

MOUNTAIN VIEWS

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



Informing the Mountain Research Community

VOL. 8, NO. 2
NOVEMBER 2014



White Mountain Peak as seen from Sherwin Grade north of Bishop, CA. Photo: Kelly Redmond

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

Layout and Graphic Design: Diane Delany, USDA Forest Service, Pacific Southwest Research Station, Albany, California

Front Cover: Rock formations, Snow Valley State Park, near St George, Utah. Photo: Kelly Redmond

Back Cover: Clouds on Piegan Pass, Glacier National Park, Montana. Photo: Martha Apple

Read about the contributing artists on page 71.

Mountain Views

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

CIRMOUNT

Volume 8, No 2, November 2014

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

Table of Contents

The Mountain Views Newsletter	Connie Millar	1
Articles		
Parque Nacional Nevado de Tres Cruces, Chile: A Significant Coldspot of Biodiversity in a High Andean Ecosystem	Philip Rundel and Catherine Kleier	2
The Mountain Invasion Research Network (MIREN), reproduced from GAIA Zeitschrift	Christoph Kueffer, Curtis Daehler, Hansjörg Dietz, Keith McDougall, Catherine Parks, Anibal Pauchard, Lisa Rew, and the MIREN Consortium	7
<i>MtnClim 2014</i> : A Report on the Tenth Anniversary Conference; September 14-18, 2014, Midway, Utah	Connie Millar	10
Post-MtnClim Workshop for Resource Managers, Midway, Utah; September 18, 2014	Holly Hadley	19
Summary of Summaries: Key Messages from the Global Fair and Workshop on Long-Term Observatories, Reno, Nevada; July 2014	Greg Greenwood	21
Brevia		
Obtaining Downscaled Versions of the Latest Climate-Change Scenarios	Mike Dettinger	30
A 2000-Year Reconstruction of Air Temperature in the Great Basin of the United States with Specific Reference to the Medieval Climatic Anomaly	Scott Reinemann, David Porinchu, Glen MacDonald, Bryan Mark and James DeGrand	31
Hotter, Drier Climate Leads to More Tree Deaths from Fire	Phillip van Mantgem	36
Climatic Changes in Mountain Regions: A Review of Historical Changes and Future Outlook in the American Cordillera and the Tropics	Henry Diaz	38
Floods, Fire, and More—Climate Change Effects and Adaptation in the North Cascades	David Peterson	42

Mountains, Climate Change, and Conservation: The Role of Landscape Genomics	Brenna Forester, Dean Urban, Thomas Schultz, Jennifer Wernegreen, and Rob Dunn	44
Interviews		
An Interview with Kelly Redmond; AGU 2014 Tyndall History of Global Environmental Change Lecturer		48
An Interview with Mike Dettinger; 2014 Fellow of the American Geophysical Union		51
Voices in the Wind		
Responses from Chris Daly, Sarah Null, Imtiaz Rangwala, Karen Pope, Steve Kroiss, Jared Oyler, Monica Buhler, Alina Cansler, and Dave Porinchu		54
News, Briefs, and Events		
David Inouye, New President of the Ecological Society of America		58
Mountain Research Initiative Convenes Meeting of the New Science Leadership Council		59
Mountains of Future Earth Conference: PERTH III		61
Mountain Social Ecological Observatory Network (MtnSEON)		62
Alpine and Arctic Treeline Ecotone Network Activities		64
New Book: Forest Conservation and the Anthropocene		65
Coordinated Distributed Experiments of Interest		66
Did You See (Hear, Feel, Touch, Smell) It?		
Willow Rust: A New Outbreak in the Great Basin or Just a Pathogen New to Me?	Connie Millar	67
Contributing Artists		
Mountain Visions		
Valerie Cohen Art		71
Mike Dettinger Poetry		72

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* of recently published articles, book reviews, mountain climate news and announcements, and our seasonal round-up of mountain artwork and poetry.

In the months since the last issue, CIRMOUNT scientists have claimed prominent recognition in professional society leadership. Kelly Redmond, Regional Climatologist and Deputy Director of the Western Regional Climate Center, Reno, NV, was selected by the American Geophysical Union (AGU) as the annual *Tyndall History of Global Environmental Change Lecturer*, which honors Kelly's outstanding contributions to understanding and communicating global environmental change. Mike Dettinger, Research Hydrologist with the US Geological Survey and SCRIPPS Institution of Oceanography at La Jolla, CA, was elected to the 2014 Class of Fellows of the American Geophysical Union for his critical body of climate-science work. I took these events as opportunities to talk with Kelly and Mike about their research goals, how they approach their work, and how mountains fit into their thinking. Read interviews with Kelly on page 48 and Mike on page 51. As a bonus, find Kelly's photographs scattered through this issue and Mike's poetry in the Mountain Visions section (inside back cover). Two other CIRMOUNT scientists are playing key roles in the Ecological Society of America: Jill Baron (USGS, Ft Collins, CO) and David Inouye (University of Maryland, College Park, MD) are 2014 President and 2015 President, respectively (see page 58). Congratulations to these four mountain scientists, and to all others in our community who have been recognized this past year.

Mountain-science events also played prominently in our summer and fall calendars. Among these was the *Global Fair and Workshop on Long-Term Observatories on Mountain Social-Ecological Systems*, sponsored by the Mountain Research Initiative (MRI) and University of Nevada at Reno, where the conference was held. This event brought together an international group of scientists that focused on the current state and future needs of mountain observatories. A key function of the Fair and Workshop was not only to communicate current research results but to engage and catalyze effective ongoing discussion (page 21). CIRMOUNT's flagship *MtnClim* conference this year was

the 10th anniversary for our consortium. The *MtnClim 2014* Climate Conference convened at the Homestead Resort in the Wasatch Mountains of Utah (page 10). I am happy to report that Andy Bunn (Western Washington University, Bellingham, WA) and Scotty Strachan (University of Nevada at Reno) agreed to take the role as lead organizers for the next conference, *MtnClim 2016*. Diane Delany (USFS, Albany, CA) and I are ready to pass the torch, although we're sure to keep our noses involved with future *MtnClim* planning.

Coming soon in December is the annual Fall Meeting of the AGU in San Francisco, with two sessions organized by CIRMOUNT, one by the Mountain Research Initiative, and undoubtedly mountain sessions organized by many of you. If you are interested in informal events during AGU, contact me (cmillar@fs.fed.us) about the annual CIRMOUNT dinner (Tues, 12/16) or Greg Greenwood (green@giub.unibe.ch) about the MRI Mountain Mixer, a new event this year (Thurs, 12/18).

The days may be getting shorter, but here in the Bay Area short-sleeve weather prevails. I hope to find snow in the Mono Basin during the holidays this week, and I wish you and your families Thanksgiving tidings and winter mountain adventures ahead.

