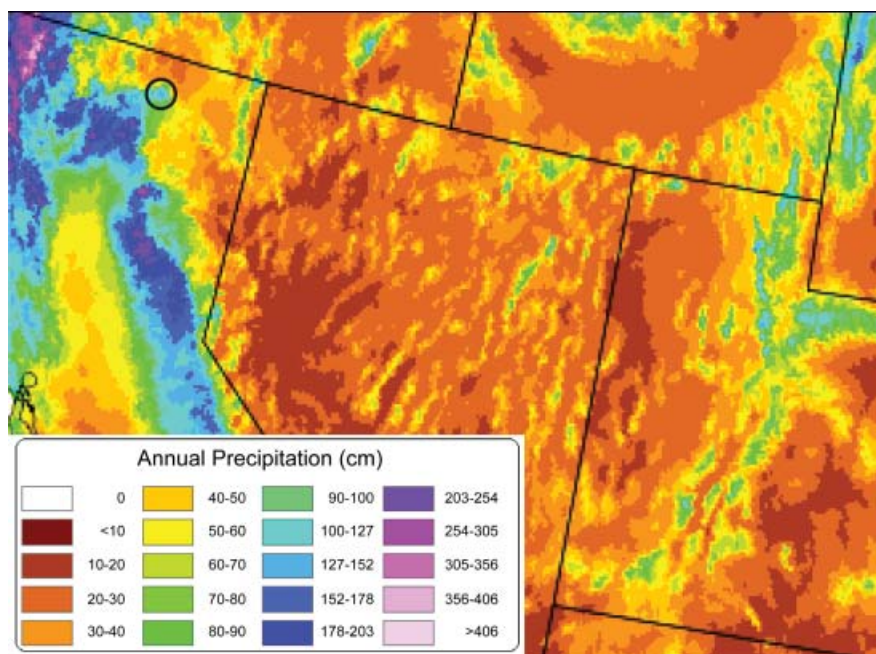


Figure 2. Annual precipitation (30-year normal, 4 km resolution) showing the location of Medicine Lake near the western border drier Modoc Plateau and Great Basin (www.prism.oregonstate.edu; accessed 5/2/15).

planktic species. Starratt (in press) has discussed the impact of lake basin morphology on diatom floras in several different lakes in northeastern Nevada.

In September 2000, core B100NC-1 (226 cm long; 12.6 m depth) was collected from the shallower western basin of Medicine Lake (Childs et al. 2000) using a Vibracore system (Fig. 1). A detailed discussion of the stratigraphy and sediments of the core can be found in Starratt et al. (2003).

Diatoms were extracted from 26 samples from core B100NC-1. More than 160 species and varieties of diatoms were identified in the modern and fossil floras. Several airborne contaminants (*Cyclostephanos* spp., *Cyclotella* spp., and *Stephanodiscus* spp.) from regional early Quaternary diatomite deposits were also present. The composition of the modern flora indicates a fresh water, circumneutral to slightly alkaline, oligotrophic lake (Starratt, unpublished). The downcore samples suggest that these conditions have not changed substantially over the past 11,400 years, making reconstruction of a lake level history possible.

Planktic taxa (Fig. 3) are abundant in the sediments deposited in the deeper part of the lake. The small fragilarioid species include *Pseudostaurosira*, *Staurosira*, and *Staurosirella*. The benthic component of the flora is represented by more than 25 genera. Several of the samples contain aerophilic taxa, which suggests that there is at least some input of sediment from the surrounding watershed. *Navicula s.l.* is the consistently dominant genus, both in terms of diversity and absolute abundance, and is used as a proxy for the relative amount of shallow shelf area in the lake.

Based on the composition of the planktic assemblages, the diatom record in the core can be divided into two intervals. The earlier assemblage was deposited between 11,400 and 5500 cal yr B.P. and the upper post-5500 cal yr B.P. assemblage. The distribution of the benthic species is more variable in abundance and less easy to interpret. Some genera show overall increasing or decreasing trends in abundance over the past 11,400 years, while others show no noticeable trends.

11,400-5500 cal yr B.P.

Cyclotella pseudostelligera and *C. stelligera* are the most common planktic species in the core. These species along with *C. ocellata*, gradually increase in abundance from the bottom of the core until ~5500 cal yr B.P. Other planktic taxa (*Tabellaria* and *Fragilaria*) fluctuate in abundance throughout the core, never accounting for more than 4% of the assemblage. Peaks in the abundance of *Fragilaria* often occur when the abundance of *Cyclotella* is relatively low.

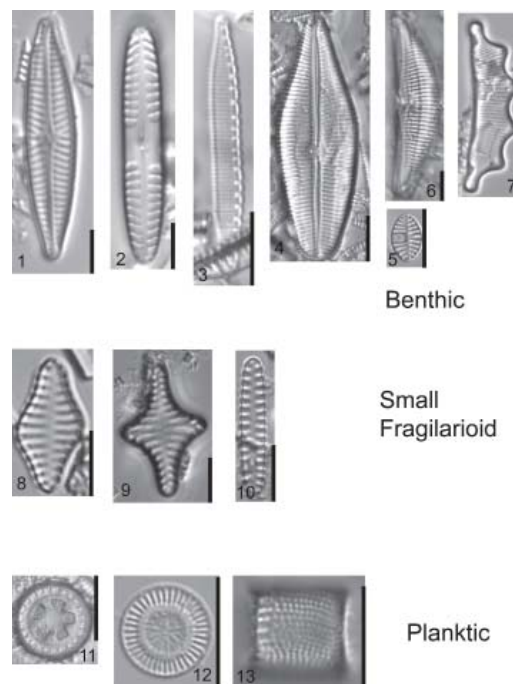


Figure 3. Diatom genera present in Medicine Lake. Benthic: 1) *Navicula*, 2) *Pinnularia*, 3) *Nitzschia*, 4) *Gomphonema*, 5) *Achnanthes*, 6) *Amphora*, 7) *Eunotia*; small fragilarioid: 8) *Staurosira*, 9) *Staurosirella*, 10) *Staurosirella*; planktic: 11) *Cyclotella*, 12) *Cyclotella*, and 13) *Aulacoseira*.

The benthic diatom assemblages deposited over the first 1500 years of the Medicine Lake record are dominated by epiphytic (attached to aquatic plants; *Cymbella*, *Encyonema*, and *Gomphonema*), circumneutral (*Navicula*, *Pinnularia*, and *Achnanthes*) to acidiphilic species (*Frustulia* and *Eunotia*). *Nitzschia* species, which have cyanobacterial endosymbionts are also present. The epiphytic species reach a maximum abundance of 26, 23, and 17%, respectively, in this interval, and then decrease to abundances of below 5% for the remainder of the record.

Most of the remaining benthic species decrease in abundance through this interval. For a small number of benthic species there is no apparent trend in abundance.

5500-0 cal yr B.P.

The abundance of planktic species and their taxonomic distribution differs in the upper part of the core. Over the past 5500 years the abundance of *Cyclotella* fluctuated between 0 and 60% of the assemblage. There are three relative abundance peaks in *Fragilaria* over the past 5500 years. Small fragilarioid species (*Pseudostaurosira*, *Staurosira*, and *Staurosirella*) are present only in the last 5500 years. *Pseudostaurosira* and *Staurosira*

vary between 0 and 4% over most of this interval, reaching their highest levels of abundances (9-10%) in the last 250 years.

Navicula, *Sellaphora*, and *Pinnularia* are the most abundant taxa deposited during the last 5500 years. *Navicula* varies in a cyclic pattern with peak abundances of about 25% at 4500, 2600, and 200 cal yr B.P.; low abundances of about 7% occur at 5000, 3500 - 3050, and 1700 cal yr B.P. Although several other taxa have individual abundance peaks that correspond to those of *Navicula*, other species do not exhibit clear trends in abundance over the past 5500 years.

Lake-Level History

During the early Holocene, Medicine Lake occupied either two small basins, with a surface about 10 m below the modern lake level, or a single narrow basin with two deeper subbasins connected by a small shallow shelf (Fig. 4). For the remainder of the Holocene the surface area of the lake varied by several meters in response to climate-driven changes in effective moisture. The most recent evidence for these variations in lake level came with a reduction in the surface area of the lake during the droughts of the 20th century (anonymous personal communication).

Therefore, the *Cyclotella/Navicula* ratio is used as a proxy for lake level (presence or absence of a shallow shelf which provided habitat for the benthic diatoms) (Figs. 4 and 5). *Cyclotella* spp. are used as a proxy for periods when the oligotrophic lake occupied a small, steep-sided basin with little shallow shelf area. Rühland et al. (2003) and Rühland and Smol (2005) have shown that planktic diatoms such as *Cyclotella* spp. increase in abundance in waters deeper than 5 m. *Navicula s.l.*, the most consistently abundant benthic genus, is used as a proxy for periods during which lake level was higher and the deep central basins were surrounded by a broad shallow shelf (less than about

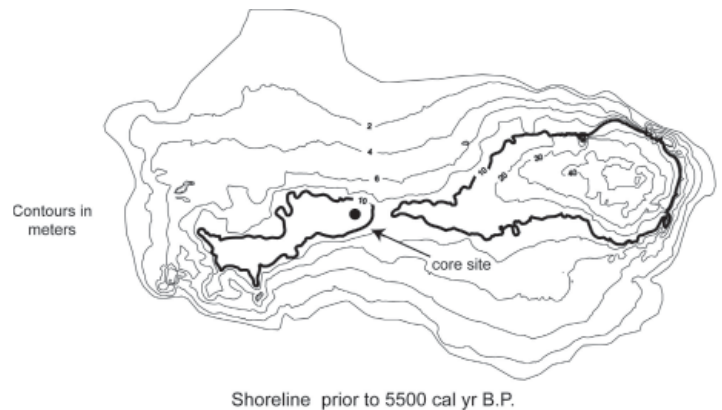


Figure 4. Comparison of modern lake boundary and a possible shoreline (bold line) for the lake at about 5500 cal yr B.P.

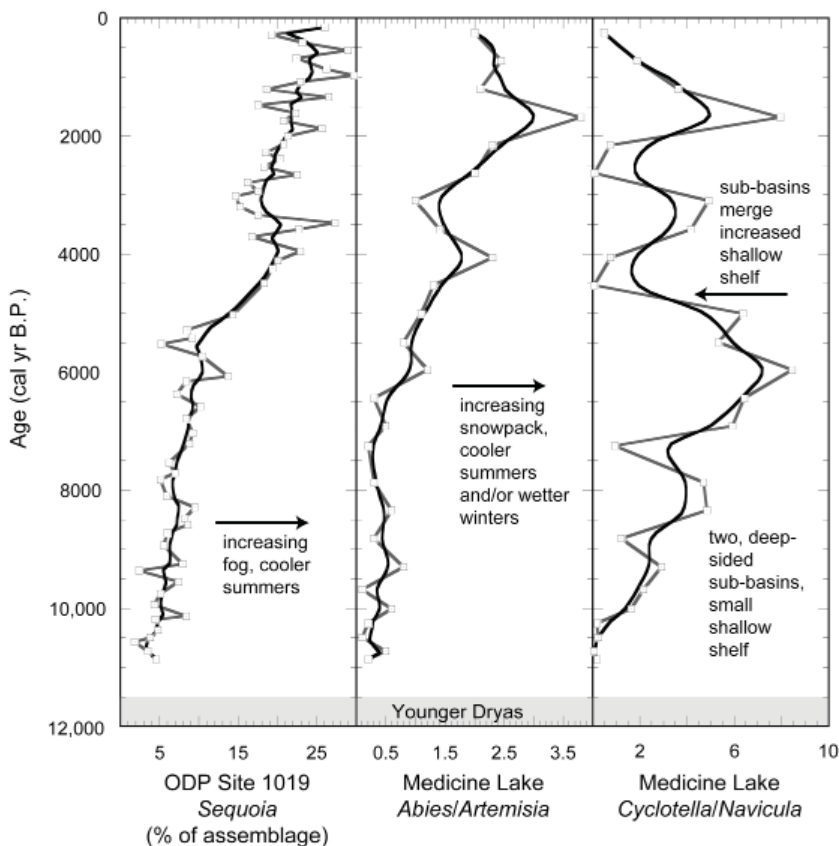


Figure 5. Comparison of northern California coastal climate and Medicine Lake moisture and lake level records. Increased *Sequoia* (redwood) pollen is a proxy for increased abundance of fog along the coast (Barron et al. 2003). The *Abies/Artemisia* ratio is a proxy for increased snowpack, brought about either by an increase in the winter precipitation or a cooler spring which results in delayed snowmelt. The *Cyclotella/Navicula s.l.* ratio is an indication of lake level; higher values reflect a higher lake level.

5 m deep). The increase in the abundance of the *Fragilaria* “complex” over the last 5500 years also suggests an increase in the availability of a shallow shelf environment. The *Cyclotella/Navicula* ratio (Fig. 5) gradually increases from near zero at 11,400 cal yr B.P., to 7.5 about 6000 cal yr B.P., suggesting a gradual rise in lake level. The ratio then drops to an average of about 3.0 for the last 5500 years, with variations in the ratio that suggest fluctuations in the amount of shallow shelf available for colonization by benthic taxa.

The ratio of *Cyclotella/Navicula*, variations in the abundance of the benthic diatom flora, and the abundance of *Isoetes* (quillwort; an aquatic macrophyte that presently covers much of the shallow lake bottom) all suggest a gradual filling of one or two small, isolated basins until about 5500 cal yr B.P. During this time, the lake may have behaved like a small arctic lake (Smol and Cumming 2000). In the early part of this period, the combination of an extended season over which the surface of the lake was frozen and the steep sides of the basin resulted in limited production of benthic and planktic diatoms. As the length of the ice-free season increased, the production of planktic species increased, but the abundance of benthic taxa remained relatively low because there was little change in colonizable habitat. The late middle and late Holocene (5500-0 cal yr B.P.) lake levels exhibited changes in depth of several meters, which affected the area of shallow shelf available for colonization by *Isoetes* and benthic diatoms (Starratt 2009, Starratt et al. 2003). As the available colonizable lake bottom increased with a longer ice-free season, the *Cyclotella/Navicula* ratio decreased. The increasing abundance of *Isoetes*, which has been shown to deplete CO₂ in the water column (Sandquist and Keeley 1990), might have had an impact on diatom abundance and diversity, particularly in shallow water. Increased evaporation in the middle Holocene may have enhanced this effect.

Between 2000 and 1500 cal yr B.P., an increase in the *Cyclotella/Navicula* ratio suggests a decrease in available moisture. This interval corresponds to decreased fresh water flow into San Francisco Bay via the Sacramento and San Joaquin Rivers (Starratt 2002, 2004, Malamud-Roam et al. 2006, Negrini et al. 2006), a brief decrease in the abundance of *Sequoia* at ODP Site 1019 (Barron et al. 2003), and low lake levels at Mono Lake on the east side of the Sierra Nevada (Stine, 1990). A more detailed analysis of high-frequency climate cycles such as El Niño (Cole et al. 2002, Moy et al. 2002) or the Pacific Decadal Oscillation (Mantua et al. 1997) is not possible at this time due to the lack of high-resolution data.

These interpretations are supported by the results of analyses from the lakes in the Klamath basin (elevation about 1230 m)

25 km to the north. Paleontological (pollen and diatom), and archaeological data suggest the lake levels were higher in the early part of the Holocene (Bradbury et al. 2004b, Hakala and Adam 2004, Rosenbaum and Reynolds 2004a, 2004b). For the last 7000 calendar years, the lake levels in the Klamath basin (Bradbury 1991) appear to have fluctuated in phase with the lake levels at Medicine Lake. The timing of regional (northern California and southern Oregon) low elevation lake level fluctuations is less clear as precipitation in individual basins is subject to local topographic conditions (Viau et al. 2002). Differences in the timing of lake level changes between Medicine Lake and Klamath basin lakes may also be due to local geological conditions. The eruption of the Medicine Lake Glass flow may have directly altered the morphology of the lake basin or the movement of magma may have indirectly caused a change in basin shape. Therefore, differences between the lakes in the Klamath basin and Medicine Lake may be due to the differences in moisture availability in low- and intermediate elevation lakes, changes in the morphology of the Medicine Lake volcano caldera due to magmatic movement, or some combination of these two processes.

Marine-Terrestrial Teleconnections

In two recent studies of sites off the northern California coast, Barron et al. (2003) and Barron and Bukry (2007) used a number of paleontological and geochemical proxies to unravel the complex Holocene climate history of the region. Over the past 11,400 years, the abundance of *Sequoia* pollen increased from about 5% to more than 25% of the palynoflora (Fig. 5). The increase is about 5% between 11,400 and 5300 cal yr B.P. Over the next 1300 years *Sequoia* doubles in abundance and then continues at a lower rate of increase through the rest of the record. An increase in *Sequoia* pollen indicates a shift towards the climate of the present, with wet winters and cool, foggy summers (Huyer 1983, Lynn and Simpson 1987, Herbert et al. 2001).

These changes along the northern California coast are reflected in the vegetation surrounding Medicine Lake, which shows a similar trend in moisture increase (Starratt 2009, Starratt et al. 2003; Fig. 5). The ratio of *Abies* (fir)/ *Artemisia* (sagebrush) is used as a proxy for moisture. Barbour et al (2007), and Heusser (1960) reports that *Abies* prefers cool, moist environments with extended snowpack while *Artemisia* requires less moisture. From 11,400 to 6500 cal yr B.P. there is little increase in snowpack. Available moisture then increases until about 1750 cal yr B.P. The fluctuations in available moisture over the last 3000 years reflect similar changes in freshwater flow into San Francisco Bay (Starratt 2002, 2004). Medicine Lake does not exhibit evidence of the late Holocene dry period (Mensing et al. 2013).

Fritz et al. (2001) showed that low elevation lake levels in the Pacific Northwest increased at about 5700 cal yr B.P. Lake levels in the northern Great Basin and central California lagged those in the Pacific Northwest by about 800 years (Fig. 6). This trend is similar to the trends found in other lakes in the western U.S. (Davis et al. 1976, Lindström 1990, Rose and Lindström 1996, Fritz et al. 2001, Benson et al. 2002), which show that the middle Holocene (to about 5500-4500 cal yr BP) was drier than the later part of the Holocene. Changes in middle Holocene seasonality along the California coast (Bogard et al. 2002, Diffenbaugh and Sloan 2004, Diffenbaugh et al. 2006, Diffenbaugh and Ashfaq 2007) may have been responsible for changes in the timing and magnitude of precipitation in the basin. Potito et al. (2006) have demonstrated a causal connection between sea surface temperatures in the northeastern Pacific Ocean and temperatures at sites in the Sierra Nevada, several hundred miles south of Medicine Lake. A similar relationship between sea surface temperature and the temperature on the Modoc Plateau would have led to increased evaporation during the summer. These changes in precipitation and evaporation affected lake level, sediment influx, and regional vegetation (Thompson et al. 1993, Bartlein et al. 1998, Thompson and Anderson 2000, Harrison et al. 2003).

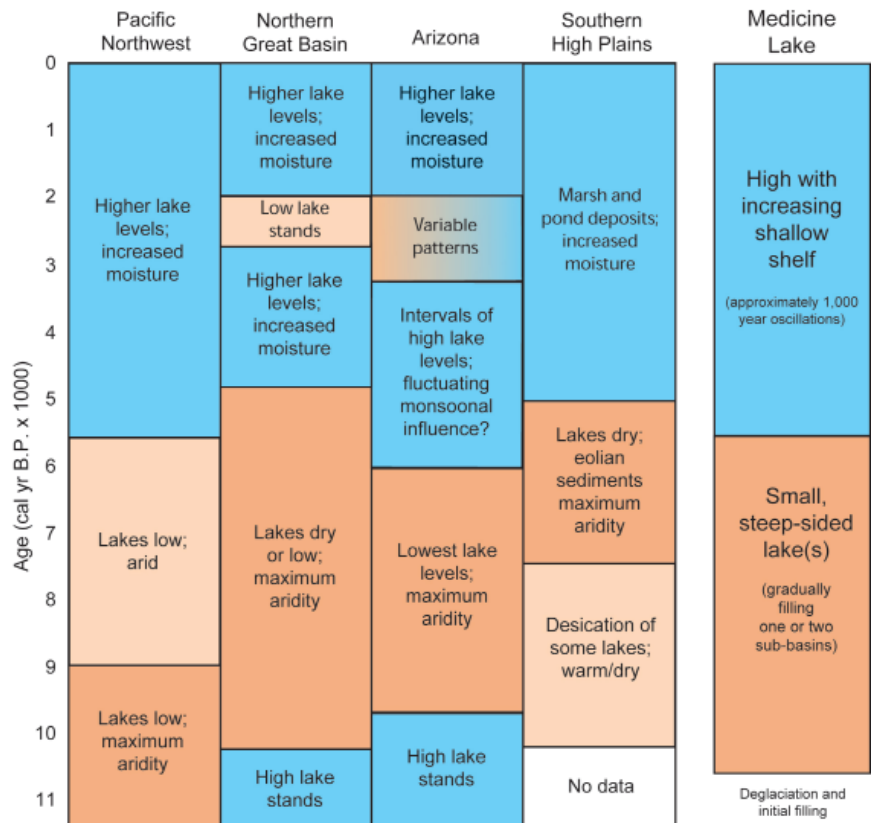
CONCLUSIONS

The Medicine Lake record is unusual because it responds not only to local and regional climate signals, but changes in conditions on Medicine Lake volcano during the Holocene. Ice retreat within the Medicine Lake volcano occurred around 11,400 years ago, followed by filling of two sub-basins. The absence of *Cyclotella* indicates that the early lake was probably less than 5 m deep. The low *Abies/Artemisia* ratio suggests that the climate was relatively dry.

Over the next 4000 years, the level of the lake rose as relatively organic-rich fine-grained sediments filled the basin. The increase in abundance of *Cyclotella* also suggests that the lake gradually deepened. The abundance of *Abies* in the basin also increased, suggesting the presence of a deeper snowpack which existed into the late spring and summer. The increased snowpack was likely the primary water source that filled the lake during this period.

About 5500 years ago, the lake flooded the shallow shelf area surrounding the two sub-basins. Variations in the abundance of *Cyclotella* and benthic taxa, dominated by *Navicula*, indicate that the area of the flooded shelf fluctuated during this interval. The abundance of *Isoetes* and *Abies* have paired responses to changes

Figure 6. Paleoclimatic interpretations of selected paleolimnological records for the United States. Darker orange areas indicate periods of aridity in the Pacific Northwest, northern Great Basin, Arizona, and the Southern High Plains (modified from Fritz et al. 2001).



in the basin, both suggesting an increase in effective moisture. This increase corresponds to an increase in *Sequoia* pollen observed at ODP Site 1019, which records the establishment of modern climatic conditions along the northern California coast (relatively warm wet winters and cool, foggy summers). A connection between coastal and inland climates appears to have strengthened at about this time. These fluctuations are in part due to these changes in moisture availability, but they may also be due to changes in the shape of the lake basin brought about by the movement of magma within the Medicine Lake volcano.

ACKNOWLEDGMENTS

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In Search of the Illusive and Iconic Ili Pika (*Ochotona iliensis*)

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Introduction

Pikas (genus *Ochotona*), diminutive relatives of rabbits and hares, are iconic denizens of mountain habitats through much of the Holarctic. About half of the approximately 30 species of pika (the genus is under revision) occupy rocky or talus habitat, mostly being found in mountains at high elevation. General characteristics of the rock-dwelling pikas are that they are diurnally active, occur at low density (individuals or pairs occupying discrete territories), have a low rate of reproduction, and are notably asocial. Many species are vocal, and most collect vegetation which is deposited in a central cache (which pika biologists call a haypile) to serve as food overwinter (Smith 1988, Smith et al. 1990). Throughout their distribution talus-dwelling pikas are revered by those who enter their domain, but recently one species has come to the forefront of the world's attention: the Ili Pika (*Ochotona iliensis*) of the remote Tian Shan (mountains) of northwestern Xinjiang-Uyghur Autonomous Region, China (Arnold 2015, Lu and Hunt 2015). Here we summarize the history of this species leading to its recent re-discovery and review what is known of its biology.



Figure 1. The first Ili Pika (*Ochotona iliensis*) seen in over 20 years; image taken at Jipuk, Borohoro Ridge, Tian Shan North, Xinjiang-Uyghur Autonomous Region, China.

Early Investigations and Natural History

The Ili Pika was discovered by WDL in 1983, and was described as a new species of pika in 1986 based on three specimens collected in 1983 and 1985 (Li and Ma 1986). It is a relatively large pika, ranging from 216.5 – 250 g in weight and with hind feet (42 – 43 mm) among the largest of all pikas (Fig. 1; for comparative measurements see Smith and Xie 2008, pgs 277–286). It sports large (36 – 37 mm) heavily furred ears, whereas most pikas have only sparsely furred ears. It has a distinctive dark rusty collar, as well as rusty-red spots on its muzzle, forehead, and crown. Even in summer its fur is longer and thicker than that of most pikas.

The Ili Pika occupies two branches of the Tian Shan south and west of Ürümqi (and north of the Taklamakan Desert; Fig. 2). In the decade following its discovery, the Ili Pika was found at 11 localities in the northern spur of the Tian Shan, extending roughly from 82° 21' – 87° 25' E longitude. An additional two populations were discovered in the center of a smaller southern spur of the Tian Shan, a range which extends from 82° 20' – 84° 13' E. These populations were initially located between 2,800 – 3,300 m a.s.l.; subsequent surveys have documented populations living as high as 4,100 m. The Ili Pika is found only on these two ridges, and these coordinates define the maximum possible distribution of the species. The Muzate River valley to the west of the southern spur apparently forms the boundary between the Ili Pika and the Large-eared Pika (*O. macrotis*), which is found in mountains farther west. The Ili Pika does not occur in the Bogda Shan (mountains) to the east of Ürümqi, and other investigations have confirmed that it does not extend into the Dzungarsky Alatau Ridge (Formozov 2000).

Most of what we know of the natural history of the Ili Pika comes from investigations conducted by WDL in the decade following their discovery (Li et al. 1988, Li et al. 1991, Li et al. 1993a, 1993b; Li 1997). During this time there were only 27 confirmed identifications of Ili Pikas based on unambiguous sightings in the wild, those collected as specimens, and those collected to initiate a breeding colony. An additional 10 sightings were documented based on interviews with local pastoralists (Li and Smith 2005).

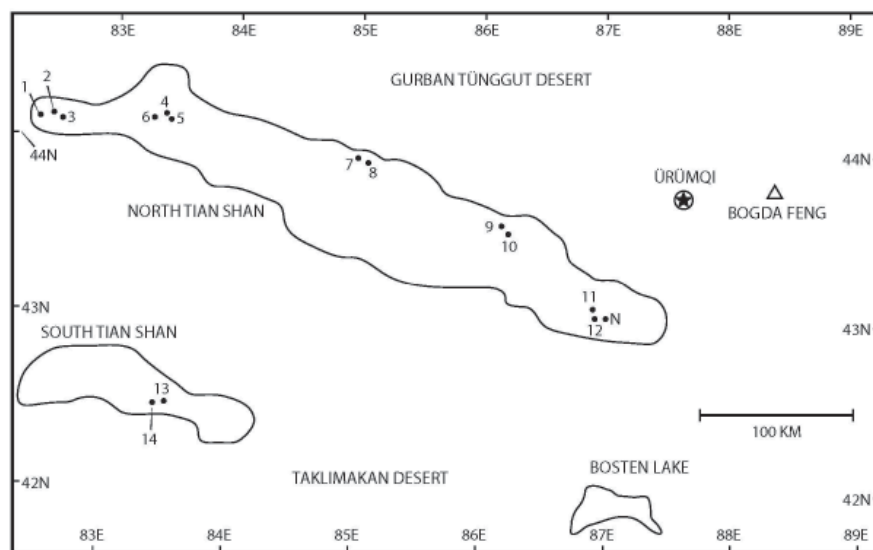


Figure 2. Map of the range of the Ili Pika (*Ochotona iliensis*) and known localities (see Table 1), Xinjiang-Uyghur Autonomous Region, China.

Mountain Region	Site	Map #	Occupancy				
			2002/2003	2006	2010	2014	
Tian Shan North							
	Borohoro	Jilimalale West ^a	1	0	0	0	-
	Jilimalale Central		2	0	0	0	-
	Jilimalale East		3	0	0	0	-
		Jipuk East #1	4	X	0	X	X
		Jipuk East #2	5	X	0	0	X
		Jipuk South	6	0	0	0	0
Illianhalpilga		Bayingou	7	X	X	X	-
		Jingohe	8	X	X	0	-
Hutubi South Mt. Qurgo Valley			9	0	0	0	-
		Qirenbulunhu ^b	10	0	0	0	-
Tianger Mountains		Apex #1 Glacier	11	X	X	X	X
		Shengli Daban	12	0	X	X	0
		#1 East Glacier ^c	N	-	-	-	X
Tian Shan South		Telimati Daban North	13	X	X	X	0
		Telimati Daban South	14	0	0	0	0
Site Occupancy				6/14	5/14	5/14	4/8

^aType Locality

^bNot censused in original surveys; added to surveys in 2002 due to abundant old sign indicating previous occupancy

^cNew site added during 2014 surveys

Table 1. Results of surveys to locate Ili Pikas in the Tian Shan (mountains), Xinjiang – Uyghur Autonomous Region, China. Map # corresponds to study site localities in Fig. 2.

Unlike most rock-dwelling pikas, which occupy talus or loose piles of broken rock, the Ili Pika inhabits slightly sloping large rock walls or cliff faces punctuated with gaps and holes which serve as their dens (Fig. 3; Li et al. 1991). Ili Pikas occupy individual territories at low density. They are asocial, a characteristic they share with other rock-dwelling pikas, but they are less prone to utter vocalizations (Li 1997). Their reproductive rate is low, based on an observation of two young found in a nest (Li et al. 1993b). The daily activity rhythm of Ili Pikas differs from that of most pika species. They appear to be cathemeral – with active periods throughout a 24 hour cycle. Also, they seasonally vary their percent of time active during the day and evening. During winter Ili Pikas are more active during the daylight hours than at night, whereas in spring and fall their nocturnal activity is higher than that during the day (Fig. 4; Li et al. 1993a).

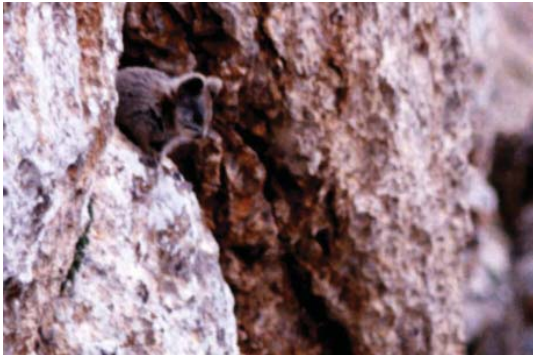


Figure 3. Cliff habitat occupied by the Ili Pika in the Tian Shan, Xinjiang-Uygur Autonomous Region, China.

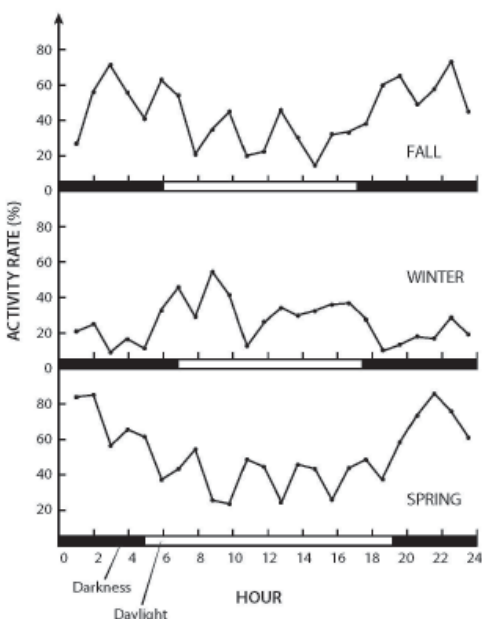


Figure 4. Daily activity level of the Ili Pika in captivity during different seasons (Li et al. 1993a).

Follow-up Investigations

Following these initial investigations, no field work or surveys were conducted on the Ili Pika for a decade. In 2002 and 2003 WDL initiated comprehensive new field surveys to re-examine the population status of the species (Fig. 5; Li and Smith 2005). A research team of 3 – 10 persons travelled 247 km by foot or horseback in seven separate trips encompassing 37 days in the field to determine the status of the Ili Pika at 13 known localities plus one additional site that contained ample sign of previous occupancy of pikas. The team searched not only sites where pikas had been seen a decade previously, but greatly expanded their investigation to include new sites in appropriate habitat. For example, at the type locality, Jilimalale (Flat-topped Mountain) they searched the entire reach extending 20 km from west to east. The results were chilling (Li and Smith 2005). No living pikas were observed, and no active sign of pikas (fresh scat or haypiles; Fig. 6) could be found at eight of the 14 sites. At only two of the sites (Jingohe and Bayingou) was the apparent abundance equal to earlier censuses of the Ili Pika a decade earlier. Pikas were absent from two regions, including the site of the type locality (Table 1), and had apparently declined in all the other sites. We chronicled these findings and discussed the potential causes of decline and the long-term ramifications of the decline in Li and Smith (2005).

Since that finding three additional surveys (2006/2007, 2010, 2014) have been conducted to determine the status of the Ili Pika (Table 1; Fig. 7). In 2006/2007 the field surveys included 3 – 20 investigators who traveled 250 km during 40 field days encompassing eight separate trips to census the 14 known locations of Ili Pikas. The results of this census mirrored the



Figure 5. Weidong Li conducting field surveys for Ili Pikas.



Figure 6. Characteristic sign of active pika occupancy – small round scats in dense accumulations.

previous one, except that only five of the 14 sites showed signs of occupancy, and no living pikas were observed. Four of the previously occupied sites continued to show active pika sign, and one previously vacant site (Shengli Daban) appeared to be re-colonized. Two sites that had pikas during the 2002/2003 surveys (Jipuk East #1 and #2) had no active sign of pikas (Table 1).

In 2010 the 14 known pika localities were investigated by 3 – 8 people who searched for 28 days covering 250 km in seven separate trips. Again no living pikas were observed, and the number of apparently occupied sites was the same: five out of 14. Four sites occupied in 2006/7 showed fresh pika sign indicating pika occupancy, one site (Jipuk East #1) appeared to be re-colonized, and pikas appeared to be extirpated from one site (Jingohe; Table 1).

The most recent survey of the range of the Ili Pika took place in summer 2014 and encompassed seven sites in three regions (Table 1). This census included 3 - 16 people working in the field for 38 days on 10 separate trips covering 150 km. In addition to searching for active sign (fresh scats and haypiles) and attempting to observe living pikas, the 2014 surveys included the placement of ~20 infrared camera traps that ran for periods of 3 – 6 months.

Six camera traps were placed at the Telimati Daban sites in the southern spur of the Tian Shan and monitored for three months (up until the onset of winter, when retrieving them was not possible). These cameras took many images, but none of Ili Pikas. Search efforts were concentrated in areas where pikas had been found previously, as well as thorough investigation at new areas in appropriate habitat. Although one of these sites (Telimati Daban North) had active pika sign in the previous three censuses,

neither it nor the southern site had any evidence of current active pika occupancy. It is highly likely that the Ili Pika has disappeared from the southern spur of the Tian Shan (Table 1).

Five camera traps were placed at the three Jipuk sites, and each site was thoroughly investigated. No active pika sign was observed at Jipuk South, which has remained unoccupied through all of the censuses going back over a decade. However, at Jipuk East #1 there was abundant fresh pika sign, and it was here that the first living Ili Pika in 20 years was observed (Fig. 1). This animal ran across the boot of WDL as he was setting a camera trap. A second Ili Pika was sighted here at a different locality later on the same day. These sightings, the 28th and 29th Ili Pikas to have been seen alive, have attracted significant international media attention (see Arnold 2015, Lu and Hunt 2015). No active sign was found at Jipuk East #2, but twice a camera trap recorded a shadow of a passing Ili Pika, indicating that the species can be found in this area. The camera at this site also recorded two Brown Bears (*Ursus arctos*) and a Beech Marten (*Martes foina*). Thus pikas are still present in the Jipuk region, but the only reliable population appears to occur at Jipuk East #1 (Table 1).

In the Tianger Mountain spur six camera traps were placed, and both sites were examined thoroughly. Here a new distribution site was included in the survey, 7-8 km east of the #1 Glacier site and on the opposite side of the upper valley of the Ürümqi River (herein called #1 East Glacier; Fig. 2). No fresh sign was found at Shengli Daban. Ili Pikas were recorded by the camera traps at the #1 Glacier site (Fig. 8; the cameras also recorded many images of Beech Martens, a natural enemy of the pika). The #1 East Glacier site also contained evidence of Ili Pikas – both videos and images were recorded here (see BBC 2014; Table 1).



Figure 7. Weidong Li instructing citizen scientists before initiating a survey for Ili Pikas.



Figure 8. Camera trap image of an Ili Pika from Tianger Mountain, #1 Glacier, Xinjiang-Uyghur Autonomous Region, China.

Black (melanistic) pikas were recorded by three separate camera traps at different localities during the 2014 surveys. WDL has heard reports of the presence of black pikas in the region for more than 30 years. Black (melanistic) pikas have been reported in several different species of pika in both Asia and North America (*O. alpina* [melanistic pikas comprising up to 20% of the species at some localities], *O. macrotis*, *O. roylei*, *O. curzoniae*, *O. forresti*, *O. princeps*; Ge et al. 2012). The Black Pika (*Ochotona nigritya*) was named in 2000, only to be later synonymized with Forrest's Pika (*O. forresti*) as a melanistic form (Ge et al. 2012). Thus, it appears that within the genus switches involved in producing melanistic forms commonly occur. One hypothesis is that these sightings of black pikas represent a second species found within the range of the Ili Pika. However, no specimens have been collected, and we are reticent at this time to disclose the localities of these observations, as indiscriminate trapping to catch a black pika could jeopardize already low populations of Ili Pikas. What can be observed from the images on the camera traps is that the black pikas appear to be larger and are lacking a hair pad on their back legs, a characteristic of Ili Pikas. On the other hand, a parsimonious conclusion could be that these sightings represent melanistic Ili Pikas, and that only one species occurs in these two spurs of the Tian Shan.

Current Status of the Ili Pika

Since their discovery, several populations of Ili Pikas have become extirpated as documented by several comprehensive surveys of known prior occupied localities (Table 1). And qualitatively, the abundance of active sign, even in sites that

we record as currently having Ili Pikas, has decreased greatly since the early investigations of the species in the late 1980s. Additionally, one of the sites we list as being occupied in 2014 is, in fact, quite marginal: the shadows of pikas being caught by a camera trap at Jipuk East #2. The overall population of Ili Pikas is a small fraction of what it was in the 1980s when it was discovered. Given their low density and the difficulty of locating sign and individuals, it is impossible to quantify the extent of this decline. Given what we know of the region and the availability of suitable habitat, we estimate that the Area of Occupancy (AOO) has declined from a baseline of 17% of the Extent of Occurrence (EOO; see IUCN Red List 2014) in the two ranges of the Tian Shan where the Ili Pika occurs, to an AOO of 5%. Thus the Ili Pika population is only about one-third of that found in the mid-1980s.

Why has this species, found in such a remote mountainous area, declined so precipitously in such a short period of time? We considered several factors in Li and Smith (2005). There is no evidence of disease causing the decline, and the very low population density of the pikas would make disease transmission unlikely in any case. The most likely direct cause of the decline appears to be an increase in the utilization of forage in the Tian Shan by pastoralists and their livestock. Sheep grazing has intensified throughout the period during which the pikas have been investigated, leading to overgrazing of meadows on which the pikas rely for food (Fig. 9). And the overall disturbance of the pastoralist population, including the presence of a new carnivore – the omnipresent mastiff dogs – may have led to direct mortality of pikas. People now occupy the highest reaches of the Tian Shan and its high plateaus, which were unoccupied in the 1980s.



Figure 9. Contemporary grazing of sheep on meadows in the range of the Ili Pika in the Tian Shan (mountains), Xinjiang-Uyghur Autonomous Region, China.

Most insidious as a potential factor driving the loss of Ili Pikas is the effect of climate change. Initial sightings of the Ili Pika were made at elevations between 2,800 – 3,300 m a.s.l. More recent evidence of their occupancy extends as high as 4,100 m. As pikas live on cliff faces, they may now be more likely to go uphill to forage and onto high plateaus which are newly occupied by pastoralists, thus compounding any effect of climate change. Much more research will be necessary to examine the effect of climate change on the Ili Pika, as well as the potential relationship between the Ili Pika and the black (melanistic) form that also occupies its range.

From a regulatory perspective, the Ili Pika is listed as Endangered (EN A2abc; C2a(i); population declining; ver 3.1; Smith and Johnston 2008) on the IUCN Red List, and perhaps this threat level should be changed to Critically Endangered. However, within China, where the species exists, there is a lack of official recognition for the Ili Pika as well as other range-restricted pikas. The Ili Pika is not included on China's List of Wildlife under Special State Protection — part of the country's 1988 Wildlife Protection Law. Most immediately, critical areas currently occupied by the Ili Pika should be protected, and grazing eliminated, until we understand more about the species' decline such that conservation biologists can formulate an active plan for recovery of the species.