—Connie Millar, Editor



Connie rings in the herd after a break during *MtnClim 2014*.
Photo: Scotty Strachan



Figure 2. The extensive Salar de Maricunga, the southernmost dry lake basin of the Altiplano, extends for 30 km from north to south, with Laguna Santa Rosa at an elevation of 3715 m lying at its southern end. Photo: Segejf.

A second topographic feature of the park is Laguna Negro Francisco, a large but shallow lake lying at 4125 m elevation in another closed drainage basin to the south. It covers an area of about 2000 ha, but with a range from 1700 to 3100 ha due to annual variation in precipitation and snowmelt. However, the average depth of the lake is only about 1 m. Despite this shallow depth, two distinct basins are present within the lake, an eastern portion with relatively saline (10,000 mhos), and a western with only moderately brackish water (5000 mhos) because of freshwater inputs. The drainage basin of the lake extends over an area of 930 km², with most of the moisture input entering along the Río Astaburuaga that brings snowmelt from the high mountains to the east. The shallow depth and variable extent of Laguna Negro Francisco has made it an important site for paleoclimate studies and conservation area for water birds.

The eastern margin of the drainage basin of the Salar de Maricunga is marked by a series of high volcanoes of the Cordillera Claudio Gay, lying largely just outside of the park along the Chilean border with Argentina (Fig. 3). The most notable of these is Nevado Ojos de Salado, the highest active volcano in the world and second highest peak in the Western Hemisphere at 6864 m. The southernmost of the three peaks of Nevado de Tres Cruces reaches 6748 m, making it the sixth highest peak in South America. The central and northern peaks of Nevado de Tres Cruces are 6629 and 6030 m elevation, respectively, with the former the eleventh highest peak in South America. Other high volcanic peaks east of the park include Barrancas Blancas (6119 m), Vicuñas (6067 m), El Ermitaño (6146 m), Peña Blanca (6030 m), and Copiapó (6052 m) in Chile, and San Francisco (6018 m), Incahuasi (6621 m, the twelfth highest peak in South America), El Muerto (6488 m), Volcán del Viento (6120 m), El Fraile (6061 m), Solo (6205 m), and Tres Quebradas (6239 m) along the Chilean/Argentine border.

Human History

The region of Nevado de Tres Cruces has a long and interesting history of human visitation despite its relatively remote location. Hunter-gatherers inhabited this area in pre-Columbian times for thousands of years, and much later the region was incorporated into the Incan Empire, with a major access route established across the Andes from the east at the Paso San Francisco. An Incan ceremonial structure was found in 1913 above 6500 m near the summit of Incahuasi, just outside of the park, and additional Incan structures and cultural materials are present near the park at Volcán Azufre o Copiapó and Nevado Jotabeche. No permanent indigenous populations have existed within the park area, however, and thus there has been no continuous history of grazing by domestic animals as has occurred in the broader areas of the Altiplano to the north.

The first European group to enter the park region was the expedition of the Spanish conquistador Diego de Almagro who crossed over the Paso San Francisco from what is now Argentina and entered the area of the Salar de Maricunga in March 1536. This ill-equipped and ill-fated winter crossing of the Andes led to horrific losses of men and pack animals because of the cold and high elevations. The outcome of this expedition was later memorialized in a number of geographic names that remain today – El Muerto, Mulas Muertos, and Toro Muerto. After struggling across the mountains, Almagro and his remaining men rested in the Copiapó Valley. Rather than again face the treacherous mountain crossing, they returned to Peru using the old Incan trail along the foothills of the western slope of the Andes.



Figure 3. View looking southeast from the Cuesta Codocedo across the Salar de Maricunga toward Nevado de Tres Cruces. The south peak on the right reaches 6748 m, making it the sixth highest peak in South America, while the central peak at 6629 m is the eleventh highest peak on the continent.

Modern geographic knowledge of the region of Nevado de Tres Cruces was not available until more than three centuries later. Beginning in 1883, a mining engineer from Copiapó named Francisco San Román directed a series of exploratory expeditions that surveyed the north-central Andes around Nevado de Tres Cruces and delineated the Chilean/Argentine border. Data from five summers of detailed field studies provided the first accurate maps of this region and bestowed most of the geographical names used today. At the same time that these geographical surveys were being carried out, the Chilean government commissioned Federico Philippi, the son of the famed Chilean botanist R. A. Philippi, to prepare a botanical and zoological description of the high Andean plateau. Philippi set out from Copiapó in January 1885 and explored a broad area including what is today Parque Nacional Nevado de Tres Cruces.

The era of the nitrate mining boom in northern Chile in the late 19th century, at the time that San Roman and Philippi were completing their surveys, led to strong economic pressures for the establishment of transportation routes for cattle and hides across the Andes into Chile from the pampas region of Argentina. The region of Paso San Francisco and Nevado de Tres Cruces provided the southern of two primary trade routes. This route was similar in length to the northern route through the oasis of San Pedro de Atacama, requiring 20 days of travel.

The high peaks of the region have attracted many mountaineers from abroad. The first ascent of Nevado de Ojos Salados near the park did not occur until 1937 when two Polish climbers reached the summit. During the 1950s there was considerable controversy raised over Nevado Ojos del Salado based on claims that it reached 7086 m, a height that would have made it taller than

Aconcagua. An expedition by the American Alpine Club in 1956 completed a detailed survey involving triangulation between 18 stations and a fixed site in the Salar de Maricunga to establish the correct height of the peak, 6864 m.

Sustaining Biodiversity

Nevado de Tres Cruces provides protection for an area of extraordinary Andean landscape with high volcanoes and associated salares and lake basins. Based on limited field surveys of vertebrate species, the stark landscape is home to at least 62 species of birds, 11 species of mammals, and four species of reptiles. Of particular significance for conservation are the large populations of wetland birds that utilize Laguna Negro Francisco and Laguna Santa Rosa. These two lakes together form one of 12 RAMSAR sites in Chile. Laguna Negro Francisco in particular is considered to be one of the most important breeding sites for water birds in the central Andes. The park is one of the few areas where three species of flamingos occur together - Andean flamingo (*Phoenicopterus andinus*), Chilean flamingo (*Phoenicopterus chilensis*), and James flamingo (*Phoenicopterus jamesi*) (Fig. 4).

Small wetland peatlands, termed bofedales or vegas depending on the shape and position, form fascinating peatland ecosystems occurring in a hyper-arid high mountain region, provide keystone ecological communities for wildlife in this dry region. Unlike typical peatlands, woody cushion-forming species of Juncaceae, most notably *Oxychloe andina* and *Patosia clandestina*, are the community dominants and primary peat-formers (Fig. 5). The sources of water for the bofedales are fresh and/or mildly saline groundwater originating from glaciers, snowmelt and



Figure 4. Laguna Santa Rosa is home to large populations of flamingos and other waterbirds. The Andean flamingo (*Phoenicopterus andinus*) shown here occurs with both the Chilean flamingo (*Phoenicopterus chilensis*) and James flamingo (*Phoenicopterus jamesi*). Photo: Sergej.