Acknowledgements

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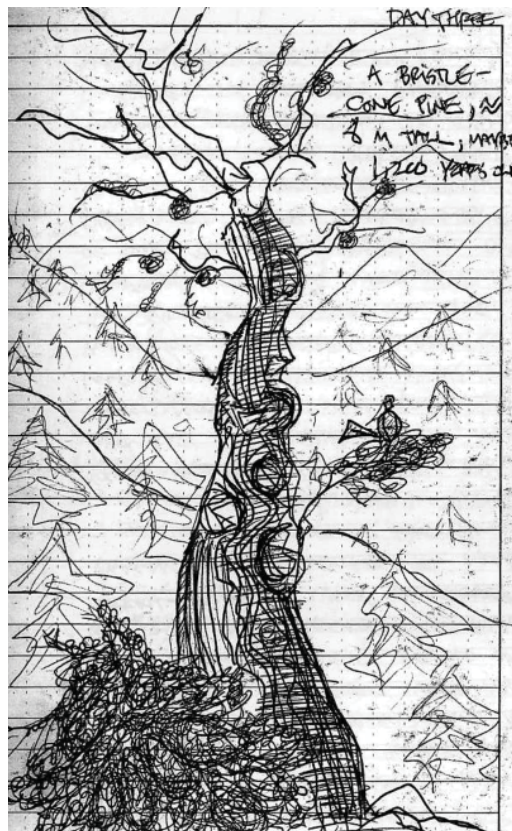
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Bristlecone pine, White Mountains, California,
May 2007. Andy Bustin

Jim Bishop wrote this article for a recent newsletter of the White Mountain Research Center, and I thought it would interest the broader CIRMOUNT community. With slight changes and support from WMRC newsletter editor, Denise Waterbury, I include Jim's piece here. —Editor

Monitoring White Mountain Alpine Plants for Impacts of Climate Change; A Page from the California GLORIA Field Notes

Jim Bishop

California/Nevada GLORIA and California Native Plant Society, Oroville, California



Figure 1. Raspberry buckwheat on dolomite, White Mtn. in the distance. Photo: Stu Weiss

A group of determined investigators trudges upward above the last of the bristlecone pines, climbing toward a summit that will be their workplace for the day. Cold wind urges closed zippers and upturned collars. At their feet are hardy and beautiful alpine plants, living in a world of less wind and greater warmth than the hikers (and trees) feel. On the peak they'll outline plots with string and spend the day identifying the plants, characterizing

their abundance and distribution, taking photos, and burying temperature loggers...much of the day spent staring at the ground or hunched over windblown data sheets. If thunderstorms don't shorten the field day too much, they should complete the summit by day's end and return to Crooked Creek Station with priceless data on dozens of sheets.

The upper limit that trees reach is imposed by the average temperature of their environment. Above that point there is insufficient warmth during the growing season to allow them to persist...basic processes of cell construction and growth being too retarded by the low temperatures. A very plausible low-temperature effect on cell development is on the slowing of "molecular motors" that convey materials throughout the cell on the cytoskeletal framework, because they are critically dependent on thermal energy for their motion.

Yet alpine plants do grow above the trees. Their main trick is to remain low-stature, taking advantage of solar heating and minimizing airflow-induced cooling to achieve sufficient warmth for growth. Many alpine plants avoid the worst of winter's bitter cold under the snowpack. The alpine flora prevails in

microclimates of sufficient warmth and shelter, where cold air and lack of soil keep trees at bay. It is a very climate-sensitive ecosystem, vulnerable to the ascent of trees, the loss of habitat with upward migration, and dependent on the snowpack. For the most part they are undisturbed by human influence. Worldwide, alpine zones span latitudes from polar to tropical, elevations from a few hundred meters to over 5000 meters, and maritime as well as continental climates. It is an ideal place to look for effects of climate change on living things.



Figure 2. Alpine flowers found in the White Mountains. Photo: Catie & Jim Bishop

To best observe impacts of climate change on the alpine flora and its diversity, an international program was born at the University of Vienna, the GLobal Observation Research Initiative in Alpine Environments, 'GLORIA'. The North America chapter was initiated by Connie Millar (USFS) and Dan Fagre (USGS); the first sites being established in 2004 in the White Mountains and the central Sierra Nevada, CA, and at Glacier National Park, MT. The basic protocol involves carefully observing the plant species, their coverage and distribution, in the zone that occupies the top 10 meters of the peak. The survey also incorporates temperature sensors buried 10 cm deep that record for years, and extensive photo-documentation of the plants and the survey system. Presently seven summits in the White Mountains are systematically surveyed every 5 years.



Figure 3. Laying out the original survey system. Photo: Jim Bishop

The White Mountain Research Center is deemed a GLORIA “world master site”. Here related studies in alpine ecology, climate, forest ecology, mammalogy, and geomorphology supplement the GLORIA alpine plant surveys. Such studies include insects, a butterfly count, periglacial processes, detailed temperature observations over the terrain, mapping of upper treelines and shrublines, forest

demography, and studies on the effects of climate on mountain mammals (pika, marmot). The potential for mutually beneficial science catalyzed by that WMRC-GLORIA based collaboration is great.

Two important additions to the GLORIA methodology were developed in the White Mountains, and are now defined and available in the international protocol. It was realized early on that the estimates of plant cover in the large survey plots were too inaccurate, and that the quantitative measures in the quadrat plots covered too small an area. So a 10mX10m plot was developed that contains 400 survey points on a half-meter grid, and that plot gives good quantitative measures over a larger and more representative area. While the summit plots are important, it was essential to know more about the distribution of plants



Figure 4. Plant identification, data-taking, and documentation. Photos: Catie & Jim Bishop

below the summits to best interpret GLORIA observations, and desirable to be able to quantify shifts in plant-population distributions. A series of “downslope surveys” was done on 5 of the slopes in the White Mountains. At each 25-meter step below the summit a 100-meter belt transect is laid out along-contour, which duplicates the area and sample-point distribution of the 10mX10m plots. The set of downslope surveys spans the elevation range from the summit of White Mountain down into the bristlecone pine woodland and the sagebrush shrublands.

One set of White Mountain summits has now been resurveyed at 5 and 10 years, and the other set at 5 years (the 10-year resurvey there this summer). Physical aspects of climate-change trends emerge on decadal timescales, but even the short-term GLORIA results are interesting. For one thing they confirm the replicability of the survey protocol, with resurveys showing essentially the same species richness (to be expected with alpine plants being predominantly long-lived perennials). They reflect some of

the short-term change that is imposed on long-term trends, such as fluctuations in annual plant occurrence and some shrub mortality in low-snow winters. And we may well get some ecological surprises with our 5-year resurveys.



Figure 5. GLORIA field team gets organized. Photo: Connie Millar

The White Mountain Research Center is a key focus of this important international program. Additional information can be found on CIRMOUNT’s webpages on the North American chapter of GLORIA: http://www.fs.fed.us/psw/cirmount/gloria/north_america/california.shtml.



Figure 6. Fieldwork done, the team heads down from White Mountain Peak. Photo: Connie Millar

BREVIA

Anthropogenic Increases in Dust Emissions Tied to Increase in Lake Productivity

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*Brahney, J., Ballantyne, A. P., Kociolek, P., Spaulding, S., Otu, M., Porwoll, T., and Neff, J. C. 2014. Dust mediated transfer of phosphorus to alpine lake ecosystems of the Wind River Range, Wyoming, USA. *Biogeochemistry* 120:259-278.*

*Brahney, J., Ballantyne, A.P., Kociolek, P., Leavitt, P.R., Farmer, G.L., and Neff, J.C. 2015. Ecological changes in two contrasting lakes associated with human activity and dust transport in western Wyoming. *Limnology and Oceanography* 60:678-695.*

Anthropogenic activities have altered the atmospheric transport of key nutrients causing ecological disturbances that transcend political and geographic boundaries. The effects of nitrogen deposition in both terrestrial and aquatic environments are generally well understood and studied (Baron 2000, Elser et al. 2009). A lesser appreciated impact is the effect of atmospheric dust deposition on aquatic ecosystems. Over the last two decades, dust emissions have increased in many regions of the western US, and in some areas by up to 400% (Brahney et al. 2013). Increased

wind speeds have contributed to the transport of soils (Brahney et al. 2013, Flagg et al. 2014), whereas the destabilization of soils, making them available to wind transport, has increased through agriculture, pastoralism, and industry (Neff et al. 2008, Field 2009, Lee et al. 2012). The effects of dust deposition on alpine lakes can be challenging to determine because dust is not routinely measured, and because nitrogen and dust deposition may be co-occurring in a variety of western US locations. Many mountain ranges in western states are downwind of urban, industrial, and agricultural sources of N as well as arid and semi-arid regions that regularly produce dust storms (Power et al. 1999, Painter 2007).

Dust has the capacity to transport nutrients, in particular phosphorus, in both organic and inorganic constituents (Lawrence and Neff 2009b). Dust can also contain up to 35% carbonate minerals (Lawrence and Neff 2009a), which can affect the alkalinity of the deposition environment (Morales-Baquero et al. 2006, Pulido-Villena et al. 2006). Because alpine lakes are

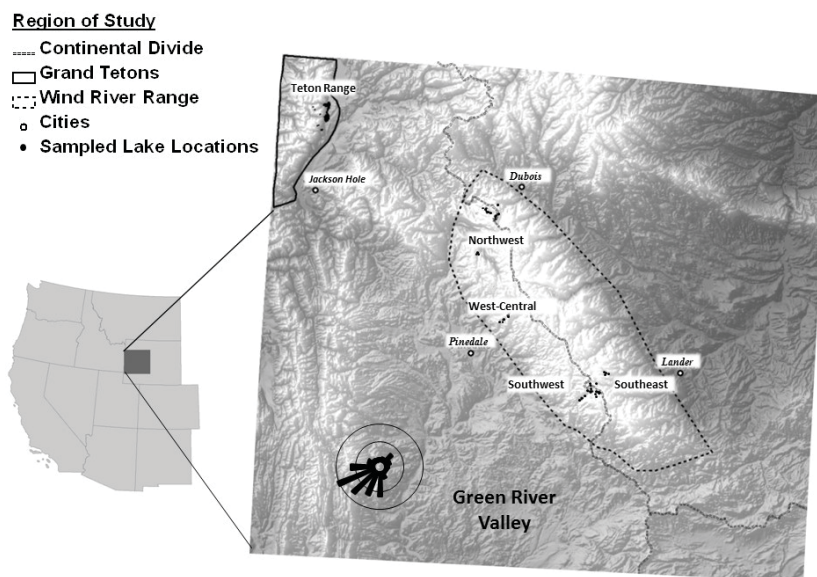


Figure 1. The Wind River Range and the Teton Range sampling areas in western Wyoming. Black circles represent the 32 lakes that were sampled in this study. The primary dust source, the northern portion of the Green River Valley, is located to the south and west of the Wind River Range. Wind rose data from the Western Regional Climate Center (1985-2014; Kopáček et al. 2011).

nutrient poor, and receive a large fraction of their nutrients from the atmosphere, relatively small changes in deposition can mean large changes in nutrient subsidies and acid neutralizing capacity (Psenner 1999, Pulido-Villena et al. 2006, Mladenov et al. 2009). We explored the potential for dust induced ecosystem change through 1) examining spatial changes in lake water chemistry and biology along a gradient in dust deposition in the Wind River Range, Wyoming, and 2) through retrospective sediment core analyses.

The Wind River Range afforded a unique opportunity to study the effects of atmospheric deposition because the dust source, the Green River Valley, is proximally located to the south-west of the range (Fig. 1). Due to the juxtaposition, the southwestern region is more heavily impacted by dust than the northern region (Dahms 1993). In addition, the range is composed predominantly of Archean granitic rocks (Frost et al. 1998) that are distinctly different from the Eocene sedimentary sequences found in the Green River Valley, which are composed of sandstone, siltstones, limestones, evaporates, and volcanic ash layers (Sullivan 1980). The geologic differences make isotopic and mineralogical separation of the Green Valley dust source from the local bedrock possible.

The Deposition of Phosphorus in the Wind River Range

Using bulk deposition samplers, we found dust deposition rates were highest in the southwest region of the range at $9.2 \text{ mg m}^{-2} \text{ day}^{-1}$, more than three times higher than deposition rates in the northwestern region at $2.9 \text{ mg m}^{-2} \text{ day}^{-1}$. These rates are low- to

mid-range as compared to other alpine regions that receive dust (Deangelis and Gaudichet 1991, Aguilera et al. 2006, Lawrence 2010). The dust collected in the Wind River Range had a phosphorus content of 3.0 mg g^{-1} , giving a dry P deposition rate of $27.6 \mu\text{g P m}^{-2} \text{ day}^{-1}$ over the summer season in the southwest and $87 \mu\text{g P m}^{-2} \text{ day}^{-1}$ in the northwest. These relatively high values are due to both the sizeable concentration of organic material in the dust (40%) and to the presence of the mineral apatite ($\text{Ca}_5(\text{PO}_4)_3\text{OH}$) (Dahms 1993). While phosphorus from the organic fraction is readily available to contribute to the nutrient pool, apatite phosphorus is not generally considered a significant source of phosphorus to lakes (Wetzel 2001). However, it has been shown that algae and bacteria can solubilize natural apatite at higher pH levels, especially if the apatite is made available at smaller grain sizes (Smith et al. 1978). Therefore, the fine-grained apatite from atmospheric deposition is a potential source of P to aquatic communities, though some fraction likely remains occluded.

Regional Differences in Lake Chemistry and Biology

To evaluate spatial differences in lake chemistry, and to relate these differences to either variation in local catchment properties or to atmospheric deposition, we sampled from the deepest section of each lake, water from the upper meter of the lake, and the top one cm of the lake sediments. We also sampled catchment bedrock across the range. Our chemical analyses focused on elements that have high atmospheric concentrations, specifically P, Ca, Cd, Cu, Sb and Pb deposition (Marx et al. 2005, Lawrence and Neff 2009b, Reynolds et al. 2010). To evaluate post-hoc

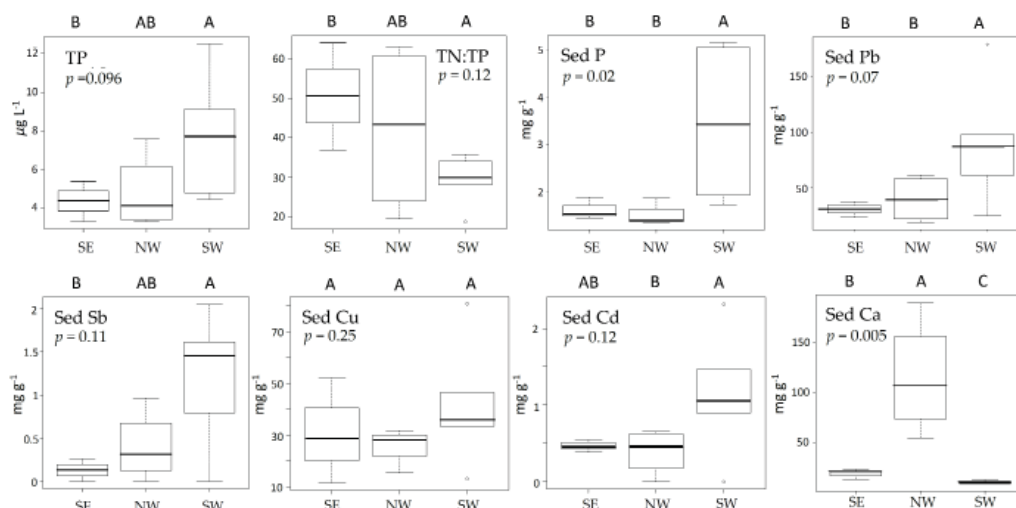


Figure 2. Box-plots of alpine and subalpine lake water and bulk sediment concentrations of select elements across three regions of the Wind River Range. Letters indicated significant differences between regions using a non-parametric post-hoc contrast test ($p < 0.05$). Overall Kruskal-Wallis significance is shown in each plot. Southwest, $n=6$, Northwest $n=4$, Southeast $n=4$

significant differences between regions, we used a non-parametric relative contrast effect test in R ($\alpha=0.1$). The test uses a Tukey test with p-values computed from a one-tailed t-test (Konietschke et al. 2012).

In the southwestern region of the range we found that alpine lakes had significantly greater total dissolved phosphorus concentrations (TDP) ($5\text{--}13\ \mu\text{g L}^{-1}$), particulate phosphorus (PP) concentrations ($2\text{--}5\ \text{mg g}^{-1}$), and sediment phosphorus (SP) concentrations ($2\text{--}5\ \text{mg g}^{-1}$) (Fig. 2). Lake sediments also had significantly higher concentrations of Pb, and higher concentrations Sb, Cu, and Cd (Fig. 2). In many mountain systems lake TDP is positively related to catchment vegetation because DOC facilitates the transfer of P to lake systems (Birck 2013). In the alpine region of the Wind River Range we find that P concentrations were correlated to factors that facilitate the transport of dust-P to the lake basin. Our analyses showed that none of the lake P measurements (TDP, PP, SP) were correlated to the amount and/or type of catchment vegetation or soil, but significantly and positively correlated to percent bare rock and steepness. Further PP was correlated to regional dust deposition indicators including Ca and ANC. These relationships suggest that normal controls on catchment P export to lakes (i.e. DOC) are overridden in bare catchments because soils cannot effectively retain the deposited P.

Calculations based on $^{143}\text{Nd}/^{144}\text{Nd}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ isotopes from the North Lake catchment, a steep and rocky basin, suggested that approximately 30% of the dust material deposited over the entire catchment was delivered to the lake, which has the potential to transfer appreciable amounts of P. The steep bare nature of these high altitude catchments combined with high summer precipitation creates an environment where deposited material is more likely to be transported into the water column as opposed to remaining in the catchment. What this suggests is that steep rocky watersheds have the smallest capacity to take up atmospherically deposited P, and therefore have a lower capacity to ameliorate the effects of atmospheric nutrient deposition.

Lakes in the southwestern region not only had relatively high phosphorus concentrations but distinct diatom communities and plankton biovolume measurements were two orders of magnitude greater than the alpine lakes in the north, and even higher than the lower elevation lakes in the same region. This finding is significant because although dust-P concentrations are high, dust deposition rates in the Wind River Range are in the lower 20th percentile of global measurements that range from <0.1 to $>100\ \text{g m}^{-1}\ \text{yr}^{-2}$ (Lawrence and Neff 2009b), yet this deposition rate appears to be substantial enough to induce ecologically relevant changes.

Dust Deposition through Time

Our spatial analyses revealed significant differences in the biogeochemistry of dust impacted and non-impacted lakes, however, it is not clear how these differences relate to historical conditions. We selected two lakes for multi-proxy sediment cores analyses from two locations in the range. For brevity, we will only discuss the results of North Lake, a dust impacted lake in the southwestern region. We used neodymium ($^{143}\text{Nd}/^{144}\text{Nd}$) and strontium ($^{147}\text{Sm}/^{144}\text{Nd}$, and $^{87}\text{Sr}/^{86}\text{Sr}$) isotope ratios from dust and local bedrock samples to separate exogenous from local material in the North Lake sediments (Grousset and Biscaye 2005, Lawrence 2010). Cores were dated using ^{210}Pb and radiocarbon and were also analyzed for geochemistry, diatom accumulation rates and species composition, diatom inferred TDP, algal pigments, and carbon and nitrogen elemental and isotope concentrations.

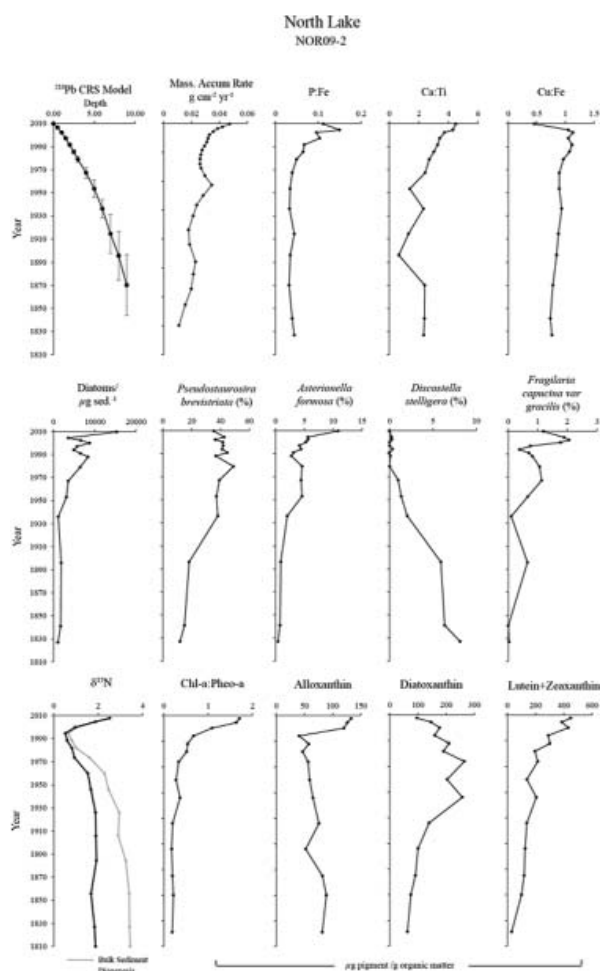


Figure 3. Sediment profile data for the North Lake gravity core (NOR09-2), including the ^{210}Pb constant rate of supply model (CRS) and associated mass accumulation rates, geochemistry, nitrogen isotopes, and representative diatom and pigment results.

Sediment core analyses indicate that prior to a recent rise in dust flux phosphorus concentrations and diatom species composition were similar to those found in other alpine lakes in the region. Concomitant with a ~50 fold increase in dust flux to the sediments circa 1940, sediment proxies revealed an increase in mass accumulation rates, a 2-3 fold increase in normalized sediment phosphorus content, an increase in the diatom-inferred total dissolved phosphorus concentration from ~4 to 9-12 $\mu\text{g L}^{-1}$, a ten-fold increase in diatom production, shifts in algal species composition including an increase in *Asterionella formosa*, and a relative increase in cyanobacteria abundance (Fig. 3).

To consider the potential causes of the recent increases in dust deposition, we evaluated the relationship between regional climate and increases in dust deposition, including precipitation, the Palmer Drought Severity Index (PDSI), temperature, and wind speeds. We evaluated the potential role of human land-use changes on soil disturbance by comparing the historical dust deposition record to statistics on land-use upwind in the Green River Valley.

Oil and gas operations are the main industrial activity in the Green River Basin. Fugitive dust is emitted during the construction of well pads, drilling, and throughout the lifetime of the well (BLM 2008). We estimate potential regional emissions from Trona mining bases on the annual production in metric tonnes (BLM 2014).

We found no significant relationships for climate factors and dust deposition in the North Lake sediment core, in fact, precipitation increased though this time period. We do however find strong and significant relationships between calculated total suspended particulate (TSP) emissions from oil and gas well operations ($r^2=0.79$, $p<0.0001$) and Trona production ($r^2=0.45$, $p<0.005$) (Fig. 4). With respect to the oil and gas industry, the first well was drilled in 1923, by 1940 TSP had risen to over 100 metric tonnes per year (mta) and culminated to an initial peak of 1021 mta in 1963. TSP emissions then drop to between 500-800 mta before beginning to rise again in the late 1980's, peaking in 2008 at 6589 mta (Fig. 4). Trona mining began in 1950 and production rose rapidly through the 1960's, 70's, and 80's eventually stabilizing at just under 2×10^7 mta (Fig. 4).

The historical intensity of industrial activities adjacent to the Wind River Range parallel the 1) calculated dust flux to the North Lake basin based on $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ isotopes, 2) sediment phosphorus concentrations, 3) the diatom inferred phosphorus concentration, and 4) the Ca:Ti ratios in sediments. The temporal consistency of these events strongly suggests that dust is contributing significantly to the phosphorus and calcium budgets of lakes in the southwestern portion of the range. Both diatom and pigment proxy data indicate substantial and recent changes in the plankton species community. Of some importance, the data indicate increases in cyanobacteria and *A. formosa* populations in North Lake, both possibly due to increased

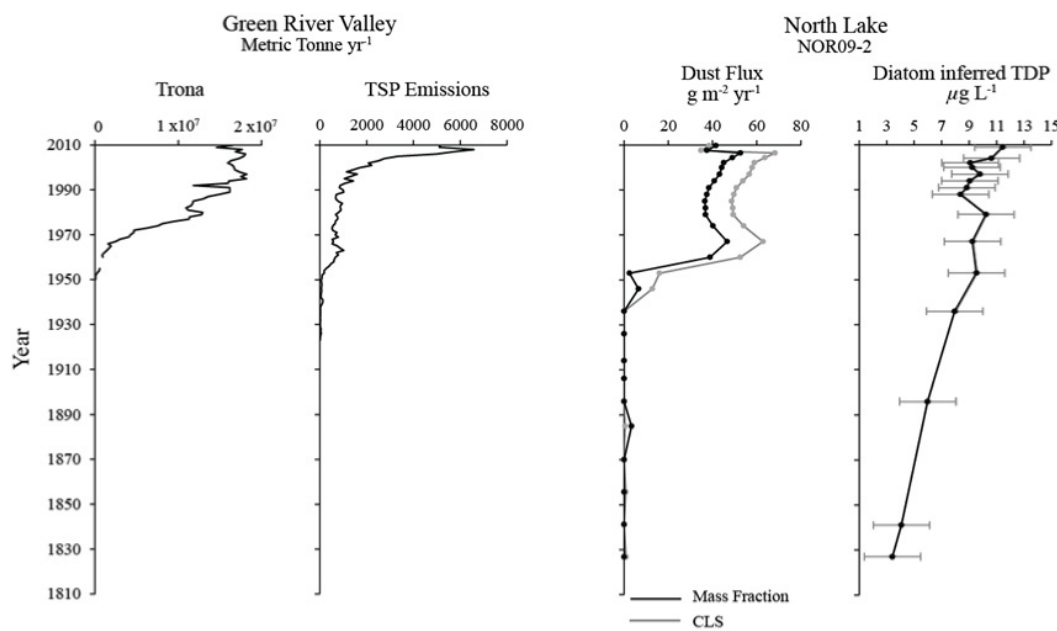


Figure 4. Calculated TSP emissions and Trona production for the Pinedale Anticline shown alongside the calculated dust flux in North Lake sediments based on isotope mass fraction calculations (black line) and constrained least-squares analysis (grey line), and the diatom inferred total dissolved phosphorus concentrations in the North Lake short core (NOR09-2).

phosphorus and/or carbonate loading. These particular shifts in plankton populations can have negative consequences for higher trophic levels. Cyanobacteria and *A. formosa* are both low quality food items for zooplankton that result in low fecundity and diminished growth rates (Balseiro 1991, Wilson 2006).

Although the recent changes to dust and nitrogen deposition are still relatively modest, the biogeochemical and biological implications are not. During the period from 1940 to 2008, North Lake underwent a shift from oligotrophic conditions ($3\text{--}5\ \mu\text{g P L}^{-1}$) to mesotrophic conditions ($12\text{--}14\ \mu\text{g P L}^{-1}$). In addition to having higher dissolved phosphorus concentrations, North Lake had 5x the particulate concentration of phosphorus than lakes in other regions (Brahney et al. 2014). These changes are associated with broad shifts in plankton communities from compositions similar to regions elsewhere in the range to distinct populations with lower food quality value. Dust and nitrogen deposition in general compromise water quality through increased nutrient and heavy metal concentrations. Further, the observed shift in algal species composition and decline in diversity affects food quality for species at higher trophic levels.

A growing number of studies are showing the effects of atmospheric deposition on alpine aquatic habitats. Data from this study and other lake sediment studies suggest that in the western USA there are large recent increases in dust deposition to lake ecosystems (Neff et al. 2008, Reynolds et al. 2010), and that increases in dust flux can broadly influence mountain lake biogeochemistry (Morales-Baquero et al. 2006, Ballantyne et al. 2010). Because dust often contains appreciable amounts of phosphorus (Lawrence and Neff 2009b) there may be substantive increases to the phosphorus nutrient budget in many alpine regions that receive dust. At present, there are no national networks capable of capturing large scale changes in dust emissions. This is because national atmospheric deposition networks do not measure particles above $10\ \mu\text{m}$ and desert dust is often made up of larger particles (Lawrence and Neff 2009b, Molotch et al. 2009). In areas near deserts, these larger particles can contribute 50% of the particle concentrations (Lundgren 1984). This means that dust phosphorus deposition may be unrecognized by current monitoring networks and thus an underappreciated cause of ecosystem changes to high elevation lakes in the western US. Our observations, combined with others across western North America and Southern Europe provide a consistent conceptual model by which arid ecosystems when disturbed by climate, humans, or both are vulnerable to widespread soil loss that can be transported to nearby alpine ecosystems supplying them with both nutrients and pollutants.

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BREVIA

Understanding the Snow Albedo Feedback over the Colorado Headwaters Region

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Letcher, T.W. and Minder, J.R. In review. Characterization of the simulated regional snow albedo feedback using a regional climate model over complex terrain. Journal of Climate.

Land regions with transient snow cover are particularly sensitive to climate change through the snow-albedo feedback (SAF). As the climate warms, snow cover is reduced on the margins of the snow pack, thus reducing the local surface albedo. This albedo reduction increases the absorbed shortwave radiation resulting in enhanced warming of the surface and lower atmosphere. Mid-latitude mountain ranges are especially sensitive to the SAF as these regions can accumulate large snowpacks that persist well into the spring and summer when solar insolation is near its peak strength. The SAF has important implications for regional climate change in the mountains that make up the Colorado Headwaters region (outlined in Fig.1, hereafter “HW region”), as water management strategies in the Western US are highly dependent on seasonal snowpack and its impact on streamflow.

We make use of a pair of regional climate simulations using the Weather Research and Forecasting (WRF) model to characterize and quantify the SAF within the HW region. WRF was run with high resolution (4km horizontal grid) for an 8-year period between from 2000-2008 (Ikeda et al. 2010, Rasmussen et al. 2011, Rasmussen et al. 2014). To predict snowpack and surface conditions WRF was coupled to the Noah land surface model (LSM), with modifications to the snow model component from Barlage et al. (2010). A control simulation was conducted, using the North American Regional Reanalysis dataset for model boundary conditions. Additionally, a pseudo-global warming (PGW) experiment (Schär et al. 1996) was conducted, wherein an idealized climate perturbation was applied to the reanalysis boundary forcing. This experiment simulates the same synoptic conditions (e.g., storms and large-scale circulations) as the control, but under a shifted climate representative of global climate model projections of the 2050's (RCP 8.5 scenario, 10-year mean centered on 2055).

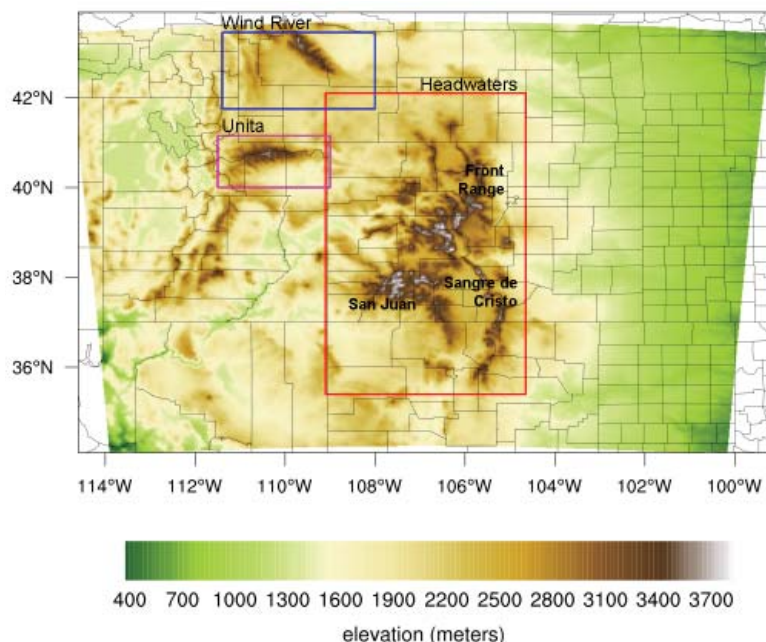


Figure 1. Model domain with 4km topography. Analysis regions outlined.

We first characterize the SAF in these simulations by examining spatial patterns of changes (PGW-control) in surface temperature, T_s , and fractional snow cover, f_{sc} (Fig.2), focusing on March–June when the SAF is most active over the HW region. In general, warming is strongly enhanced over regions of snow loss, suggesting that the SAF is the primary cause of regional variations in climate warming. However, areas of enhanced warming typically extend beyond areas of snow loss, suggesting transport of SAF-enhanced warming by atmospheric circulations is also important. The most widespread warming occurs over the low-to-middle elevations during March and April. As the spring progresses into May and June, the regions of enhanced warming shrink and shift to higher elevations following the snow margin as it retreats.

To better quantify the strength and variability of the SAF we apply a regional linear feedback analysis (modified from Qu and Hall, 2007). In this analysis, the strength of the SAF is quantified as the change in top of the atmosphere radiative solar energy flux per Kelvin of surface warming caused by changes in snow cover (units of $W\ m^{-2}\ K^{-1}$). Figure 3 shows the seasonal cycle of SAF strength averaged over each of the three domains outlined in Fig.1. There is a clear spring maximum in SAF strength within the HW region with mean of $\sim 4\ W\ m^{-2}\ K^{-1}$ in April. The

peak SAF strength occurs in April for the Wind River and Uinta Mountains as well. There is a secondary, but weaker, maximum in SAF strength during the fall. Both maxima correspond with times when the surface temperature is close enough to $0\ ^\circ C$ that modest warming affects both the precipitation phase and the snowpack ablation rate. The spring maximum is substantially stronger than the fall maximum due to stronger solar insolation during the spring relative to the fall. Year-to-year variability in SAF strength is quite large in March–May, when snow cover at low and mid elevations is most dependent on highly variable weather conditions that are specific to each winter.

Interesting variations are also found between geographic regions and model configurations. The spring SAF is stronger, and persists later into the summer in the Uinta and Wind River regions relative to the HW region in part because of their higher elevations that allow them to maintain larger fractional snow cover into the late spring and early summer. Results from the base 4 km simulation were compared to two lower-resolution simulations (12 and 36 km grid-spacing). Shifts in the timing and magnitude of the SAF occur when the grid spacing is coarsened to 36-km (not shown), suggesting biases in the SAF exist in regional climate simulations over complex terrain that do not utilize high-resolution.

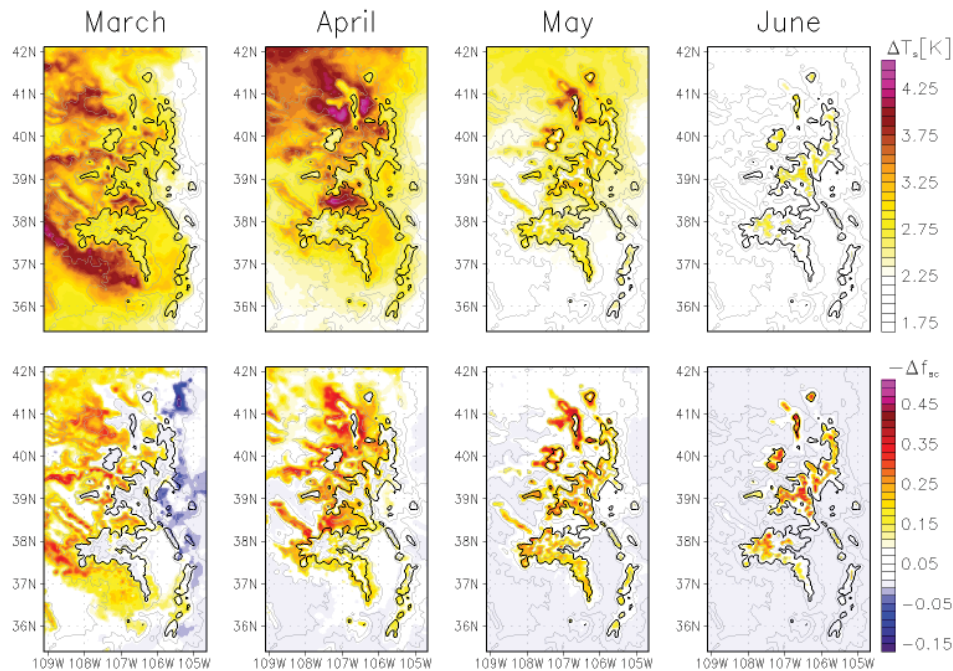


Figure 2. Change (PGW-control) in surface temperature (T_s) and fractional snow cover (f_{sc}) over the "Headwaters" region (Fig. 1). 7-year monthly mean values are plotted. Light gray contours show the topography. The thick black line shows the 3000m elevation.

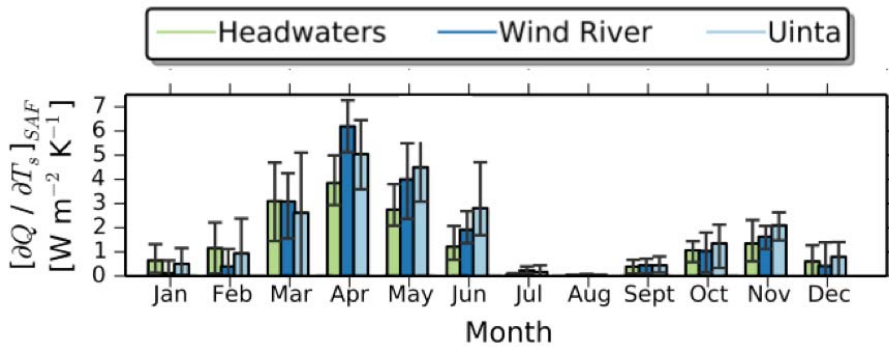


Figure 3. 7-year monthly mean SAF strength. Whiskers show the 10th-90th percentile of year-to-year variability.

There is still a need for greater observational constraints on these results. Currently, we are working to compare WRF-simulated snow cover with satellite-based estimates using the MODIS MODSCAG algorithm (Painter et al. 2009). Preliminary analysis indicates that snow cover extent in WRF compares well to MODIS observations, however, WRF tends to overestimate the sub-pixel snow cover fraction at high elevations. This is consistent with findings from a recent study by Wrzesien et al. (2014) over the Sierra Nevada. Such biases suggest that the model's simulated SAF is likely artificially large. The biases are likely due to shortcomings in the treatment of canopy-snow-radiation interactions in the model. An evaluation of simulations with a more-advanced treatment of these processes is underway.

Overall, the analysis presented here provides a better understanding of the regional SAF over the interior mountain west. It demonstrates that the SAF is the dominant mechanism shaping spatial variations in simulated climate warming over the region's complex terrain. The methodologies described here can be applied to other regional climate modeling experiments to further expand understanding of the SAF over complex terrain and how it varies between model configurations, mountain ranges, and climate scenarios. Current work is investigating the interactions between the SAF and regional atmospheric circulations.

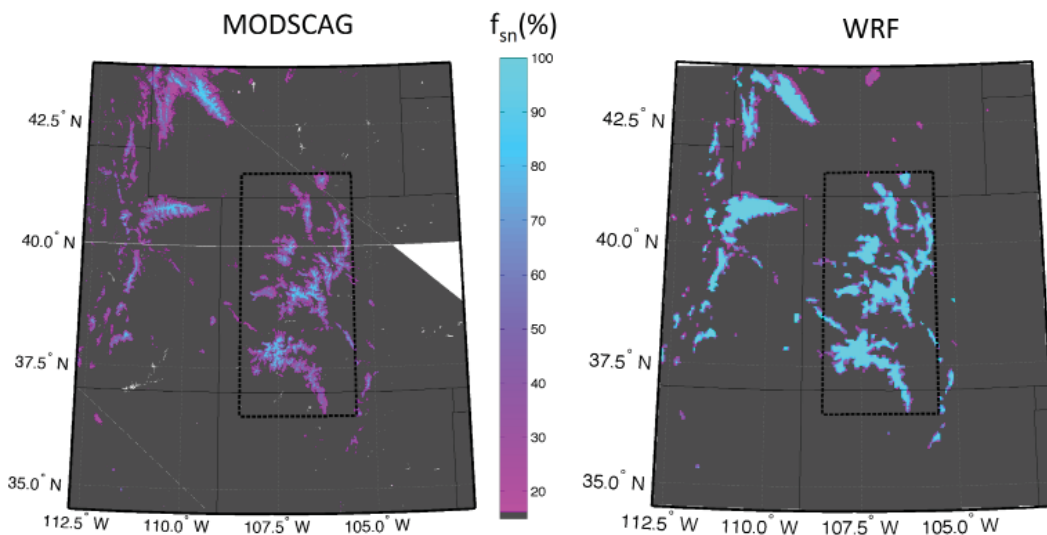
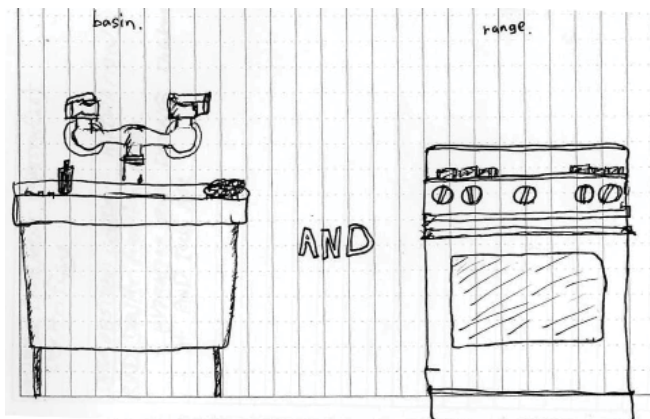
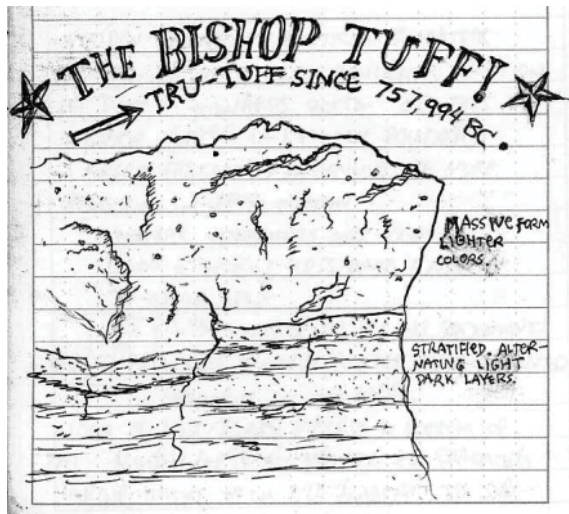


Figure 4. Comparison between MODSCAG-estimated and WRF-simulated fractional snow cover (f_{sc}). Comparisons are based on averages from 9-29 May 2005.