Figure 5. Author Kleier with frozen cushions of *Oxychloe andina* and *Patosia clandestina* (Juncaceae) along the margin of Laguna Santa Rosa. The woody cushion growth-form of these rushes and their spiny surface help protect them from grazing by vicuñas and other animals.

rain. Paleoecological investigations suggest that these wetlands are recent features of the landscape having generally developed within the last three thousand years or less. These wetlands are unique, extremely fragile ecosystems and highly sensitive to even modest climate change and human disturbance. The bofedales of Nevado de Tres Cruces and other areas of the Altiplano in northern Chile play a critical role in sustaining a small but unique diversity of rare animals and plants that depend upon the peatlands for grazing, nesting and water. Small indigenous communities of native Aymara and Atacameños in the Altiplano to the north are also dependent upon the bofedales for grazing by their domestic herds of llamas (*Lama glama*) and alpacas (*Vicugna pacos*), which are the basis of the indigenous economy.

Seventeen species of vertebrate animals in the park are taxa with conservation concerns within Chile. Species classified as endangered include vicuña (*Vicugna vicugna*), guanaco (*Lama guanicoe*), short-tailed chinchilla (*Chinchilla chinchilla*), puma (*Felis concolor*), and peregrine falcon (*Falco peregrines*) Fig. 6). The rare and poorly known Andean cat (*Felis jacobita*) is thought to be present. There are seven additional species whose conservation status is considered vulnerable in Chile. Special efforts are being made throughout northern Chile to reverse the dramatic decline in populations of flamingos that has occurred in recent years, and thus nesting sites within the park are critical habitats for these and other water birds. Increased mining activity and the related problem of shrinking water reserves are major factors in this decline, but global change with lowered levels of annual precipitation are also significant.



Figure 6. Vicuñas (*Vicugna vicugna*), once highly endangered, graze in the bofedales around Laguna Santa Rosa. Guanacos (*Lama guanicoe*) preferentially graze in open shrublands on drier sites. Photo: Wikipedia, Jespinos.

Plant species richness and cover within Nevado de Tres Cruces is low owing both to the aridity and the severe temperature conditions of the high elevations. Strong desiccating winds are also a limiting factor for plant growth. No thorough investigation of the flora of the park has been carried out, but the total flora is estimated to be no more than 85-95 species. Outside of wetland habitats, only scattered local patches of plant cover are present within the park. Vegetation is largely absent from extensive areas of drier slopes and the saline Salar de Maricunga. The upper limit of vegetation that we observed occurred at about 4800 m on the western slopes of the Cuesta Condocedo, just outside of the northwestern park boundary (Fig. 7).



Figure 7. Large mounded individuals of *Adesmia echinus* (Fabaceae) at about 4,500 m elevation on the Cuesta Condocedo, just outside of the park boundaries. These mounds reach more than 1 m in height and 3-4 m in diameter, growing upward as they collect sand beneath their canopies.

Sustainability and Mineral Extraction

Mining activities in the north-central Andes represent a challenge to the sustainability of Nevado de Tres Cruces with management issues associated with mineral extraction. The disjunction of the two sections of the park, for example, has everything to do with the presence of the Maricunga Belt and its minerals. Thus, several significant wetlands in this mineral belt form critical wildlife habitat but are excluded from protection. Moreover, mining activities potentially threaten wetland habitats through concessions allowing the withdrawal of scarce water resources. Further impacts have come from pollution from mine tailings and chemicals, and from exploration activities, which open up formerly inaccessible areas. Such impacts may be related broadly to recent declines in the populations of flamingos across northern Chile.

Ecotourism

Ecotourism remains relatively limited for Nevado de Tres Cruces, but will almost certainly grow as the areas more widely known and facilities improve. CONAF operates two refugios in the park. There is a small hut at Laguna Santa Rosa and a larger facility at Laguna Negro Francisco with sleeping accommodations, running water and electricity (Fig. 8). While a visit to the park is highly rewarding, it requires careful planning and organization because of the difficult means of access and the high elevations present. As ecotourism develops, there will be new environmental impacts. Landscape degradation from uncontrolled activities of four-wheel drive vehicles in both wetlands and dry habitats is already an issue and will become more significant as visitor usage increases. Strict management policies are required to protect fragile wetlands that are critically important for wildlife. These wetlands are highly fragile and easily subject to human disturbance and climate change.



Figure 8. CONAF Refugio available for visitors at Laguna Negro Francisco, 4125 m elevation. Photo: Sendero de Chile.

Acknowledgements

The authors thank the Corporación Nacional Forestal (CONAF) for its assistance in carrying out this project and Beatriz Palma for help with logistic arrangements.

Further Reading

- Arroyo, M.T.K., Marticorena, C. and Villagrán, C. 1988. La Flora de la Cordillera de los Andes, en el área de la Laguna Grande y la Laguna Chica, III Región, Chile. *Gayana, Botánica* 42:3-46.
- Arroyo, M.T.K., Castor C, Marticorena C., Munoz M., Cavieres L., Matthei O., Squeo F.A., Grosjean M. and Rodriguez R. 1998. The flora of Llullaillaco National Park located in the transitional winter-summer rainfall area of the northern Chilean Andes. *Gayana Botanica* 55:93-110.
- Arroyo, M.T.K., Squeo FA, Armesto J.J. and Villagrán C. 1988. Effects of aridity on plant diversity in the northern Chilean Andes: results of a natural experiment. *Annals of the Missouri Botanical Garden* 75:55-78.
- Bowman, I, 1924. *Desert Trails of Atacama*. New York: American Geographical Society Special Publication No. 5.
- CONAF. 1997. *Parque Nacional Nevado de Tres Cruces: Plan de Manejo*. CONAF Santiago.
- Earle, L.R., Warner R.G. and Aravena R. 2003. Rapid development of an unusual peat-accumulating ecosystem in the Chilean Altiplano. *Quaternary Research* 59:2-11.
- Squeo F.A., Osorio R. and Aranacio G. 1994. *Flora de los Andes de Coquimbo: Cordillera de Doña Ana*. La Serena: Ediciones Universidad de La Serena.
- Squeo, F. A., Warner, B. G., Aravena, R. and Espinoza, D. 2006. Bofedales: high altitude peatlands of the central Andes. *Revista Chilena de Historia Natural* 79:245-255.

We reproduce in full this concise summary of the history and work of the **Mountain Invasion Research Network (MIREN)**, a coordinated, international research consortium focusing on the patterns and processes of invasive species in mountain regions. Reproduced under permission of the Creative Commons copyright, *GAIA Zeitschrift* (www.gaia-online.net/)

Kueffer, C., C. Daehler, H. Dietz, K. McDougall, C. Parks, A. Pauchard, L. Rew, and the MIREN Consortium. 2014. *The Mountain Invasion Research Network (MIREN). Linking local and global scales for addressing an ecological consequence of global change.* *GAIA* 23:263-265.