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Bishop Tuff and field note doodles, Long Valley, eastern Sierra Nevada, Great Basin of California, May 2006. Mike Harpring

BREVIA

The Pika and the Watershed

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Wilson, M.C., and Smith, A.T. 2015. The pika and the watershed: the impact of small mammal poisoning on the ecohydrology of the Qinghai-Tibetan Plateau. Ambio 44:16-22.

The mountains of the world play a key role in hydrologic regimes, but perhaps none are as critical as the effect of the Qinghai-Tibetan Plateau (QTP) on downstream watersheds. Occupying 2.5 million km², a quarter of the land area of China, the QTP is locally referred to as “China’s Water Tower.” Many of the world’s great rivers (Huang He, Yangtze, Mekong, etc.) have their source in the QTP, and conservative estimates suggest that approximately 20% of the world’s human population live in its downstream watersheds (Xu et al. 2009, Immerzeel et al. 2010). However, the grasslands of the QTP, which regulate the headwaters of these rivers, are becoming increasingly degraded (Zhou et al. 2005, Harris 2008, 2010). One agent of change is over-grazing by domestic livestock (yak, sheep, goats; Harris 2010), which has resulted in elevated population densities of a native small mammal, the Plateau Pika (*Ochotona curzoniae*; Shi 1983, Fan et al. 1999, Holzner and Kriechbaum 2001, Zhou et al. 2005, Harris 2010, Dong et al. 2013, Li et al. 2013). Presence of high-density pika populations on degraded grassland has led local authorities to classify them as pests and initiate poisoning campaigns in an attempt to restore grassland quality. Poisoning began in 1958, and the first wide-spread attempts to control pika populations were initiated in 1962 with applications of the rodenticide zinc phosphide (Smith et al. 1990, Fan et al. 1999). By 2006 an area of 357,060 km² had been poisoned in Qinghai province alone (An 2008). More recently poisoning operations utilizing type C botulinum toxin were a central feature in the allocation of a special 7.5 billion yuan (\$925,000) fund for management in the recently gazetted Sanjiangyuan National Nature Reserve in Qinghai province from 2007-2010 (Ma 2006). This poisoning has gone on for over five decades, is massive in scale, and has not improved rangeland health (Smith and Foggin 1999, Harris 2010, Delibes-Mateos et al. 2011).

In Wilson and Smith (2015) we address the issue of Plateau Pika poisoning against the putative importance of pikas to the hydrological dynamics of the QTP. This approach is set against the backdrop that Plateau Pikas are demonstrably a keystone

species for biodiversity on the QTP. Where pikas have been poisoned most native (endemic) passerine birds (e.g. snow finches *Montifringilla* spp; Tibetan Ground-tit *Pseudopodoces humilis*) disappear because they nest primarily in pika burrows that collapse after poisoning occurs (Lai and Smith 2003). Biodiversity is further reduced because nearly every raptor (Little Owl *Athene noctua*, Black-eared Kite *Milvus migrans lineatus*, Northern Goshawk *Accipiter gentilis*, Upland Buzzard *Buteo hemilasius*, Golden Eagle *Aquila chrysaetos*, Steppe Eagle *A. nipalensis*, and Saker Falcon *Falco cherrug*) and carnivorous mammals (Chinese Mountain Cat *Felis bieti*, Pallas’s Cat *Felis manul*, Lynx *Lynx lynx*, Wolf *Canis lupus*, Tibetan Fox *Vulpes ferrilata*, Red Fox *V. vulpes*, Brown Bear *Ursus arctos*, Mountain Weasel *Mustela altaica*, and Steppe Polecat *M. eversmannii*) on the QTP subsist primarily on the high density of non-hibernating pikas (Smith et al. 1990, Schaller 1998, Smith and Foggin 1999, Li et al. 2004, Xu et al. 2006, Hornskov and Foggin 2007, Badingqiuying 2008, Cui et al. 2008, Worthy and Foggin 2008, Liu et al. 2010, Ross et al. 2010, 2012, Harris et al. 2014). [n.b. Snow leopards (*Uncia uncia*) primarily prey on blue sheep (*Pseudois nayaur*), but have also been known to supplement their diet with pikas; Schaller 1998]. Poisoning pikas also lowers the species richness of vegetation on the QTP (Bagchi et al. 2006, Hogan 2010), and Pech et al. (2007) determined experimentally that grazing by livestock appeared to have a stronger influence than Plateau Pikas on the biomass of standing vegetation in alpine meadows on the QTP. Wilson and Smith (2015) also expose the false claims common in much of the QTP ecological literature that the presence of high density Plateau Pika populations exacerbates erosion (Fan et al. 1999, Limbach et al. 2000, Zhou et al. 2005, Wei et al. 2007, Dong et al. 2013, Li et al. 2013); this is shown to be a shibboleth as none of these studies present evidence to support this contention.

In the QTP hydrologic system where the Plateau Pika occurs, precipitation can account for as much as 40% of annual flow and 100% of dry season flow of downstream rivers (Immerzeel et al. 2010). Thus, infiltration rates, runoff, and groundwater storage in these upstream ecosystems can potentially impact downstream ecosystems and communities, including the 1.4 billion people living in the QTP’s watersheds (Xu et al. 2009, Immerzeel et al. 2010). However, despite being the most populous native mammal

in the region, the ecohydrological impact of pikas on this ecosystem had not yet been assessed. We hypothesized that the burrowing activity of pikas might act to increase the infiltration rate of water, particularly during summer monsoonal storms, thus providing a critical ecosystem service in this headwaters ecosystem with potential watershed level effects.

To test this hypothesis, infiltration rates were measured at three treatment sites. These were defined as: 1) Adjacent to (touching) an active pika burrow entrance (On Burrow; Fig. 1a); 2) Between two (or more) active pika burrows, but at a distance of at least 1 m from an active burrow (On Colony; Fig. 1b); and 3) Areas where pikas had been thoroughly eradicated due to poisoning campaigns and absent for more than two years (where burrows have collapsed; Poisoned Site; Fig. 1c). This experiment took place at five localities broadly spread across Qinghai Province in the Sanjiangyuan (“Three Great Rivers”) region which serves as the headwaters for the Huang (Yellow), Yangtze, and Mekong rivers (Figs. 2 and 3). Special consideration was given to site selection. All active colony sites were located in flat bottomland meadow and central to a surrounding large population of pikas in all directions. Poisoned sites were areas that had supported pika colonies before poisoning campaigns and that were physically similar to areas with currently established pika populations. Previous studies have shown that ground cover on and off pika

colonies varies little (Shi 1983, Pech et al. 2007), eliminating possible interactions between ground cover and infiltration rates, groundwater recharge, and surface runoff (compare Fig. 1b and 1c). Thus our observed variation in infiltration rates appears representative of local-level ecohydrological processes.

Measurements of infiltration rate of water were obtained using a double-ring infiltrometer (Turf-Tech International – Model IN8-W; <http://www.turf-tec.com/>) with an inner ring diameter of 15.24 cm and an outer ring diameter of 30.48 cm, and accompanying Mariotte tubes. Infiltrometer placement at each site was randomly determined by throwing a piece of yak dung over one’s shoulder in a randomly determined direction. The apparatus was then situated adjacent to the closest site meeting the specifications of the treatment (Fig. 4). All placements were approximately level as the thick sod mat inhibited driving the apparatus more than 1-2 cm deep, and leakage could only be prevented on nearly flat surfaces. To assure consistency of measurement, the constant head (ponded) method was used, and testing sites were brought to, or near, saturation by allowing a minimum of 20 cm of water to infiltrate into the soil before measurements were taken (Bodhinayake and Si 2004, Wu et al. 2007). To assure precision, infiltration rates were measured and averaged over two or three 15-minute periods, depending on local conditions (i.e. availability of water, etc.).

We found that the infiltration rate of water varied significantly across treatment sites (Fig. 5; Blocking-Factor ANOVA (two tailed): $F_{2,8} = 16.992$; $\alpha < 0.001$). The lowest infiltration rate was consistently recorded at poisoned sites (95% CI [0.08,0.58]). Intermediate infiltration rates were observed at sites within a colony but away from burrows (95% CI [1.25,1.88]), and the



Figure 1. Portrayal of sites identified for ecohydrological measurements on the Qinghai-Tibetan Plateau. a, “On Burrow.” Infiltrometer was placed centered in disturbed area outside the plateau pika burrow entrance; b, “On Colony.” Infiltrometer was placed at least 1 m from an active pika burrow; c, “Poisoned Site” showing the condition of pika-free grassland. Infiltrometer placement at each site was randomly determined (see text). Photos: a: Max Wilson; b: Andrew Smith; c: Andrew Smith



Figure 2. Map of the study area on the Qinghai-Tibetan Plateau, People's Republic of China. Locations for measurements were broadly spread across the alpine meadows of eastern Qinghai Province (average elevation = 4,000 m), and encompassed the drainage systems of the Mekong (Nangqian = map site 1), Yangtze (Chendou = 2, Zhenqin = 3), and Huang He (Dawu = 4; Sendou = 5) rivers.

highest rates of infiltration were consistently measured at sites adjacent to burrow openings (95% CI [3.01,5.02]) (see Fig. 5 for Tukey-Kramer comparisons).

These data confirm that through its burrowing activity, the Plateau Pika is an ecosystem engineer; the infiltration rate of water is higher in areas occupied by pikas, and our observed variation in infiltration rates appears representative of local-level ecohydrological processes. Though impossible to quantify accurately due to gaps in geographical data (i.e. maps of now contracted pika ranges, fine grained precipitation data, fine grained soil moisture data) the additive impacts of an increased



Figure 3. Environment at the Dawu study site, Qinghai Province, China; 34°24' N, 100°21' E, 3,846 m a.s.l. Photo: Andrew Smith



Figure 4. Plateau Pika (*Ochotona curzoniae*) checking out the infiltrometer apparatus. Photo: Max Wilson

infiltration rate across the range of the Plateau Pika (nearly the entire QTP) on the hydrology of this headwaters region could be massive.

This work speaks to the importance of more broadly integrating local ecohydrological processes into hydrological models. We view our work as integrating the “eco” into “ecohydrology” – a feature we found lacking in our review of the ecohydrology literature (but see Whitford and Kay 1999, Eldridge and James 2009). Additionally, Westbrook et al. (2013) show in their meta-analysis of peer-reviewed papers on ecohydrology that < 7% focused on the influence of animals on hydrological patterns. Our study shows the importance of burrowing mammals in the scheme of hydrological processes – particularly in mountains where their impacts may be distributed to downstream ecosystems and communities. Last, we argue that the policy of poisoning Plateau Pikas should be reconsidered. Not only does this policy lead to critical losses of biodiversity on the QTP (Smith and Foggin 1999, Lai and Smith 2003, Badingqiuying 2008, Hogan 2010, Delibes-Mateos et al. 2011), but it ignores the ecosystem services pikas provide. Our precise experiments using the infiltrometer approach conducted across much of the range of the Plateau Pika demonstrate that the radical reduction in infiltration rates that accompanies pika poisoning exhibits the potential to alter the hydrologic regime of this headwaters region. Future research should focus on closing the data gaps necessary for directly quantifying these risks; however, in the absence of such data, these results are compelling evidence that pikas play a key role not only in biodiversity on the QTP, but in the flow of the rivers that originate throughout their geographic range.

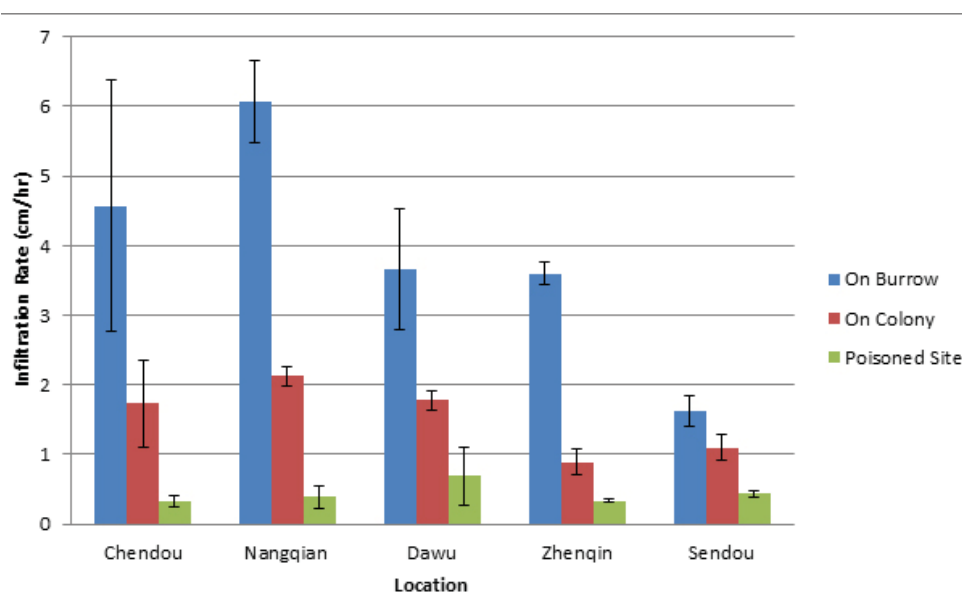


Figure 5. Average infiltration rate of water by treatment and location. Error bars represent 1 SEM. Blocking-Factor ANOVA was used to test for significant variation in mean infiltration rate of all three treatments across localities. Treatments included measurements On Burrow (adjacent to an active pika burrow), On Colony (at least 1 m from active burrows, but within an active pika colony), and Poisoned Site (a location where pikas had been poisoned and old burrows had collapsed). Total sample size for the project was 54 trials with sample sizes varying from nine (three per treatment) to 15 (five per treatment) by locality. Blocking-Factor ANOVA (two tailed): $F_{2,8}=16.992$; $P<0.001$. Tukey-Kramer comparisons between sites: Poisoned Site v. On Burrow = $P<0.001$; Poisoned Site v. On colony = $P<0.004$; On colony v. On burrow = $P<0.001$.

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BREVIA

Temperature Trend Biases in Gridded Climate Products in the Western United States

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Oyler, J. W., S. Z. Dobrowski, A. P. Ballantyne, A. E. Klene, and S. W. Running. 2015. Artificial amplification of warming trends across the mountains of the Western United States, Geophys. Res. Lett. doi:10.1002/2014GL062803.

In the mountainous western U.S., temperatures from high-resolution gridded climate products are often used to assess climate impacts on local hydrology, ecosystem processes, and biotic communities. However, there has been little formal analysis on the ability of these products to accurately capture temporal variability and trends in climate.

It is well-known that many station temperature records contain non-climatic temperature variations produced by changes in instrumentation, station siting, or observation protocols. Because these artificial changes, termed inhomogeneities, can affect interpretations of temperature trends and, at worst, lead to erroneous conclusions, there is a rich statistical and climate literature on homogenization—the statistical identification and correction of inhomogeneities. Most global gridded temperature datasets, which are specifically designed for analyzing climate variability and trends at continental and global scales, use station observations that have been rigorously homogenized

(e.g. CRUTEM4; Jones et al., 2012). In contrast, the widely used PRISM (Daly et al., 2008) and Daymet (Thornton et al., 1997) products do not homogenize input station data. This is an important and underappreciated distinction between the different types of gridded climate products available to the research community.

We recently showed that PRISM and Daymet have incorrectly amplified minimum temperature warming trends across western U.S. mountains due to a significant inhomogeneity in the SNOTEL observation record (Oyler et al., 2015). From the late 1990s through mid-2000s, a field campaign to standardize SNOTEL instrumentation (Julander et al., 2007) caused annual average minimum temperatures to artificially rise by +1.5 to +2.0°C across the network. Because PRISM and Daymet rely upon the SNOTEL network for observations of mountain climate, they subsequently propagated the spurious temperature jump across many western U.S. mountain ranges. The propagation of the SNOTEL inhomogeneity is apparent when we compare recent minimum temperature trends in PRISM and Daymet to those from a homogenized gridded product (TopoWx; Oyler et al., 2014; Figs. 1 and 2).

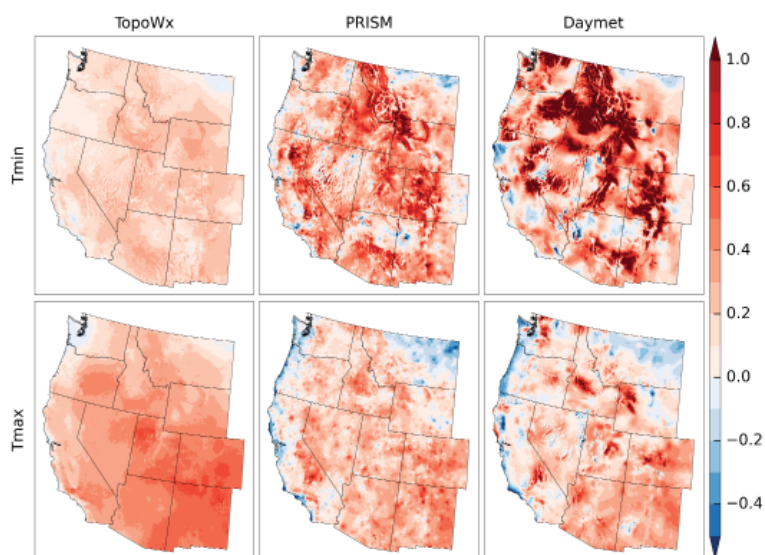


Figure 1. The 1981–2012 annual minimum and maximum temperature (Tmin, Tmax) trends for the western U.S. for the homogenized TopoWx data product, PRISM, and Daymet.

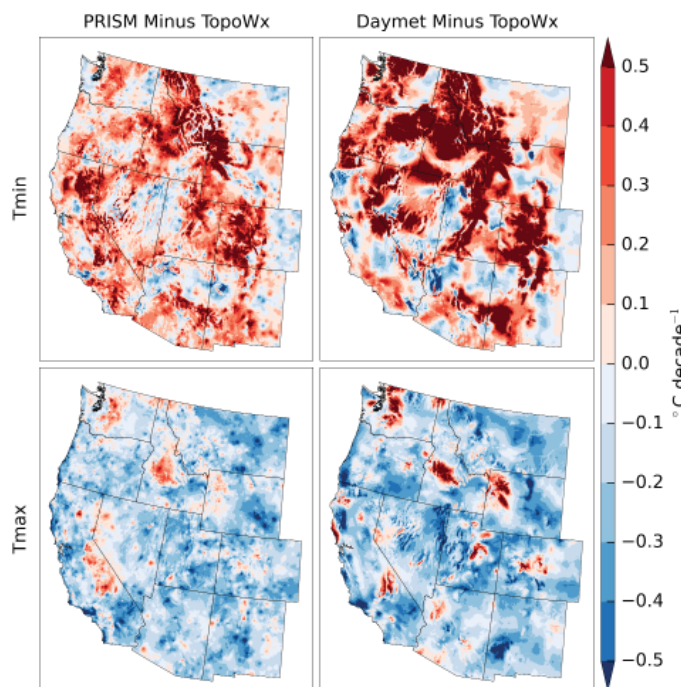


Figure 2. Differences in 1981–2012 annual minimum and maximum temperature (Tmin, Tmax) trends from Figure 1. First column is PRISM minus TopoWx. Second column is Daymet minus TopoWx.

Although the SNOTEL-driven bias in PRISM and Daymet could have a strong effect on local interpretations of apparent temperature trends, it needs to be viewed in the context of inhomogeneities from other networks as well. For example, there is a well-documented maximum temperature cold trend bias in the National Weather Service's Cooperative Observer network resulting from changes in reporting practices and instrumentation (Menne et al., 2009). Similar to the SNOTEL inhomogeneity, this cold bias becomes apparent in PRISM and Daymet when we compare their western U.S. temperature trends to those from the homogenized TopoWx product (Fig. 2).

These simple comparisons provide strong evidence that gridded climate products commonly used for climate impact analyses in the western U.S. are not robust to station inhomogeneities and subsequently contain spatially structured warm and cold trend biases (Fig. 2). Depending on the spatial and temporal scale of a specific climate analysis, these biases could have a substantial impact on climate attribution studies and possibly lead to erroneous conclusions. As a result, homogenized observations either in the form of a station record database (e.g. USHCN; Menne et al., 2009) or a gridded product (e.g. TopoWx; Oyler et al., 2014) should be used to ascertain trends.

A broader application of standard homogenization algorithms is a logical step to address some of these issues, but many challenges and questions remain. TopoWx likely provides an improved representation of regional climate trends (Fig. 1), but it is unknown if the product adequately represents temporal climate variability at the topoclimatic scale. Homogenization algorithms are also limited both in their ability to fully correct for inhomogeneities and in the possibility that they can remove local climate phenomena and over smooth trend fields. Further improvements in gridded climate products are needed in order to quantify temporal variability and trends in local climate.

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Interview with Tom Swetnam

Tom Swetnam was one of the founding coordinators of CIRMOUNT, and remains an enthusiastic supporter of the consortium. I am pleased to have interviewed Tom, recently emeritus Regent's Professor of Dendrochronology and Director of the University of Arizona's Laboratory of Tree-Ring Research, Tucson, in honor of his election as a Fellow of the American Association for the Advancement of Science. This recognition is for Tom's investigations of tree rings as a record of past changes in climate, which have allowed scientists to predict future forest-fire frequencies and other historic disturbances in the American Southwest. While congratulating Tom on his election to AAAS Fellowship, I also thank him, on behalf of our greater science community as he moves to emeritus status, for the decades of contributions in research, teaching, leadership, and advancing science-based resource management. I know Tom has many plans for continuing research, and we look forward to what the years ahead bring.

—Editor

TOM SWETNAM



Photo: Michaela Kanés

Connie: Who or what was especially influential in your early life that helped steer you toward a career in forest ecology, fire science, paleoecology, and dendrochronology?

Tom: My forest and fire obsessions came naturally to me. My father was a district ranger with the US Forest Service, and so I grew up in rural areas of northern New Mexico, surrounded by trees, ancient pueblo ruins, and wildfires. After I finished my bachelor's degree in biology at the University of New Mexico in the late 1970s, I went to work for several years as a wildland firefighter in the Gila Wilderness of southern New Mexico. I met Jack Dieterich one summer while I was working as a go-fer on a wilderness pack trip with a bunch of Forest Service scientists in the Gila. Jack was a fire scientist with the USFS Rocky Mountain Research Station, and he was working with Professor Marvin Stokes developing some of the first tree-ring based fire histories for Southwestern ponderosa pine landscapes. Jack showed me fire scarred trees and explained how they record

past surface fires in their tree rings. I was hooked. I applied for graduate school at the University of Arizona Laboratory of Tree-Ring Research to work with Professor Stokes. Thirty-five years later I am still here, sort of. Jack, Marvin, and many other great people here at the Tree-Ring Lab helped me and shaped my career in many ways, for which I am forever grateful.

Connie: Looking at your career, what were some of the most exciting and/or difficult research challenges you confronted?

Tom: Our most exciting projects have been in the giant sequoia groves of the Sierra Nevada and the vast pine forests of central and eastern Siberia. It was such a privilege and honor to study the magnificent sequoias. The National Parks needed more specific scientific and historical knowledge of past fire history variations in the sequoia groves, so they allowed us to take big chainsaws into the groves and go to work on old stumps and logs (no living trees were cut, of course!). It was awesome to cut into 20 foot diameter stumps and logs and pry out table-top size slabs of wood. Sometimes a slab would come out with only a couple of thousand rings (!) and sometimes it would come out with two thousand rings plus a couple of dozen fire scars! It felt like we were mining for some strange kind of gold in those gnarly, massive chunks of wood. One of the significant results was our three thousand year-long chronologies of climate and fire history, which we put to use in tracking centuries-long changes, such as maximum fire frequencies during a Medieval drought period (circa 900 to 1300 AD).

Siberia has been an unparalleled travel and field-science adventure for us on numerous trips. We have been collecting fire scarred tree samples on 1000-kilometer-long transects from several regions in central and eastern Siberia, with a goal of improving our understanding of long-term climate, fire

and carbon dynamics. It's an ocean of forest, with enormous wildfires burning there in recent decades. Every trip has been a culture shock as well as a great physical challenge. The science is still developing from our years of work on this project, but it is shaping up in very interesting ways, including new insights on how the jet stream may be involved in synchronizing fire in multiple regions around the planet.

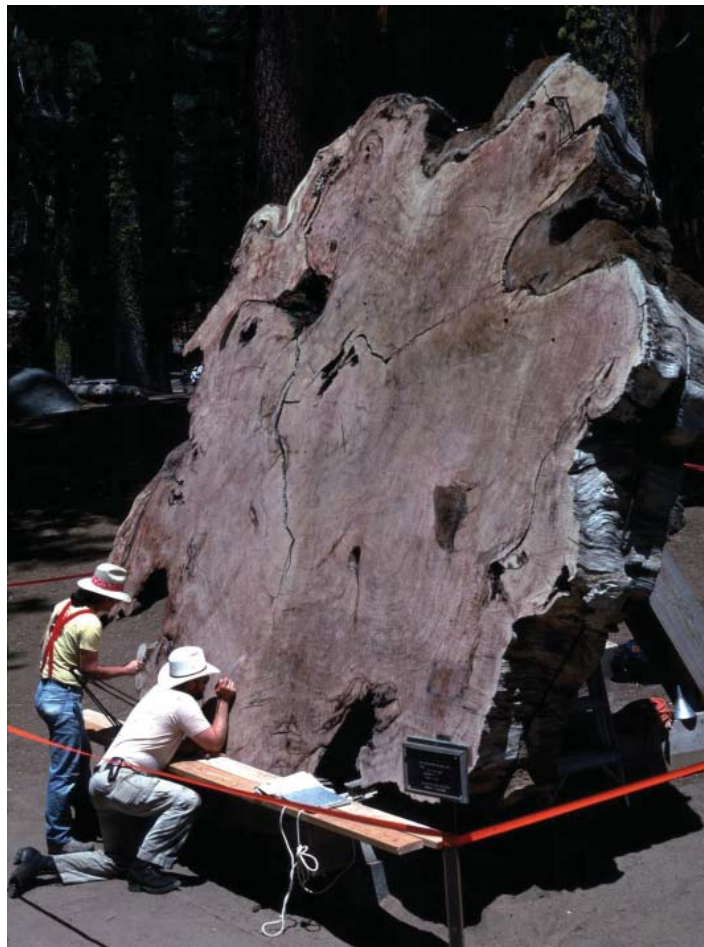
Connie: Your career has been a daunting mix of research, applications to natural-resource management, program development and leadership, and University administration. How much of this was a natural evolution versus intention and forethought? What aspects do you attribute to being able to balance these activities so successfully?

Tom: I actually thought I would finish my master's thesis here at the UA, and then take a job somewhere working in fire management. But the job market was tight in the early 1980s (like now) and so I continued my graduate work. By the time I finished my PhD work (studying insect outbreaks with tree rings),

I was a full-blown, obsessive tree ringer! I was lucky to land a faculty job here at the Tree-Ring Lab, and I would probably have continued primarily and happily as a scientist and teacher if I hadn't taken the director job at the Lab when Malcolm Hughes stepped down in 2000. If I recall right, I got the job mainly because no one else on the faculty wanted to do it! Anyway, it has been a rewarding and interesting job over the years. What success I have had as both an administrator and researcher I honestly attribute to my good fortune in having great colleagues and students, and a good bit of luck. Sure, my energies and ideas have been key too, but none of the best things we have done would have possible without the talent, passion and hard work of our teams of students, associates and collaborators over the years.

Connie: What do you consider your most important contributions, research or otherwise?

Tom: On the research side, I would guess that is the expansion of the use of fire scars in tree rings to understand broad-scale, regional climate and human controls over fire regime variations,



Dating fire scars on Giant Sequoia. Photo: Tony Caprio

as well as specific insights about major drivers such as the El Niño and other oscillatory climate behaviors. On teaching and mentoring, I am most proud of the two dozen or so Masters and PhD students who worked with me as their major advisor, and all that they have done now in tree rings, ecology, and climate studies. Administratively, I think surviving more than a decade of budget cuts is high on the list of accomplishments! More tangibly, our brand new Tree-Ring Building on the University of Arizona campus is great to see, after so many decades of being stuck under the bleachers in the football stadium! Again, these are certainly not things that I accomplished alone. The new building is due to a very generous donor, the University of Arizona, and my colleagues on campus who helped me make this happen.

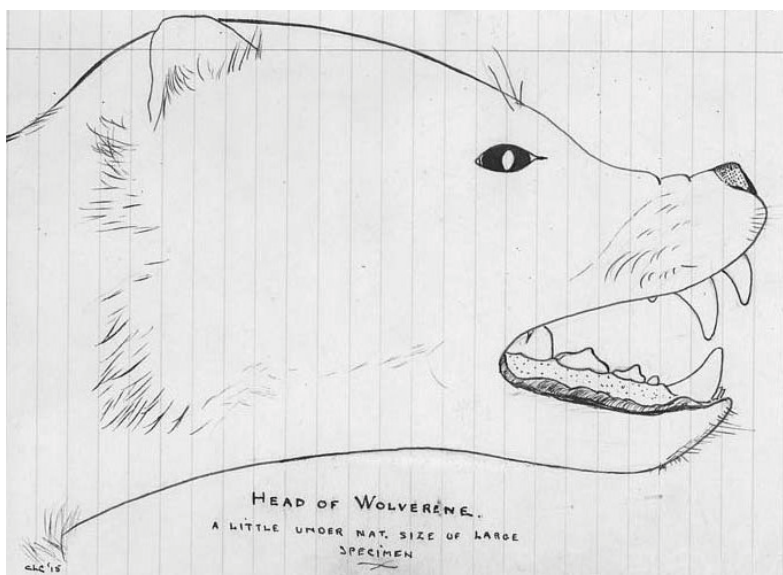
Connie: What questions, problems, or topics motivate your interest and pique your passion these days – any thoughts on activities in next few years?

Tom: I am most excited these days about our work on human-environment interactions, looking at how forests, fires and people co-existed in pine forests in New Mexico and Siberia over multiple centuries. The New Mexico work includes archaeology,

fire ecology, paleo-climatology and various other aspects. This project (supported by NSF's Coupled Natural-Human Systems Dynamics Program) feels like we are weaving together threads of science that dendrochronology has been involved in from the beginning, and in a landscape that I know and love the most: the Jemez Mountains of northern New Mexico. I think the passion here comes from the richness of these landscapes with deep human history, as well as the spectacular geology and ecosystems. It also comes from a sense that now is a very important time to study places where people lived for long periods of time, apparently with some degree of sustainability in the past, but now those same places are changing very abruptly and probably irreversibly due to climate change.

Connie: Thank you so much, Tom. On behalf of your CIRMOUNT colleagues, congratulations on your nomination as Fellow of AAAS, and thank you from all of us for your many contributions to date! Is there anything else you'd like to add?

Tom: Connie, my sincerest thanks and appreciation to you and CIRMOUNT for all you have done and are doing. Truly CIRMOUNT has been one of the best groups I have been associated with during my career.



Wolverine. Field notes of Charles Camp from the Archives of the Museum of Vertebrate Zoology, University of California, Berkeley (<http://bscit.berkeley.edu/mvz/volumes.html>; Volume 557, Section 3, 26 July 1915, page 195).

Voices in the Wind

In this section, we query members of the CIRMOUNT community for their perspective on a question of current interest. As the deepening drought squeezes resources in the West, this topic is on everyone's mind. I put the following question to colleagues around the West:

The persistent drought of western North America brings ongoing bad news for the environment and society. In that we can't do anything in the moment to change the weather, we can look for a silver lining. In what ways has the drought brought unexpected or beneficial opportunities for your work, or, have you seen any environmental conditions that have benefited from the drought?

Bob Coats, Hydroikos Ltd., Berkeley, CA

Drought effects on the Lake Tahoe Basin ecosystem are largely detrimental. There are, however, some effects of warming and drought that are beneficial, at least in the short run. Increased mortality of large trees (from moisture stress, beetles or fire) means more nesting sites and food resources for cavity-nesting and insectivorous birds. Less runoff from the streams entering the lake means less input of fine sediment, nitrogen and phosphorus, which are responsible for the long-term decline in the lake's clarity. If the current drought continues, we will most likely see some increase in clarity. Large floods are less likely (but not impossible) in dry years than in wet years, though some modeling studies project increases in large floods in this century.



Using the data from the Lake Tahoe Interagency Monitoring Program, we recently recalculated total constituent loads of nitrogen, phosphorus and sediment for 20 watersheds in the Tahoe basin over up to 40 years. For nitrate-N, we found significant ($p < 0.0025$) downward trends in load for 7 of the 20 watersheds. Over the same period we found no trend in the Palmer Drought Severity Index, although the inter-annual variability in the PDSI is increasing. One hypothesis that might explain the downward trends in nitrate-N is the long-term recovery of vegetation from the heavy logging and grazing of the 19th and 20th centuries, with concomitant increased efficiency of nutrient cycling. A second (and complementary) hypothesis is

that warmer temperatures have accelerated plant growth through earlier onset of spring, and thus increased nutrient uptake. Though the downward trends in nitrate-N loads are interesting and heuristic, their beneficial effects are probably slight relative to the other impacts of drought and climate change on the Lake.

Colin Maher, College of Forestry and Conservation, University of Montana, Missoula, MT

The section of the Northern Rocky Mountains where I live has not experienced the magnitude of drought that much of the West is enduring, especially my home state of California. The basins around Missoula currently have 70-80% of normal SWE. Southwestern Montana is doing worse with 50-60% SWE. In line with trends, a high proportion of our precipitation this spring fell as rain. The upshot of this is that I'll be able to access my treeline field sites earlier this year. This is always a benefit with the limited window we high-mountain ecologists have.



In the much drier West, one benefit of extreme drought conditions could be a decrease in the rate of spread of *Cronartium ribicola*, the introduced fungus that causes white pine blister rust. *C. ribicola* thrives in cool, wet environments. It has caused massive mortality in high elevation whitebark pine and limber pine forests in the northern (and wetter) parts of those species's ranges. To my knowledge, the fungus has not yet caused widespread damage in these high-elevation white pine populations in the Sierra Nevada.

Great Basin bristlecone pines can also be infected, and thankfully the fungus has not yet been observed in wild bristlecones. Given these trees can handle the direct stress of drought, then current conditions may buy them more time against blister rust.

For those who are dendrochronologically inclined, another benefit down the road is that this year will almost certainly be represented by small (or missing) tree-rings across the west. It will be interesting to observe how these modern rings compare to the rings formed during ancient droughts.

Nina Oakley, Western Regional Climate Center, Desert Research Institute, Reno, NV



One of the silver linings I see in the current drought is that its severity and duration have the potential to change the way we utilize water in the West and force us to become more resilient. I visited friends in Brisbane and Gold Coast, Australia, in 2014 and noticed that what we call “water conservation” in the western US was a way of life for my Aussie friends. The toilets, showers, and washing machines I

encountered were designed for low water consumption. Lawns were few and far between in the neighborhoods I visited. The water use habits of Australians I met contrasted starkly with my own and with those I am used to seeing in the West. They were impressively diligent with turning the water on and off while doing tasks like cleaning vegetables and washing dishes. None of these activities were prefaced with talk of conservation; it was just how things were done. My Aussie friends explained that Australia’s most extreme drought, the *Millennial Drought* from 1997-2009, crippled the southeastern part of the country and forced major change in water management and policy, agricultural practices, and human perceptions. Now, this region is prepared to withstand severe drought and conservation seems to be engrained in the culture. I think that this fourth dry winter will force similar changes in the West. Already we have seen legislature supporting regulation of California groundwater. Gov. Jerry Brown mandated a 25% reduction in urban water usage and replacement of 50 million square feet of lawns with artificial turf or drought tolerant landscape. There are many movements and programs in progress to educate citizens on conservation. Perhaps we’re on our way to resilience?!

At the Western Regional Climate Center (WRCC), this drought helps us understand what climate information people need to make decisions under dry conditions. We can then work on building tools to meet these needs so that next time a drought occurs, the tools are available to decision-makers. Drought conditions have motivated stakeholders to come together with the climate community (and vice-versa) and several tools for decision makers have come out of these meetings. One such tool developed at WRCC is the Climate Outcome Likelihood tool that looks at the likelihood of recovering a precipitation deficit in some future period based on observed precipitation in a weather station record (<http://wrcc.dri.edu/col/>). Additionally, the current drought highlights the need for more meteorological observation stations to capture climate variability and drought conditions across the complex terrain of the West. As decision-makers realize the need for improved observations, they are hopefully more likely to support projects that involve long-term monitoring.

For me personally, the persistent high pressure of the last couple winters made for many excellent paddling days on Donner Lake and Lake Tahoe. Several boat launches around Tahoe have closed, so it is looking like this summer will see reduced boat wake conditions for those who enjoy calm conditions on the lake!

Lisa Cutting, Mono Lake Committee, Lee Vining, CA

Living and working on behalf of Mono Lake and its tributary streams, my colleagues and I are experiencing unexpected challenges. Since State Water Board Decision 1631 in 1994, Mono Lake has slowly been rising toward the management level of 6392’. But these last four years of drought have brought us almost back to square one. When each potential storm fizzled out last winter and the blue-sky days just kept coming, depression gripped our staff. Fears were confirmed with snow surveys and runoff forecasts. Signs of the magnitude of the situation were everywhere. It was hard. It is still hard. And who knows, it may get harder still.



I have finally come to the conclusion that no matter what happens, this is the place I am committed to—committed as in marriage. You know, “for better or worse, in sickness and health, in good times and bad.”

Kathleen Dean Moore wrote, “May this drought be the peeling of bells to announce the new, more sensible and reverent future.” I add, may this drought call us to immediate action, inspire a deep reimagining of who we are in relationship to everything else, and motivate us to be the best partners to place we can possibly be.

“Speak to your fellow humans as your place
Has taught you to speak, as it has spoken to you.”

—Wendell Berry

Ben Hatchett, Department of Geography, University of Nevada, Reno, NV

Benefits of the drought? Let me count the ways! For better or worse:

1. Past droughts have lasted hundreds of years, therefore you have to start somewhere. The obvious question is: what produces the quasi-stable climate system state that persists for so long?

2. Sufficient time has passed such that a new equilibrium state of watershed hydrologic function has likely been achieved, which is interesting from a hydroclimate dynamics perspective.

3. Previously submerged terrestrial plants in rivers and lakes become exposed or begin to establish along newly desiccated shorelines. These present stark reminders of climatic outcomes possible in western North America.

4. Lowering of base level promotes incision that exposes new sedimentary structures with potential dateable material.

5. There is no better way to incentivize and catalyze socioeconomic change than a direct test of present-day vulnerability. Independent of causality, society can use this opportunity to adapt to a drier mean state. However, the differing cases of Montecito, CA and Mendota, CA provide examples of how complex the matter truly is.



6. The geomorphic responses to climatic change can be examined using advanced technology such as unmanned aerial vehicles and terrestrial LiDAR that was not available during previous extended droughts in the twentieth century.

7. Now we can really start to see how much of a difference the North American Monsoon can make in the northern Great Basin during a climate characterized by warmer and drier winters.

8. Species competition and natural selection becomes more interesting as the timing, duration, and magnitude of precipitation events varies.

9. We should begin to ask better questions about climate dynamics. Are we experiencing a new climatic plateau in the step function of global climate model (GCM)-based projections of long-term (50-100 year) changes in mean climate? Or are the GCMs missing key nonlinearities inherent in the complex system? Even the best tools need skillful operators, and an ongoing drought scenario provides an ideal laboratory to improve our modeling skills and understandings of fundamental climate processes.

10. Funding outlooks for drought research will be positive until a wet year.

Vachel Carter, Department of Geography, University of Utah, Salt Lake City, UT

[Vachel sent two replies and asked me to choose one. I thought both were important and insightful, so with Vachel's permission, I include them both here. —Editor]

Sudden aspen decline:

Recently there has been a great deal of research and debate around the observed ‘sudden aspen decline’ (SAD) in western North America. Many authors have attributed the recent drought as the main mechanism influencing aspen mortality and dieback.

As a paleoecologist, understanding how past ecosystem dynamics have responded to climate and disturbances is critical for determining resiliency of ecosystems. By understanding what we see historically, paleoecologists examine historic droughts and understand the mechanisms



causing droughts and examine the resiliency of ecosystems in the past in order to understand present and future ecosystem resiliency. The most recent drought and debate about SAD have led to the unexpected and beneficial opportunity to study how dynamic quaking aspen forests are. I say unexpected and beneficial opportunity because aspen pollen does not normally preserve well in sediment cores. However, at a site in the Medicine Bow Range in southeastern Wyoming, we were able to examine a unique change in vegetation from a lodgepole pine dominated forest to a mixed quaking aspen, lodgepole pine, Engelmann spruce, and subalpine fir forest roughly 4,000 years ago. During this time period, we had excellent aspen pollen preservation, which lead to this unique paleoenvironmental reconstruction. Preliminary analysis suggests that drought and fire influenced this unique change in vegetation composition. The next step is to apply what we have learned from this research and determine the similarities and dissimilarities between past droughts, modern droughts, and aspen responses. This research demonstrates that ecosystems are dynamic and respond to droughts and disturbances, which can be beneficial to land managers in offering mitigation strategies against aspen decline in the future.