The Mountain Invasion Research Network (MIREN)

Linking Local and Global Scales for Addressing an Ecological Consequence of Global Change

Many modern environmental problems span vastly different spatial scales, from the management of local ecosystems to understanding globally interconnected processes, and addressing them through international policy. MIREN tackles one such “glocal” (global/local) environmental problem – plant invasions in mountains – through a transdisciplinary, multi-scale learning process at the science-policy interface. The approach led to a new framing of invasions in mountains, and promoted innovation by engaging scientists and practitioners.

Christoph Kueffer, Curtis Daehler, Hansjörg Dietz,
Keith McDougall, Catherine Parks,
Aníbal Pauchard, Lisa Rew, MIREN Consortium

The Mountain Invasion Research Network (MIREN). Linking Local and Global Scales for Addressing an Ecological Consequence of Global Change | *GAIA* 23/3 (2014): 263–265 | **Keywords:** boundary organization, case-study research, global change, invasive species, mountain

Addressing the Multi-scale Nature of Environmental Problems in the “Anthropocene”

Ongoing profound anthropogenic environmental changes on Earth are characterised by many and often interacting factors, such as changing biogeochemical cycles, vanishing biodiversity, and transformation of the last remnants of wildlands through human land use. Because of the global extent and synchrony of many of these changes, scientists often refer to them collectively as “global change”. However, changes, and their consequences, happen at different spatial scales. The multi-scale nature, typical of many environmental problems, requires integrating expertise and action across all scales (from local to global), posing particular challenges for transdisciplinary research. The *Mountain Invasion Research Network (MIREN)*¹ is designed to address a complex global change issue, biological invasions, through a multi-scale learning process at the science-policy interface.

Plant Invasions in Mountains

Biological invasions are threatening biodiversity and ecosystem services throughout the world. They represent a transdisciplinary problem involving both natural and social processes, touching upon controversial value-laden issues (e. g., native/non-native, natural/artificial, uncertainty and ignorance, precautionary principle), and requiring multi-agency and multi-stakeholder solutions across multiple spatial scales, from the management of local natural areas to the regulation of global trade (Kueffer and Hirsch

Hadorn 2008, Richardson 2011, Kueffer 2013, Humair et al. 2014). The expert field of biological invasions is unique insofar as it has a 50-year history of addressing a complex environmental problem through problem-oriented and interdisciplinary research (Kueffer and Hirsch Hadorn 2008). Moreover, mountains are a particularly good study system to develop and test a multi-scale transdisciplinary research approach that supports anticipatory and proactive policy responses. Mountain ecosystems are still relatively uninvaded (Pauchard et al. 2009), they share many similarities on different continents and in different climate zones, and there is a globally connected mountain expert community.

The Mountain Invasion Research Network (MIREN)

Founded in 2005, *MIREN* is a boundary organization that bridges across scales and expert groups to understand invasion processes and support preventive measures against future invasion. Four elements are pivotal:

Global network of local case studies: *MIREN* links local scales with the global scale. It encompasses eleven case-study sites carefully selected from different ecological (subarctic to tropical, continents and islands) and socioeconomic contexts (developed and develop-

Contact: PD Dr. Christoph Kueffer | ETH Zurich | Institute of Integrative Biology | Universitätsstr. 16 | 8092 Zurich | Switzerland | Tel.: +41 44 6328759 | E-Mail: christoph.kueffer@env.ethz.ch

© 2014 C. Kueffer et al.; licensee oekom verlag. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

¹ www.miren.ethz.ch

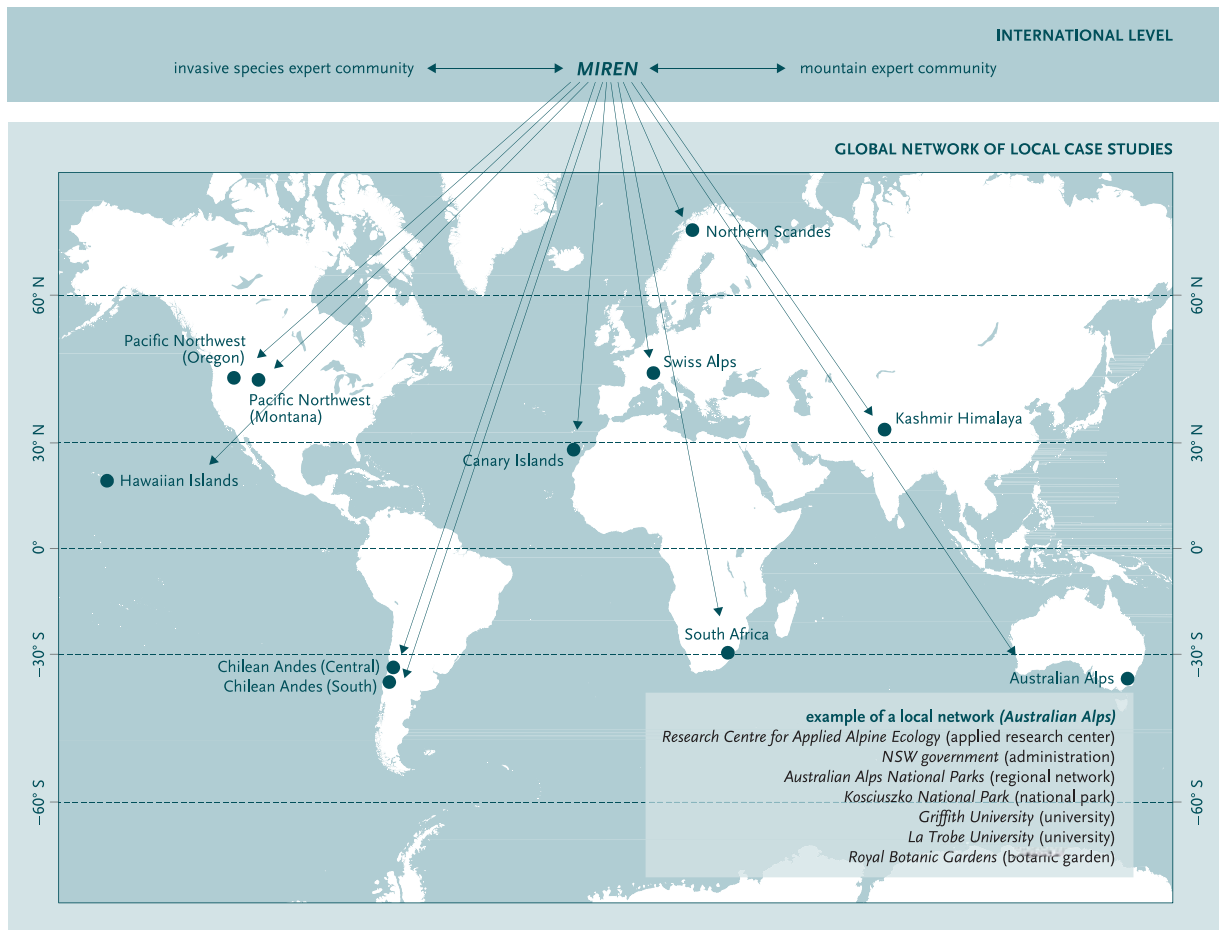


FIGURE: The multi-scale science-policy network of MIREN. Local multi-agency networks form the basis of eleven case-study sites that are distributed across different climate zones and socioeconomic contexts. At an international level, MIREN bridges the interdisciplinary fields of expertise on invasive species and mountain science/management. Made with *Natural Earth* map data, see www.naturalearthdata.com.

ing countries), including both research and management institutions at all sites (see figure). It aims to strengthen anticipatory research and precautionary management through replicated local case studies and cross-site learning. Through its integration at the global scale with existing international invasive species and mountain networks such as the *Global Mountain Biodiversity Assessment (GMBA)* and *Mountain Research Initiative (MRI)*, it reaches out to the broader research and management communities.

Inter- and transdisciplinary “community of practice”: MIREN links two interdisciplinary fields of expertise on invasive species and mountains, respectively. Its scientific and outreach publications explicitly target both expert fields. MIREN members – experts from academia and management institutions – meet biennially at a case-study site to: 1. maintain strong personal relationships among members with contrasting geographic and professional backgrounds, 2. discuss cross-site and local research projects, 3. acquire experience-based knowledge about study systems through field visits, and 4. interact with local managers and policy makers. Two chairs (that rotate every two years and are from academic and management institutions) represent MIREN.²

Open-ended, long-term process: MIREN is funded through small grants and in-kind funding raised by the local teams. Such bottom-up funding allows for adapting activities continuously in response to scientific insights and emerging management needs, and ensures that all members are personally committed to the project.

Focused empirical research: MIREN performs standardized research (observational and experimental) across all sites, plus regionally-based associated research. Involvement in focused research is important for structuring discussions, nurturing creativity, and forming shared understandings and interests. Thanks to its structure, MIREN is exceptionally well positioned to perform research that integrates in-depth studies about particular ecosystems or species at a local scale with statistical analysis of large datasets from many invasions worldwide at a global scale (Kueffer et al. 2013); as illustrated by publications in leading scientific journals (e.g., Alexander et al. 2011).

² The main co-authors include all MIREN chairs since its inception in 2005.

MIREN's Successes

MIREN has framed invasion risks in mountains in a new way by identifying human history as the primary reason for low levels of invasion at increasing elevation. Historically, non-native species were moved from one lowland area to another and these new floras did not contain mountain specialists; therefore only species with broad climate niches have reached high elevations (Alexander et al. 2011). However, the increase in tourism, recreation and residential habitation in mountains results in non-native horticultural mountain specialists being introduced to higher elevations. These ecologically novel non-native species pose a far greater invasion risk to mountain ecosystems. Thus, proactive management of invasion risks in mountains should anticipate socioeconomic change and focus on emerging introduction pathways of new species (McDougall et al. 2011); an insight that is of very general importance for invasive species management in a time of rapid societal change (Kueffer et al. 2013).

Mountain invasions are now recognized as a conservation issue by local, regional and international policy makers (e.g., Inter-governmental Panel on Climate Change). MIREN engages in mutual relationships with practitioners and policy makers in all case-study sites for developing locally-adapted solutions (McDougall et al. 2011). MIREN has established a "community of practice", which is global but locally-rooted and capable of addressing diverse multi-scale global change problems in mountains. At a local scale scientists and managers collaborate to understand the context-specific dimensions of plant invasions and their management. Such local knowledge is exchanged and cross-validated through personal encounters among scientists and practitioners from multiple sites. Emerging concerns that require international policy responses – such as weed risk assessments specific to mountains or databases as a basis for preventive action – are infused into international science and policy bodies among others through MIREN's partner organizations (e.g., *Global Change in Mountain Regions* conference series co-organized by MRI or policy-oriented activities of GMBA).

Building on such institutional capacity, MIREN is expanding its scope by collaborating with plant pathologists and zoologists to understand all type of bio invasions in mountains and by addressing other global change impacts on mountain vegetation.

Conclusions

Many modern environmental problems span vastly different spatial scales from the management of local ecosystems to understanding globally interconnected processes and addressing them through international policy. The institutional model of MIREN illustrates how such global environmental problems can be addressed through a cost-effective, rapid and transdisciplinary research and policy process. A key idea is complementarity: MIREN builds on existing institutions at a local and international level but focuses on a specific problem.

References

- Alexander, J. M. et al. 2011. Assembly of non-native floras along elevational gradients explained by directional ecological filtering. *Proceedings of the National Academy of Sciences of the United States of America* (PNAS) 108: 656–661.
- Humair, F., M. Siegrist, P. J. Edwards, C. Kueffer. 2014. Understanding misunderstandings in invasion science: Why experts don't agree on common concepts and risk assessments. *Neobiota* 20: 1–30.
- Kueffer, C. 2013. Integrating natural and social sciences for understanding and managing plant invasions. In: *Biodiversity and Society in the Pacific Islands*. Edited by S. Larrue. Aix-en-Provence: University Press of Provence (PUP), Canberra: ANU ePress. 71–96.
- Kueffer, C., G. Hirsch Hadorn. 2008. How to achieve effectiveness in problem-oriented landscape research: The example of research on biotic invasions. *Living Reviews in Landscape Research* 2: 2. doi:10.12942/lrlr-2008-2.
- Kueffer, C., P. Pyšek, D. M. Richardson. 2013. Integrative invasion science: Model systems, multi-site studies, focused meta-analysis, and invasion syndromes. *New Phytologist* 200: 615–633.
- McDougall, K. L. et al. 2011. Plant invasions in mountains: Global lessons for better management. *Mountain Research and Development* 31: 380–387.
- Pauchard, A. et al. 2009. Ain't no mountain high enough: Plant invasions reaching new elevations. *Frontiers in Ecology and the Environment* 7: 479–486.
- Richardson, D. M. (Ed.). 2011. Special issue: Human-mediated introductions of Australian acacias – A global experiment in biogeography. *Diversity and Distributions* 17: 771–1075.

Submitted May 26, 2014; revised version
accepted July 9, 2014.