Bark beetles:

Bark beetle outbreaks have been all over the news lately. The recent drought along with anthropogenic modifications to the landscape have created the perfect conditions for wide spread bark beetle epidemics. As a paleoecologist, the recent eruption in bark beetles has lead to the unique opportunity to study the recent bark beetle outbreaks and frame them in a long-term context. By examining sediments from lakes or bogs, paleoecologists look to examine the role of climate and previous disturbances. Based on the dates we have gathered thus far, the most recent bark beetle outbreak is unprecedented in magnitude. The magnitude of the event is attributed to anthropogenic climate change and historic land use. For example, my site in the Medicine Bow Range of southeastern Wyoming documents widespread logging during the late 1800s for the construction of the transcontinental railroad. This has created a large, single age homogenous forest, which creates a unique vulnerability. The benefit of paleoecological reconstructions is that we see forested ecosystems across the western U.S. have been resilient to large magnitude beetle outbreaks during past droughts, but it was not until humans began modifying the landscape in a new and unique way the landscape has not experienced before that beetle populations could reach sizes needed for the mass attacks witnessed today. The silver lining is that by understanding the role of anthropogenic climate change and land use modifications, we can certainly describe ecosystem resiliency and thresholds for ecosystem change to mitigate against widespread epidemics.

Park Williams, Lamont Doherty Earth Observatory of Columbia University, Palisades, NY

One thing I am coming to view as beneficial about the current drought in California is that it will hopefully cause California to improve the sustainability and efficiency of its water usage. Even while some of the regulations on urban residential water usage may seem like superficial political theatrics, they will help to reinforce the ongoing seriousness of the drought into the public consciousness. Public support is a necessary part of slow and politically dangerous process of enacting much-needed revisions to decades-old water policies that are now known to not be sustainable.



Greg Pederson, US Geological Survey, Northern Rocky Mountain Science Center, Bozeman, MT

With no intention of making light of a difficult situation, there are some positive aspects to this otherwise challenging situation. First, current drought conditions serve as a reminder that water in the West is a limited and fickle resource, necessitating resource planning around both extended drought and deluge type scenarios. Recent events have also increasingly brought the agricultural community, resource managers, and the general public to the table for scientific information related to resource impacts and drought planning. Otherwise, I struggle to find evidence of environmental conditions that have improved due to increased heat and lack of water since my personal preference is for cold, snowy conditions. A net positive, however, "Drought is the best thing that ever happened to my lawn. And my beard." –Jarod Kintz



Christy Briles, Department of Geography and Environmental Sciences, Denver, CO



I spent almost two years living in southeastern Australia between 2010 and 2012. The region was experiencing a decade long drought that resulted in significant water shortages, crop failures, and grazing restrictions for livestock. Having to live with drought for extended periods makes you very cognizant of your water usage and ways to conserve. The entire

infrastructure of Australia is designed to conserve water and individual homes can capture, store, and use rainwater. After returning to the US, it was striking how unconscious we are about water usage and how outdated policies are surrounding water use and storage. I believe if we are to cope with our current and inevitable future of living with drought, we need to look to places that have been affected with water shortages and consider their ideas, technology and policies that have allowed them to survive in a drought prone environment.

I am a paleoecologist and have been reconstructing past environments of the western US for more than a decade. My research, and that of many other scientists, shows that we have just come out of the Little Ice Age period (~1250-1850 CE), which resulted in unusual conditions in comparison to the last millennia and today. In particular, cooler and wetter conditions during this period resulted in greater snow packs and more effective moisture in the western US. Dense forests developed in many places and fire activity was low, and, in some cases the lowest seen in the last 15,000 years. This was also a period of significant land cultivation, technological innovation, and population increase. However, the Little Ice Age was short-lived and we are now in a much drier time with anthropogenic influences accelerating and enhancing drought conditions. Now ecosystems are changing at rates never seen in the past with unprecedented impacts worldwide (e.g., widespread fire and beetle infestations, historic storms, novel plant communities, crop declines, species extinctions, etc.). The lesson I take away from the paleorecord is that climate and ecosystems change, and we

need to equip our society to better deal with climate variability. Does Australia or other drought prone nations have the answer? To a degree, I think so. However, once we accept our climate for what it is, and what humans are doing to change it, the trajectory of how to flourish in drought conditions will become much clearer and achievable.

Doug Clark (with daughter, Anni), Geology Department, Western Washington University, Bellingham, WA

In Praise of Drought Years in the Sierra Nevada

Despite the heavy toll they take on mountain environments, I look forward to dry years in the Sierra Nevada, even exceptional ones like 2015. This may seem ironic to most people, given that I'm an alpine glacial geologist, yet there is a reason to the rhyme. With the lack of mountain

snow, I often hear the comment that "with all these droughts, you'll run out of things to study!" But the situation is actually quite the opposite. Unlike my glaciology brethren, who mostly study glacier ice, I'm a glacial geologist, who focuses on the remnants of glaciers, rather than the ice itself. As glaciers shrink, my field areas grow, exposing new mysteries and areas to explore in the newly uncovered land. And with less winter snow, my field season gets longer too; the sooner the snow melts, the sooner I can start studying the striations, moraines, and lakes left behind by the retreating glaciers.

I have another, more practical reason to anticipate dry summers in the Sierra Nevada: mosquitoes, or more accurately, lack of mosquitoes. As much as I admire John Muir's advocacy for the mountains, I have never grasped his ability to praise the little parasites*. Having spent my career hiking and working in the backcountry of mountains around the world, I have found many of my most trying situations are related to biting bugs,



particularly “mossies.” I’m not talking about the occasional annoying buzz in your ear or the itch of a few persistent bites; I’m referring to those times when the horizon seems to darken and shift as clouds of the little biters rise from the grasses and bogs in anticipation of your approach. Or evenings when they attack with such ferocity that the only means of escape is to dive into a hastily staked tent and listen as they bounce like raindrops off the fly. Heavy snow years in the Sierra beget abundant meltwater ponds lasting into the summer, which in turn act as ideal breeding factories for bugs of all variety but most noticeably mosquitoes! In contrast, during dry years like 2015, the ponds mostly dry up before they become warm enough to act as incubators, so the bugs never have a chance to really get going.

None of this is to minimize the negative effects of this year’s severe drought on humans and on the environment. I would love to see glaciers expand and grow healthy again, even at the expense of my field areas and bug-abatement. But in the face of the dire long-term effects of climate change, I strive to find something to anticipate in my summer sojourns to the mountains.

*“I have always befriended animals and have said many a good word for them. Even to the least-loved mosquitoes I gave many a meal, and told them to go in peace.” John Muir, John of the Mountains.



Paradise Lake, Sierra Nevada, California, July 13, 2014. Adrienne Marshall

News, Briefs, and Events

Mountains of our Future Earth Conference, Perth, Scotland, 4-8 October 2015

The Centre for Mountain Studies at Perth College, University of the Highlands & Islands, in collaboration with the Mountain Research Initiative and the Global Mountain Biodiversity Assessment is organizing a third conference – Perth III – on ‘Mountains of Our Future Earth’. The conference is a contribution to the global Future Earth program.

The aims of the conference are:

- 1) To present, evaluate and synthesize progress in our understanding of global change in mountain regions, and share examples of innovative approaches, particularly in terms of progress towards addressing the gaps in global research in mountain regions noted at the 2010 conference;
- 2) To refine and agree agendas for collaborative research and action relating to global change and mountain regions, and to significantly increase the use of applied research findings on the ground in mountain regions;
- 3) To foster effective interdisciplinary and international interactions between participants: researchers, practitioners, and policy-makers.

Planning for the conference is now well-advanced. Some 620 abstracts from 70 countries were submitted and reviewed by session organisers. 350 abstracts were accepted for oral presentation and 120 for poster presentation. The very wide range of themes for parallel sessions and roundtables can be found here: <http://perth.uhi.ac.uk/specialistcentres/cms/Conferences/Perth2015/Pages/Programme.aspx>.

In addition to these parallel sessions, there will be plenary presentations by global experts; details can be found here: <http://perth.uhi.ac.uk/specialistcentres/cms/Conferences/Perth2015/Pages/Plenaryspeakers.aspx>.

There will be field trips on 4 October (each will include a visit to a whisky distillery or winery!). Registration is now open: <http://perth.uhi.ac.uk/specialistcentres/cms/Conferences/Perth2015/Pages/Registration.aspx>.

We look forward to seeing many CIRMOUNTaineers in Perth!



Eastern Sierra Nevada escarpment, California, 2014. Denise Waterbury

Conference - Mountain Forest Management in a Changing World

7-9 July 2015

Smokovce, High Tatra Mountains, Slovakia

First Announcement and Call for Abstracts

Mountain forests are characterized by steep ecological gradients and constraints on silviculture and logging techniques. At high altitudes, harsh environmental conditions limit productivity and slow down regeneration processes, making mountain forests sensitive to management interventions. Interest in intensified biomass utilization for energy production and supply of wood-based industries may increase the pressure on mountain forest ecosystems. At the same time, the share of mountain forests where management is abandoned is increasing in Europe because commercial forestry is no longer profitable due to the increasing cost of management and/or decreasing revenues from timber production, or decreasing interest of new landowners in forest management. Beyond wood production and biodiversity conservation, such developments are highly likely to also affect the provisioning of ecosystem services such as protection against gravitational hazards or recreational values. Global climate change has been particularly pronounced in mountain regions across the 20th century, reaching twice to three times the temperature increase of the global average. Further climate change is anticipated for the coming decades that will strongly affect mountain regions and thus the delivery of ecosystem services from these areas. The compounding effects of these developments become more acute as there is a large demand for a vast array of ecosystem services by a heterogeneous group of stakeholders.

The conference will provide the opportunity to present and discuss the potentials and limitations of current and possible future approaches to mountain forest management for providing portfolios of ecosystem services under current and future climatic and socio-economic conditions.

Themes of the conference are:

- Potentials and limitations of current management approaches to provide multiple ecosystem services
- Climate change impacts on ecosystem service provisioning in mountain forests
- Disturbance regimes in mountain forests and implications for ecosystem services
- Alternative management strategies in mountain forests and consequences on ecosystem service provisioning
- Decision support tools for mountain forest management
- Governance approaches to secure multiple ecosystem service provisioning in the future

The conference will include invited keynote talks, sessions with contributed oral presentations, a poster exhibit, a field trip (1/2 day) and a panel discussion with decision makers and stakeholder representatives. We will organize a review process for a Special Issue of an international scientific journal.

More information will be posted as it becomes available at <http://www.nlcsk.sk/mfm-conference>.

The venue Smokovce in the High Tatra Mountains (<http://slovakia.travel/en/spa-vysoke-tatry-novy-smokovec>) can be reached conveniently via Vienna International Airport (VIA). We will organize shuttle buses to/from VIA and the conference venue (details will follow).

Contact:

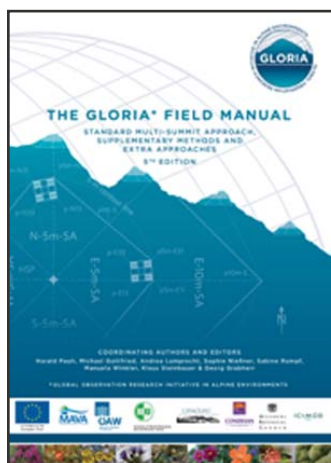
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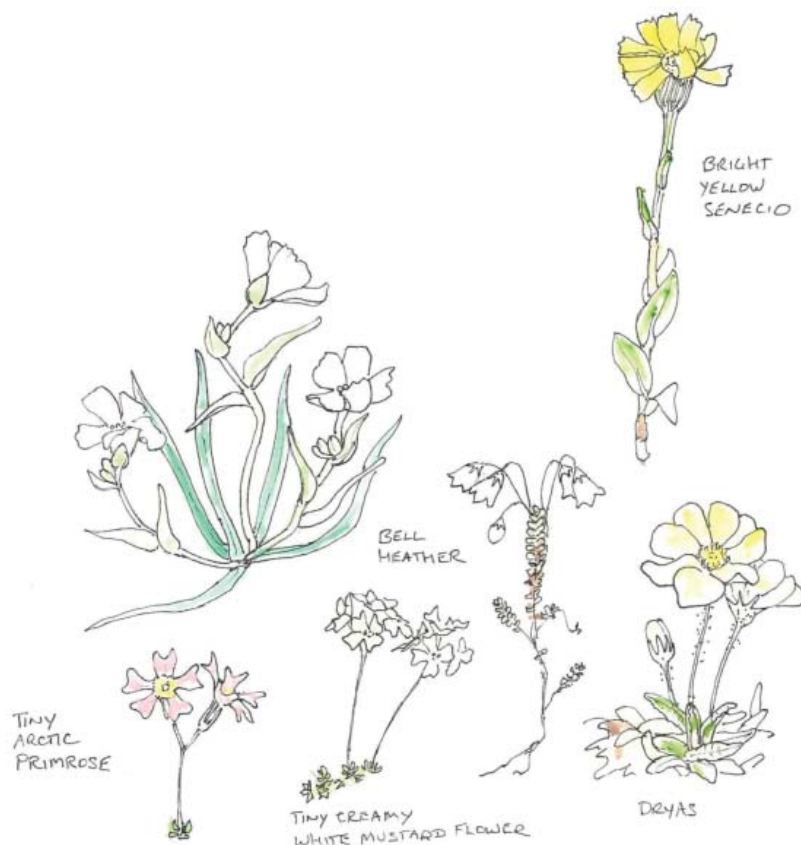
Publication: GLORIA Field Manual



The GLORIA Field Manual.
Standard multi-summit
approach, supplementary
methods and extra approaches.
5th edition, March 2015.

The 5th edition of the *GLORIA Field Manual* represents the state of the art of the sampling methods for GLORIA's Multi-Summit approach. This revised manual is based on thorough discussions and agreements made at the GLORIA conference in Perth/Scotland in September 2010, which was attended by participants from 34 countries from all continents. The manual, further, contains additional approaches which may be applied in GLORIA target regions supplementary to the standard methods.

The *GLORIA Field Manual* is available for download from:
<http://www.gloria.ac.at/?a=20>.



Tundra flowers, Cape Krusenstern, Alaska,
June 16, 2014. Fred Paillet

First Person

This new section of Mountain Views Newsletter highlights experiences of our colleagues as they encounter climate effects in mountain environments firsthand. I invite your contributions —Editor

Mountain Drought Hits Home: Trouble This Side of Paradise

Jeff Holmquist

*University of California Los Angeles, Institute of the Environment and Sustainability
White Mountain Research Center, Bishop, California*

Well, at least we'll have a good story to tell.

So I thought, as we hunkered down in a motel room with a winter windstorm gusting outside. My wife and colleague, Jutta Schmidt, and I were en route home from a pleasant and productive sampling trip in Yosemite National Park. The forecast indicated that we'd encounter strong winds arriving ahead of a winter storm as we drove down the east side of the Sierra Nevada en route to our home near Bishop, California. Not unusual for the Sierra Eastside in winter.

As we descended to the valley to the east of the Sierra we saw a brown wall of suspended sand and dirt ahead. Not long after encountering the winds and whirling debris, we passed a long series of power lines leaning at a sixty-degree angle.

After some slow driving, we reached a road closure due to downed trees, but a motel was conveniently located nearby. The power was out, and we were blissfully away from cell towers. Jutta duct-taped the door to keep the wind and sand at bay. I sat in the dark, happily typing away on a manuscript that focused, in part, on effects of the Yosemite Rim Fire and that noted the increased likelihood of wildfire in a changing climate.

The drought was in fact much on our minds as a result of our sampling trip. After a boat ride to the inlet end of the Hetch Hetchy reservoir, we had needed to hike for fifteen minutes across newly-exposed substrate in order to simply reach the inlet stream (Fig. 1). Beached driftwood was strewn across the landscape like a giant pile of Pick Up Stix.

In the morning I photographed a couple of cottonwoods downed by the storm front, and we hopped in the car to finish our trip home. After we drove back into cell reception, both of our phones began beeping and buzzing. Too much beeping and buzzing.

Our friends and neighbors quickly made the situation clear: an early February wildfire had been swept into our mountain community of Swall Meadows by the previous evening's windstorm. Many homes were destroyed (Fig. 2).

We stopped at the command/post shelter for the fire to learn more and to check in with friends. Little was known, and we drove to vantage points that would provide a view of the community using borrowed binoculars and a spotting scope. There's the water tank . . . there's Harvey's house, good! And Amy and Mike's, great . . .



Figure 1. Hetch Hetchy Reservoir, dry lake-bed, Feb. 3, 2015.



Figure 2. Round Fire, Feb 6, 2015, eastern Sierra Nevada, California. View north to Swall Meadows community. Photo: Jerry Dodrill, www.jerrydodrill.com

but that should be the spot for our house . . . can't see anything but smoke . . . but our house is smoke-colored, so maybe it's still there under the haze (Fig. 3).

Then the call to the incident commander: we, along with 35 other families, were on The List.

The fire that had started less than 24 hours ago was now essentially out and had been out for some time, thanks to the rains that followed the winds. None of this business about slowly

gaining containment. The fire had started, burned ~3000 ha and 35 homes, and had vanished before we could see it.

After a few days, we were allowed to reenter our neighborhood, living the scene that we have all viewed on the small screen so many times: hugging neighbors, poking through rubble, walking around with a twisted and charred memento or two (Fig. 4). I grew up in hurricane country, but the totality of this sort of destruction was beyond my personal experience: there was essentially nothing to salvage.



Figure 3. Round Fire. View northwest to Swall Meadows and Wheeler Crest. Photo: Jerry Dodrill, www.jerrydodrill.com



Figure 4. Little remained after the fire.

Slowly, the story began coming together—it's still coming together. A power line probably went down in the valley below Swall, and the resulting fire was fanned upslope by the winds that were gusting to over 160 km/hr. The erratic winds first drove the flames toward the community of Paradise, veering at the last second and thus taking only one home, then the fire was driven westward a thousand meters up the crest of the Sierra before finally tearing into Swall from several directions. Some homes may have survived the first pass of the fire but may have been destroyed as the fire came back though the community with evening downslope winds. The fire was by then a firestorm

with 30 meter flames. And there were cyclones of flame that awed firefighters and a shaken resident who was the last to leave. Firefighters were almost overrun and were lucky to make a last-minute escape with their lives.

In the end, about 60% of the homes were spared, and no one was sifting ashes for the bones of their loved ones. All considered, our community is fortunate indeed (Figs. 5, 6).

The fire has affected both Jutta and me in all of the predictable ways: loss of our family remembrances, field gear, shop, truck,



Figures 5, 6. Remains of home and grounds around Jeff and Jutta's Swall Meadows property.

plus the general life disruption that the legal profession rather wonderfully terms “annoyance.” But the truly life-changing elements have been positive, not negative: developing even closer relationships with friends and neighbors and being absolutely buoyed by an outpouring of support from our scientific colleagues and many others, including a number of contributors to *Mountain Views*.

One doesn’t expect a mountain community in the northern hemisphere to burn in early February (Fig. 7). Power lines come down all the time during winter storms in the mountains, but we are playing a different game now, both here and in many other places. Just a few years ago, lines came down in Swall during a winter storm, and we were out of power for several days—a minor nuisance. Power lines that fall into snow or wet desert shrubland pose little hazard. If lines are instead falling into drought-stricken shrubland, with the 3% humidity recorded on the afternoon of the fire, then it’s a matter of “when, not if.”



Figure 7. Jeff and Jutta’s home in a more “typical” prior winter, when snow covered the ground in February.

Free-standing lines, dictated by risk management evaluations, may no longer be as viable as buried lines in windy mountain environs. These sorts of changes in probabilities and cost:benefit ratios currently affect many aspects of life in the mountains, from water delivery issues, to ski resort management, to the science that many of us do. The world has shifted under our feet (Fig. 8).



Figure 8. The Round Fire burned 35 of 110 residences in the community of Swall Meadows, CA. Photo: Wally Woolfenden (another CIRMOUNT colleague, whose Swall Meadows home was spared although two out-buildings and grounds burned)

Jeff Holmquist has had the fine privilege of living, working, and playing in the Sierra Nevada with his colleagues and friends for the past seventeen years. His research addresses plant-animal interactions, landscape structure as a determinant of invertebrate movement and assemblage character, and the effects of anthropogenic and natural disturbance on ecological function in the Sierra Nevada. Except as noted, photos are by Jeff.



Jeff Holmquist and Jutta Schmidt. Photo: Barbara Barnum

Did You See (Hear, Touch, Smell, Feel) It? Oddities of Mountain Weather and Climate

This section of Mountain Views Newsletter highlights unusual mountain-weather events or climate-related phenomena of western mountains. I welcome your comments on processes and observations described, and encourage submissions for future issues. Thanks this time to Ben Hatchett for his inspiring and educational contribution here on a mountain phenomenon we all love but haven't necessarily understood. —Editor

On the Nature of Light in the Sierra Nevada

Benjamin Hatchett

Nevada State Climate Office, University of Nevada, Reno



Middle Palisade and Norman Clyde Peak, April 2011

“The Sierra should be called, not the Nevada or Snowy Range, but the Range of Light. And after ten years of wandering and wondering in the heart of it, rejoicing in its glorious floods of light, the white beams of the morning streaming through the passes, the noonday radiance on crystal rocks, the flush of the alpenglow, and the irised spray of countless waterfalls, it seems above all others the Range of Light.”