CONTRIBUTING AUTHORS

PD Dr. Christoph Kueffer
Dr. Hansjörg Dietz

both: ETH Zurich, Institute of Integrative Biology, Zurich, Switzerland

Prof. Dr. Curtis Daehler

University of Hawaii at Manoa, Department of Botany, Honolulu, HI, USA

Dr. Keith McDougall

La Trobe University, Department of Environmental Management and Ecology, Wodonga, Australia

Dr. Catherine Parks

U.S. Forest Service, Pacific Northwest Research Station, La Grande, OR, USA

Prof. Dr. Aníbal Pauchard

Universidad de Concepción, Facultad de Ciencias Forestales, and Institute of Ecology and Biodiversity (IEB), Concepción, Chile

Prof. Dr. Lisa Rew

Montana State University, Land Resources and Environmental Sciences Department, Bozeman, MT, USA

MIREN Consortium

Jake Alexander, José Ramón Arévalo, Lohengrin Cavieres, Peter J. Edwards, Sylvia Haider, Lloyd Loope, Richard N. Mack, Ann Milbau, Bridgett J. Naylor, Rüdiger Otto, Fred Pollnac, Zafar A. Reshi, Ian Rushworth, Tim Seipel, Neville Walsh

Christoph Kueffer

PhD in environmental sciences (2006) and habilitation in plant and global change ecology (2013) from ETH Zurich, Switzerland. Project manager of MIREN since the start of the project in 2005 and senior scientist at ETH Zurich. Research interests: plant ecology, global change ecology, mountains, oceanic islands, invasive species, transdisciplinary environmental research, environmental humanities.



View from The Crater, Homestead Resort, Midway, Utah. Photo: Jeff Hicke

MtnClim 2014: A Report on the Tenth Anniversary Conference **September 14-18, 2014, Midway, Utah**

Connie Millar

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

The Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT) circles 2004 as its founding year. In May of that year, we convened the first conference, the *Mountain Climate Sciences Symposium*, at Kings Beach, Lake Tahoe, California, as a means to gauge interest among mountain scientists for an interdisciplinary consortium, and to vet high priority climate-related research and management issues facing western North American mountains. The vibrancy of that first meeting and enthusiasm of participants encouraged us to organize regular meetings, now convened biennially as the *MtnClim Climate Conferences*. The first meeting also prompted a project to develop *Mapping New Terrain, Climate Change and America's West* (www.fs.fed.us/psw/cirmount/publications/), a publication that documents key issues emerging from the 2004 meeting.

MtnClim 2014, held at the Homestead Resort in the Wasatch Mountains of Utah, marked the tenth anniversary conference. In general, the MtnClim Conferences seek to be a forum for promoting the goals of CIRMOUNT, that is, to advance the sciences related to climate and its interaction with physical, ecological, and social systems of western North American mountains. As such, the meetings emphasize interdisciplinary communication through oral and poster sessions, and especially recognize the importance of networking and small group meetings. To foster this exchange, the meetings are located in mountain venues, and attendance is held to about 100 participants. Our motto is, "Serious Science in an Informal Setting".

Field Trip to the Uinta Mountains

Our *MtnClim 2014* week in the Wasatch Mountains of Utah began with a pre-conference field trip through the nearby Uinta Mountains, led by John Shaw, lead scientist with the Forest

Inventory and Analysis (FIA) Program of the US Forest Service, Rocky Mtn Research Station (Ogden, UT), who provided abundant material, experience, and information about the range. The Uinta Mountains are unusual in North America in that they are oriented east-west, forming a high-elevation bridge between the Colorado portion of the Rockies and the Wasatch Mountains of Utah. The Uintas form biogeographical boundaries of several sorts, that is, separating historical Ute and Shoshone Tribal lands, marking the northern limit of influence of the North American Monsoon, and forming the northern or southern range limits of several tree species. The mountains are a prime example of a geological anticline, contain deeply carved glacial valleys, and exhibit textbook vegetation zonation patterns.



John Shaw, Kathy Jacobs, and Brenna Forester in the Uinta Mtns.



The north slope of the Uinta Mtns, with characteristically flat glacial valley floors, and recently burned forests.



Craig Allen proclaims to Kelly Redmond, while Justin DeRose and Bob Westfall look on. Lodge from the "Tie-Hacking" era behind.

The field trip traveled along the western portion of the Uintas along Mirror Lake Highway over the crest of the range at over 3000 m, in the shadow of Hayden Peak (3804 m). On the north slope, we continued through a nearly continuous band of lodgepole pine forest, which served as the main source of wood for the building of the regional segment of the Transcontinental Railroad. At the same time, large tracts of forest dominated by trees that pre-date Euro-American settlement also remain. The unique pattern of disturbance that produced this situation was obvious, along with the ongoing patterns of disturbance from insects and fire. Farther along the north slope, we passed from continuous forest into aspen parkland and sangelands. Although the abrupt transition from forest to sagebrush steppe is not unique to the Uintas, this area of the north slope is notable for the absence of woodland species such as pinyons, junipers, and scrub oaks. The presence and absence of these species in different parts

of the range are likely clues to climatic controls over vegetation in the region.

Of particular interest to field trip participants were the views we saw and data John provided about recent forest mortality. In all dominant conifer types (including whitebark pine, Engelmann spruce, subalpine fir, and limber pine), abundant landscape-scale mortality was apparent throughout the tour. Much of this, as elsewhere in the West, was bark-beetle induced, drought-related, accelerated around 2007 (Fig. 1a), and has been in decline since 2012. The widespread distribution and high density of FIA forest plots throughout the Uintas afford quantitative estimates of the cumulative forest health conditions in the range. These are summarized qualitatively in a simplified graphic of the relative proportions of live standing forest in 2012, average annual growing stock, and average annual mortality (Fig. 1b).

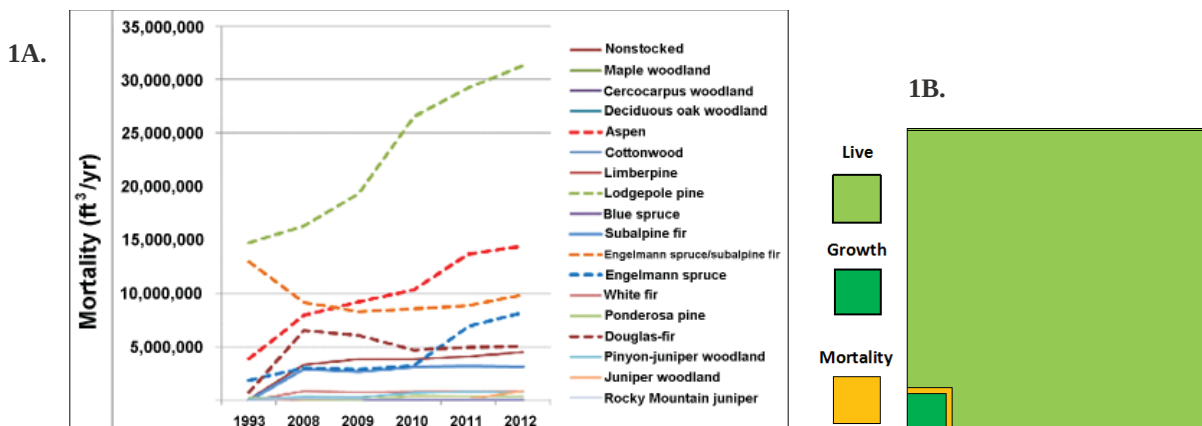


Figure 1. Patterns of forest mortality in the Uinta Mountains, Utah. A. Annual mortality by species. B. Relationship of live forest, annual growth, and mortality. Light green is the live standing forest in 2012; dark green is the average annual growth (2003-2012); yellow is the average annual mortality (2003-2012). The difference between the boxes is the projection of net annual growth (in this case, negative) into 2013. Data derives from a large network of FIA plots in the Utah portions of the range. Map and graphics developed from the Forest Inventory and Analysis database (FIADB; <http://apps.fs.fed.us/fiadb-downloads/datamart.html>) by Sara A. Goeking and John D. Shaw.

MtnClim 2014 Conference Highlights

The main *MtnClim 2014* Conference began Monday evening with the now-classic lecture given at the opening of each *MtnClim* event (as well as at the Pacific Climate Workshops) by Kelly Redmond, Regional Climatologist, Desert Research Institute, Reno, NV. Kelly presented a round-up and analysis of weather, climate, and other noteworthy atmospheric conditions since the last meeting in October 2012, highlighting unusual events as well as not-so-unusual events, and comparing these to longer term averages.

For the invited sessions that followed, I excerpt below—with some license—key points from the abstracts of individual talks.

The invited presentations Tuesday began with a keynote lecture by Kathy Jacobs, who directed the most recent National Climate Assessment:

- Assessment, Adaptation, and Co-Production of Knowledge:** In developing the Third National Climate Assessment, released in May of 2014, there was a deliberate attempt to shift the focus from producing products to establishing credible processes and building assessment teams that would continue past the development of this report. Building networks that include scientists, managers, and stakeholders has a number of benefits, because those relationships, initially formed around assessment processes, can evolve into support systems for adaptation and resilience. Mountain-climate scientists can contribute to the ongoing assessment individually or collectively. *Kathy Jacobs, University of Arizona*



Kelly Redmond launched *MtnClim 2014*. Photo: Jeff Hicke

Kathy's lecture prompted discussion about the roles that CIRMOUNT scientists could take in providing input to the forthcoming national assessments. Discussion about such a collective project arose at the last several meetings as well, with suggestions that the time is ripe for a revision of the *Mapping New Terrain* document. Not only would information our community could provide be important to the assessment process, but doing so could be a means for the mountain community to spotlight the importance of mountain environments in global change discussions. It is my hope to galvanize this interest into CIRMOUNT action this winter. Anyone interested in participating, please let me know (Connie).



Homestead Resort, Midway, Utah.

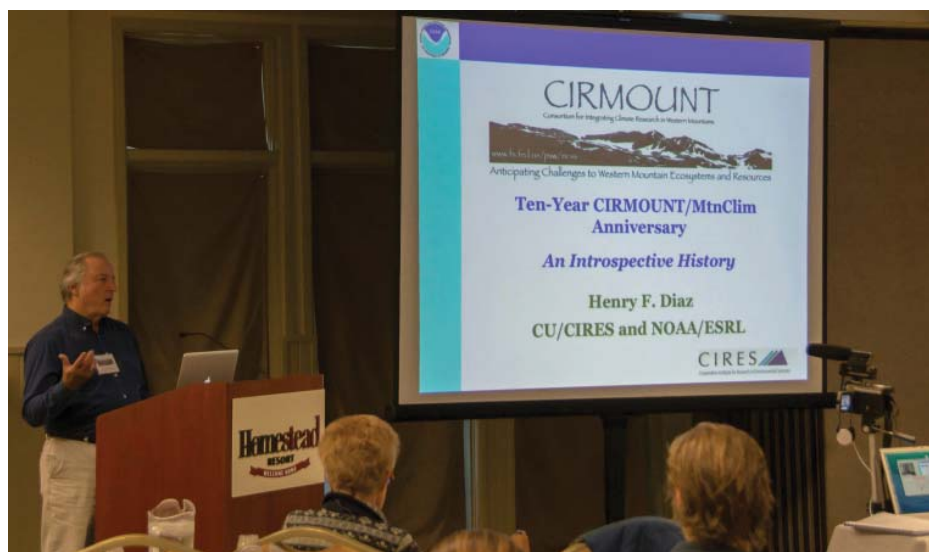
Other keynote talks reflected on mountain climate science retrospective and prospective—the 10th Anniversary of CIRMOUNT—and highlighted advances on phenology, and bark beetles and climate change, long-standing topics of interest to the community:

- **10-Year CIRMOUNT/MtnClim Anniversary:** After 10 years, many of the same critical issues identified in CIRMOUNT's initial document, *Mapping New Terrain*, not only continue to affect the West, but the impact of climatic extremes on western society has increased. While improvements in policy, management, and public awareness of these issues has substantially increased, a coordinated approach to sustainability and a national recognition of the special problems facing western society in the face of rapid climate change and related extreme events are still lacking. *Henry Diaz, Colorado University/NOAA*
- **Phenological Variability:** In the West, both snowmelt and accumulated heat needed to bring plants out of winter dormancy in the West covary and track Pacific Ocean variability. In the atmosphere, spring onset variations also appear linked to the Pacific North American (PNA) pattern and the Northern Annular Mode (NAM). By contrast, last spring frost, first fall frost, and the duration of the growing season in the coterminous U.S. follows Indian and North Atlantic Ocean variability. *Julio Betancourt, US Geological Survey*

- **Bark Beetles and Climate Change:** Focusing on the mountain pine beetle (*Dendroctonus ponderosae*), it is clear that evolved, thermally-dependent traits that serve to maintain seasonality will constrain population response in some areas as temperatures continue to warm. *Barbara Bentz, USDA Forest Service*

Climate refugia are areas that were first identified for Quaternary environments where local climate processes buffered locations from ongoing rapid declines in regional and global temperature and served as safe havens for vulnerable species. In recent years, climate refugia have been proposed as a tool for contemporary climate adaptation, but little specific delineation or detailed science has gone into such suggestions. A special session on Mountain Refugia; How they Work, and Options for Adaptations sought to improve this situation, and included five talks:

- **Past and Future Mountain Refugia:** We face at least two critical science challenges relevant to management under climate change. First, can we develop sufficient capacity to provide not only precise but accurate projections of future environmental states within complex terrains? Second, to what extent can we account for or forecast the diverse array of contingent events (dispersal, disturbance, recruitment, antecedent ecological states) that will likely govern distribution and abundance of species in a changing climate? Successful management may not require unilaterally positive answers to these questions. *Steve Jackson, US Geological Survey*