John Muir, *The Yosemite*, (1912)

Anyone who bestows their glance upon the slopes of the Sierra Nevada during daylight hours can relate to Muir's words. Though light is favored upon all facets of Earth's surface, in the high mountains, it takes on a magical character by giving extra character to the landscape. When dawn casts her rose-red fingers along seemingly blank vertical rock walls jutting into the sapphire sky, she brings them to life as laser-cut cracks, water streaks, and flying buttresses descending from the serrated mountain crest become illuminated. Ancient trees and lakes sitting in the shaded lowlands catch the reflections of the crimson and gold rays. With the sun rising higher and light reaching the meadows, the mountains fully emerge from rest. The day passes with stark brilliance as the sun arcs overhead casting white light upon all landforms and creatures but slowly causing once-warm morning slopes to fade into the shadows. With the approach of evening, the ingredients for another light show return to the western slopes to aid the transition of the Earth into the night. White light slowly melts into orange and burns into red before the looming purple shadow of the Earth (the penumbra) is cast upon the landscape as fading daylight sweeps over the range and the planet continues on its celestial path.

These twice-daily shows of color are popularly referred to as the "magic hour" or alpenglow, which derives from the German, *alpenglühén*. Countless minds have been calmed, inspired, and impassioned by the morning and evening displays that are embodied by *aisthesis*, a Greek term for perception and its bond with understanding; the mode of expression of the self and

the link with Nature. Those who find beauty in understanding Nature through its physical behaviors and have experienced the magic hour might be left wondering, "How is such glorious light possible and why is the Sierra Nevada truly the Range of Light?" Here, I will outline answers to these questions by describing the key atmospheric processes that produce alpenglow and discussing how the Sierra Nevada provides an ideal physical landscape to create luminous alpine perfection through favorable geologic and geographic factors. Should I be successful in this endeavor, those who experience alpenglow anywhere on Earth will have a greater appreciation and understanding of its physical origins.

Let us first focus on the basics of how light travels through the planetary atmosphere. The presence of an atmosphere on Earth is important not just for the habitability of the planet (it keeps the surface about 34°C warmer than if no atmosphere were present) but also for the changing the optical properties of incoming solar radiation from both physical and aesthetic perspectives. Naturally occurring gases (e.g., N₂, O₂, H₂O) and aerosol particles produced by volcanic emissions, forest fires, and anthropogenic activities interact with incoming radiation as it passes through the atmosphere. These interactions include the scattering and absorption of light, which reduce the intensity of light of certain wavelengths as it passes through the atmosphere, a process known as extinction. The contributions to extinction are linearly proportional to the intensity of light at a given point along the ray path, the local concentration of gas or aerosol matter, and the effectiveness of this matter in scattering or absorbing the light.



Donner Lake and the Carson Range, February 2014

The extinction efficiency is the ability of the available atmospheric matter to eliminate light at given wavelengths and is equal to the sum of the absorption efficiency and scattering efficiency. Assuming spherical particles for simplicity, the extinction efficiencies can be described as a function of a dimensionless size parameter X , equal to $2\pi r/\lambda$, where λ is the wavelength of light and r is the radius of the particle. The type of scattering regime is dependent upon the particle size with respect to the wavelength of light in question. For visible wavelengths, a small subset of the electromagnetic spectrum of light that our eyes can sense, there are three primary scattering regimes. For large particles of sizes much larger than the wavelengths of light ($X > 1$), for example, water droplets, visible light can be refracted to produce rainbows. Particles having sizes on the order of the wavelength of visible light ($X \approx 1$) undergo scattering in the Mie regime, which include the blue-ish haze of smoke created by aerosol particles or the white glare of the sky as one looks towards the sun. Lastly, the Rayleigh scattering regime occurs where the characteristic sizes of particles, usually gas molecules, are much smaller than the wavelengths of visible light ($X \ll 1$).

It is the Rayleigh regime where both alpenglow and the color of the sky derive their colors. Under the Rayleigh regime, the scattering efficiency is proportional to $1/\lambda^4$, and scattering occurs equally in the forward and backward directions. Mie scattering, on the other hand, scatters primarily in the forward direction, and is not nearly as wavelength-dependent as Rayleigh Scattering ($1/\lambda - 1.3$ versus $1/\lambda^4$). Because blue light ($\lambda = 400\text{nm}$) has a shorter wavelength than does red light ($\lambda = 700\text{nm}$), it is more effectively

scattered than red light (by nearly a factor of 10). During a clear, clean-air day, the highly effective scattering of blue light by the atmosphere results in the blue sky we are familiar with. In the case of alpenglow, we must examine scattering during the beginning and ends of the day and in a generally clean environment. As the sun approaches the horizon, the ray path that incoming light must take through the atmosphere becomes longer as the relative thickness of the atmosphere grows larger (by approximately $1/\cos \theta$, where θ is the zenith angle, or angle from the vertical). Light travelling through this thicker airmass and shining upon features on the Earth's surface, including mountains or buildings, will be depleted in blue light (the blues having been scattered out) leaving only red light to illuminate these features. Note how in many of the photographs included in my article, the skylight still appears blue while the surface objects are illuminated by red light. More polluted places, where aerosol concentrations are high, will have a grayer sky due to the forward and non-wavelength dependent Mie scattering regime. In mountain valleys, the establishment of a stable boundary layer during the night traps pollutants and results in more Mie scattering during the morning. In summary, the wavelength dependence of light scattering, the length of the beams of light entering and travelling through the atmosphere, and the sizes of matter that light interacts with results in the color of the sky and the color of objects near the surface.

We turn now to the geographic and geologic settings of the Sierra Nevada that makes it an ideal location to observe the results of Rayleigh scattering. Located approximately 160 km inland



Morning fog over Bridgeport Reservoir with the Sawtooth Range illuminated.



Skiing into the alpenglow on Mt Langley

from the Pacific Ocean along the west coast of North America at latitudes spanning 35°N — 41°N , the range is oriented northwest-southeast and has a characteristic crest elevation ranging from 2500 m—4200 m (increasing as one heads south). The proximity to the Pacific Ocean and its relatively low latitude produces a mild and wet cool season and hot and dry warm season. During the cool season, the climate is dominated by prolonged large-scale ridging with occasional transitions to waves of transient extratropical cyclones that bring rain to the lowlands and snow to the high country. The warm season is also characterized by large-scale ridging with occasional monsoonal moisture surges that move poleward along its eastern flank that act in concert with strong surface heating to produce thunderstorms in the higher elevations. The result of the often-fair weather is a large proportion of sunny days, allowing for maximum solar radiation to bathe the range. Air quality on the eastern side of the range is often excellent, however the western side is susceptible to various pollutants, produced by California's nearly 40 million residents, which are transported into the Sierra Nevada by the mean westerly wind. Forest fires throughout the range are a perpetual air quality hazard, among other problems, and while they contribute to interesting optical phenomena, even the most intrepid fans of alpenglow will likely avoid smoky regions.

With a favorable climate on its side, the keystone of the Range of Light lies in its geology and geomorphology. Born from plate tectonics, the Sierra Nevada is composed of many granitic plutons that formed in the shallow subducting oceanic crust as the Farrallon plate slid beneath the less-dense continental North American plate. The plutons formed incrementally over millions of years and cooled slowly, allowing elements such as calcium,

oxygen, aluminum, silicon, potassium, and sodium to crystallize into large-grained felsic minerals including quartz and feldspar. The relative abundance of quartz and feldspar in granite give it a much lighter color than more mafic rocks such as basalt and gabbro, which are rich in heavier elements such as magnesium and iron. The felsic nature of the Sierra Nevada yields a generally lighter color of rock and enhances the range's albedo, or ability to reflect the red, orange, and purple (recall that this is Earth's shadow) lights of the alpenglow hours.

Tectonic uplift and faulting along the western margin of North America during the past four million years combined with the erosive power of Quaternary glaciations during the past 2.6 million years have honed the Sierra Nevada granite into a perfect observatory for alpenglow. Near-vertical walls of ice-polished granite lining deep U-shaped valleys sprawl into the valleys on both sides of the crest, formed by rivers of ice that flowed bank-full 20,000 years ago, a blink of geologic time. The agency of ice smoothed large feldspar and quartz crystal grains to glass-like smoothness, making their surfaces reflect light in a coherent manner and contributing to the overall reflectivity of the range. Although the ice has since left with the termination of the last Glacial Maximum 16,000 year ago, the effects of glaciers on geomorphology linger on. The rapid reduction in pressure on the once ice- and snow-covered granitic mountainsides and monoliths like Half Dome (Tis-sa-ack)—or the Incredible Hulk—has resulted in a rebound effect that increased mass-wasting rates.

Un-balanced forces cause large slabs and blocks of rock to constantly exfoliate, resulting in vertical canvases for the twice-daily solar art shows to take place. These erosive processes are

aided by moist winters where water flows into the numerous fractures, freezes, expands, and dislodges the slabs, and by hot summers, where thermal expansion literally shifts the weakened material over the brink of instability where it can fail catastrophically and plummet towards the canyon floors and form massive talus cones of debris. Erosion depends strongly upon the grasp of gravity, and with regional tectonic uplift launching the granite towards space while the downward pull of Earth is perpetually being exerted upon the mountainsides leading to an ongoing battle between planetary forces of nature.

The Range of Light represents an iconic confluence of planetary phenomena that yields a bountiful harvest of aesthetic and scientific pleasures. The presence of a clean atmosphere favoring Rayleigh scattering regimes results in morning and evening hours enriched in deep hues of reds, oranges, and golds separated by gleaming blues throughout the middle of the day. The present-day Mediterranean climate favors a high frequency of cloudless days and sufficient effective moisture to yield

glistening waterfalls, snow-cloaked hillsides, and vast forests that can be illuminated by light depleted in blue and rich in red. Plate tectonics at the continental margin gave birth to granitic plutons rich in minerals capable of reflecting light and regional tectonics uplifted the plutons into the path of Rayleigh scattered-light. The millennial pulse of glacial cycles carved and polished the uplifted plutons into spectacular landforms to observe such light upon. The perpetual forces of gravity, supplanted by the thermal properties of water and rock, further hone the faces of the mountains into exquisite reflective surfaces. It must be noted that these processes do not operate in the Sierra Nevada alone. Much of the topographic relief on Earth has some or all of these characteristics, but in the Sierra Nevada, the convergence of geographic, geologic, and atmospheric factors leading to a unique and highly pleasing landscape to spend one's time is perhaps unmatched. With these thoughts in mind, I leave you, kind reader, with the words of Israel Cook Russell to take with you on future journeys to mountainous lands:

"The glare of the noonday sun conceals rather than reveals the grandeur of this rugged land, but in the early morning and the near sunset the slanting light brings out mountain range after mountain range in bold relief, and reveals a world of sublimity. As the sun sinks behind the western peaks and the shades of evening grow deeper and deeper on the mountains, every ravine and cañon becomes a fathomless abyss of purple haze, shrouding the bases of gorgeous towers and battlements that seem incrustated with a mosaic more brilliant and intricate than the work of the Venetian artists."

Israel Cook Russell, Geological History of Lake Lahontan, (1885)

All photographs by Ben Hatchett



Descending the Incredible Hulk, July 2012

Contributing Artists

In this issue of *Mountain Views*, we feature field notebook sketches and drawings or paintings made from field views in the course of mountain studies and nature observation. Where appropriate, we included the text that accompanied the original sketches. May we all be inspired by these scientist-artists to take time to observe and draw what we are studying (including what we see and don't understand) in the course of field research.

Jim Patton, mammologist professor emeritus from the University of California, Berkeley, introduced me to the early 20th-century field notebook work of **Charles Camp**. Charles was a UC undergraduate in the 1915s when he sketched the drawings we include, having worked under George Grinnell on the now-famous natural-history studies from that era. In regard to the wolverine drawing (pg. 49), Jim noted to me that Camp's field notes indicate (p. 487), "July 25, 1915. Sunday, - the Lord hath sent us a wolverine..." Jim also told me that the last Sierran wolverine that was accessioned into the Museum of Vertebrate Zoology collection was collected by Albert Gardisky, a professional trapper that Grinnell knew well, at Saddlebag Lake (nearby the Camp drawing) in 1922.

Adrienne Marshall is a graduate student in the Energy and Resources Group at the University of California, Berkeley. She has wide interests in hydrology, watershed studies, and mountain systems. Adrienne is an avid mountain walker, and has spent considerable time in the Sierra Nevada of California, where she sketches mountains, lakes, skies, trees, and animals that she encounters. In addition to drawings like those included in this issue, Adrienne has a gallery of completed paintings, which you can view at: <https://adriennehikes.wordpress.com/2014/07/17/paradise-lake-07132014/>.

Fred Paillet is professor emeritus in the Department of Geosciences at the University of Arkansas. His research expertise focuses on hydrogeology of fractured bedrock aquifers, in situ measurement of permeability, groundwater flow modeling, and scale analysis in aquifer characterization, but this is only the tip of Fred's science interests. I first met Fred at the PACLIM conferences in the 1980s, where we found we shared an interest in trees. Fred describes his forest ecology and vegetation science work as "hobbies", but his observations—combined with extensive knowledge of geomorphology—have enlightened this forest ecologist for several decades now. We have included Fred's art in past issues of *Mountain Views* and I'm glad to include works from his field notebooks again.

Denise Waterbury is on the staff of the University of California's White Mountain Research Center in Bishop, California. Among other mountain jobs, Denise spent summers in the past as US Forest Service wilderness ranger in the Sierra Nevada, CA and Uinta Mountains, UT. Her expertise in California botany makes her an invaluable advisor to our GLORIA (alpine plant survey) projects in California.

Wally Woolfenden is retired paleoecologist and archeologist formerly with the US Forest Service, Pacific Southwest Region, California. Wally's research has been on vegetation and climate reconstruction using pollen from sediment cores of lakes, including the 800,000 yr Owens Lake, California record. Wally's geosciences training gives him ample expertise to read the geomorphology as he passes through the landscapes of his Sierra Nevada, CA homelands. I am pleased to include Wally's artwork again in this issue.

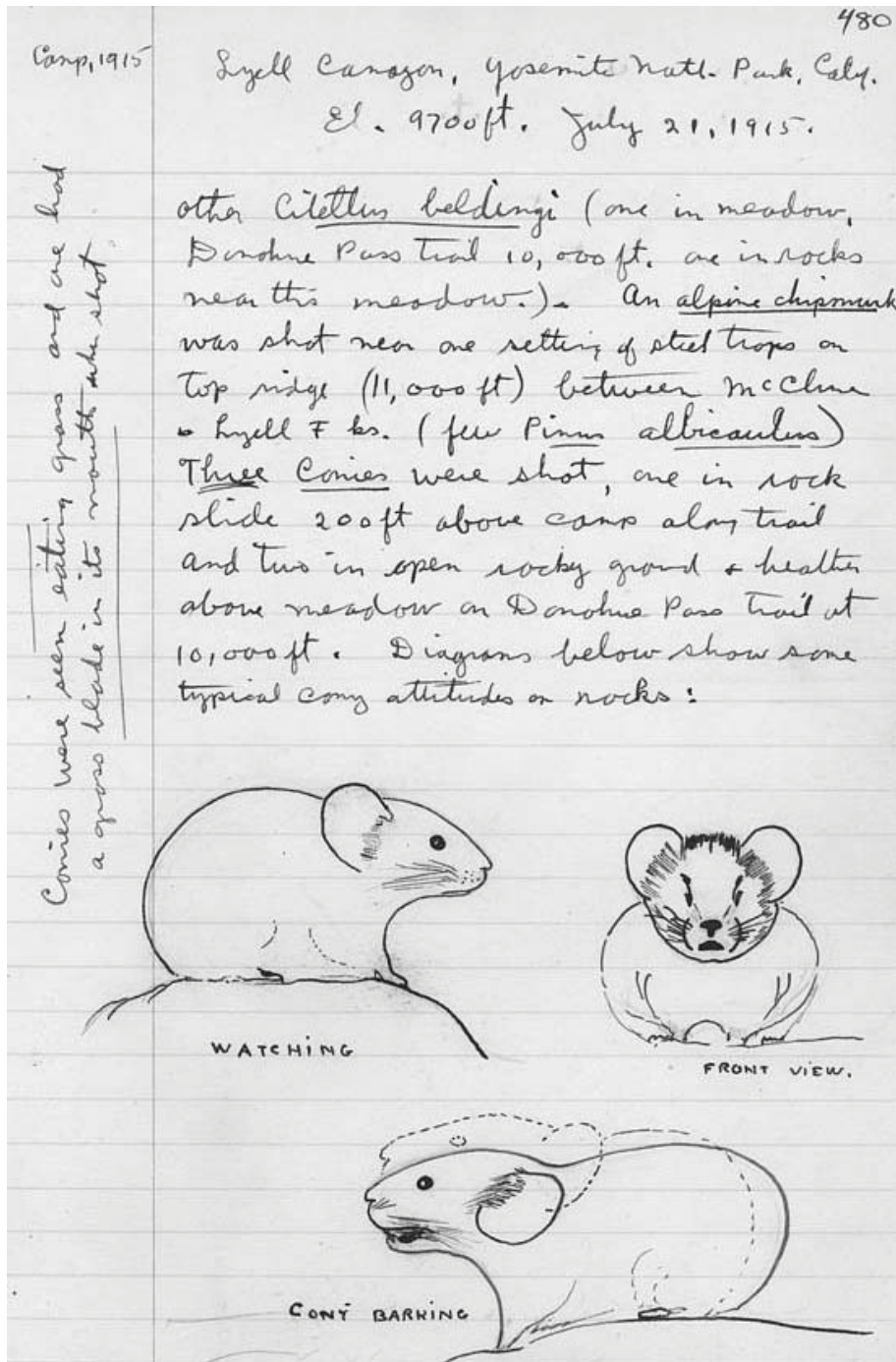
For the past 12 years, I have been teaching a tree-ring portion of a geology field class in the eastern Sierra Nevada, CA led by Dr. Michael Hamburger, professor of geology at Indiana University, Bloomington. Michael stresses the importance of keeping a detailed field notebook, and many students also sketch what they are studying. I am pleased to include drawings from the notebooks of **Mike Harpring** and **Andy Bustin**, who took Michael's course in 2006 and 2007, respectively.



Tundra flower, Cape Krusenstern, Alaska, June 16, 2014. Fred Paillet

Mountain Visions

Charles Camp



American pika. Field notes of Charles Camp from the Archives of the Museum of Vertebrate Zoology, University of California, Berkeley (<http://bscit.berkeley.edu/mvz/volumes.html>; Volume 557, Section 3, 21 July 1915, page 182).

Adrienne Marshall



Showers Lake, Sierra Nevada, California, July 7, 2014

In a continuation of our Southbound journey through Northern and Central California, we headed south out of the Tahoe area and into spectacularly beautiful and lightly visited wilderness areas. This chunk of trail includes the Carson-Iceburg and Mokelumne Wilderness, both of which are areas I had never heard of before hiking the PCT. They're situated solidly in the Sierra Nevada, but I found a lot of the scenery there to be more diverse, and sometimes bizarre, than the classic Sierra scenery we might think of.

This painting was a bit of an experiment – the drawing was done on a cold evening, but despite chilly fingers, I found myself drawn into a trance-like state as I followed the curving branches of the small lodgepole pine in the foreground. I've realized that a lot of my paintings recently have been dominated by blues, so I pushed myself to do this one in tones of yellow. To some extent, I think it was a successful experiment, but I think paying more attention to the warm/cool tones and the value (dark/light) contrasts while at this lake would have helped set me up for this experiment a little better. Either way – might be something to explore more in the future!

Fred Paillet



REDPOLL NEST IN WILLOW IN
BROOKSIDE MEADOW - NO
EGGS BUT AT LEAST ONE
LITTLE CHICK



JUNE 17, 2014

THE GRASSY MEADOWS ALONG THE LITTLE
BROOK IN THE VALLEY JUST NORTH OF CAMP
PLEASANT WALKING AND HOST TO SEVERAL
EXTENSIVE CLUMPS OF ALASKA IRIS WITH NEW
FOLIAGE EMERGING AND STALKS FROM LAST
YEARS FLOWERS STILL IN EVIDENCE.

ARCTIC POPPY - ONE OF THE FEW EARLY TUNDRA
FLOWERS SURVIVING INTACT.

Sketches from field notebook, Cape Krusenstern, Alaska, June 17, 2014



JUNE 16, 2014

VIEW ACROSS TUNDRA
VALLEYS AND HILLS
WHERE MUSK OXEN
COULD BE GRAZING.

NOTE STONE STRIPES
AND SOLIFLUCTION LOBES

Fred Paillet. Cape Krusenstern, Alaska,
June 16, 2014