Henry Diaz reflected on CIRMOUNT's past and future. Photo: Scotty Strachan

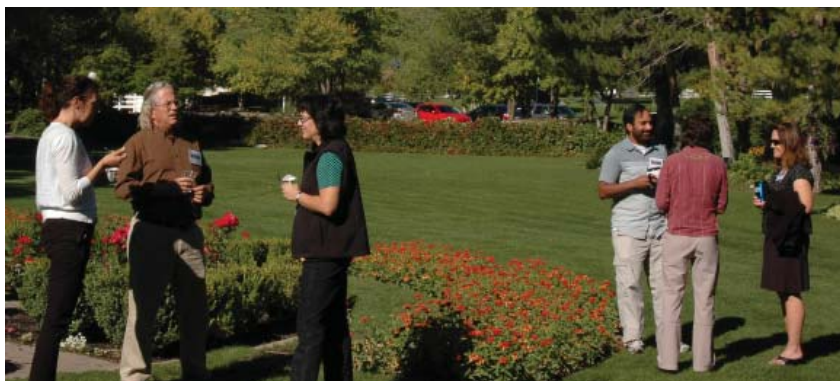
- Topoclimatic Variations as the Basis for Mountain Refugia:** The floors of basins and valleys favor development of mountain refugia, as physical processes there create local microclimates that can differ significantly from the regional climate. These processes lead to spatio-temporal differences in temperature microclimates within topography and have distinctive characteristics. Of importance are the diurnal evolution of vertical temperature structures that develop in valleys and basins, their relationship to thermally and dynamically driven winds, and the effects of atmospheric stability on the vertical transport and diffusion of airborne contaminants. *David Whiteman, University of Utah*
- Refugia as Climate Adaptation Tools:** The concept of refugia has been discussed from theoretical and paleontological perspectives to address how populations persisted during periods of unfavorable climate. Recent studies have applied the idea to contemporary landscapes to identify locations that are buffered from climate change effects so as to favor greater persistence of valued resources relative to other areas. I offer a definition and process for identifying and testing refugia for contemporary contexts, based on Belding's ground squirrel (*Uroditellus beldingi*), and propose that climate change refugia are important tools for prioritizing habitats for management intervention to conserve populations, including genetic diversity and evolutionary potential. *Toni Lyn Morelli, University of Massachusetts*
- Velocity of Climate Change:** A concern for species conservation is whether the rate of climate change will exceed the rate at which species can adapt or move to suitable environments. This has prompted the use of climate change velocity as a metric for estimating the exposure of organisms to current and future climate changes. Climate change velocity vectors for these variables show complex patterns that vary spatially and temporally and are dependent on the spatial resolution of input climate data. These results suggest that we may be overestimating the rate at which species will need to move in order to keep pace with ongoing climate changes. *Solomon Dobrowski, University of Montana*
- Refugia as a Management Tool:** Devils Postpile National Monument (DEPO) identifies refugia in planning documents as a key management tool for climate adaptation. This is supported with the scientific value of the monument by informing best management practices in refugia management. DEPO will implement a pilot study based on a 6-step management process to increase resilience of the ecologically important/ fundamental resource of Soda Springs Meadow. *Deanna Dulen, National Park Service*



Homestead Resort.

In honor of Dennis Machida, institutional analyst who had worked with the California Tahoe Conservancy until his untimely passing while delivering a speech to the *MtnClim 2005* audience, a special session is convened at each *MtnClim* on governance and social/institutional issues relevant to mountain regions. For the 2014 session, Greg Greenwood (Mountain Research Institute, Bern, Switzerland) organized a series of speakers and panelists on Coupled Human-Natural Systems, which sought to present systematic insight into institutional analysis through the frameworks developed by Elinor Ostrom:

- **Institutional Analysis and SES Frameworks:** Research on human-environment interactions and climate change has adopted the concept of complex social-ecological systems and recognized the role of governance in shaping processes and outcomes. Among the theoretical approaches, the Institutional Analysis and Development (IAD), Social-Ecological Systems (SES), and Robustness frameworks provide systematic bases for identifying key biophysical and social variables with attention to governance arrangements, and examining interactions that influence system outcomes. Modeling approaches based on these frameworks help to conceptualize interactions among the biophysical, social and governance components and their outcomes. *Catherine Tucker, Indiana University*
- **Institutional Resilience:** Based on theories of institutional change derived from the IAD framework and policy sub-system change in punctuated equilibrium theory, a method for measuring multiple properties of resilience within a policy sub-system was developed. The approach offers a tool for understanding how specific decision-making structures within complex institutional settings can influence resilience, permits tracing institutional change and learning, and offers a means for comparative analysis of the resilience of a range of natural resource management systems. *Derek Kauneckis, University of Nevada Reno*
- **Adaptive Governance:** The course of a river runs through multiple jurisdictions without regard for political or cultural differences. A river basin is thus an archetypical complex social-ecological system and essential to the sustainability of mountain regions. The Adaptive Water Governance [Project] looks at the integration of resilience and law to identify legal barriers, catalysts, and mechanisms for achieving adaptive governance and is working toward the development of a process for assessment and a package of tools that may be tailored to the circumstances of a specific basin. *Barbara Cosens, University of Idaho*
- **Legal Constraints:** The State's presumed monopoly on the use of force—a critical element in establishing the legitimacy of law as a means for resolving conflict—is not recognized as legitimate by some actors (including some states and those charged with enforcing state and federal law). The result is an uneasy standoff between formal legal structures and informal cultural systems that alter the power relations that determine substantive outcomes. *Tim Duane, University of California Santa Cruz*
- **Collaborative Governance as Legal Pluralism:** Federal land management agencies now widely embrace adaptive, collaborative, and co-management concepts (adaptive management) to address both social conflict and ecological complexity. In practice, however, agreement depends on actors who choose strategically among overlapping cultural and legal rules and powers to pursue their values or interests at multiple scales. Legal pluralism theory and methods from social anthropology help to understand behavior in these multijurisdictional and multi-cultural landscape contexts. *Sandra Pinel, Universidad Técnica Particular de Loja*



A break during sessions at Homestead Resort.

A very popular invited session, also a regular feature of the *MtnClim Conferences*, is the Early Career Scientists session, which always includes a potpourri of sizzling new studies:

- North Pacific Jet and Influence on Sierra Nevada Fire Regimes:** The Northern Hemisphere polar jet - the fast-flowing, high-altitude westerly air current that meanders over mid and northern latitudes- is an important driver of mid-latitude weather extremes and the societal, ecosystem, and economic damage related to them. Studies suggest that the jet has experienced an anomalously meridional (i.e., more north-south oriented) trajectory and slower progression in recent decades. A strong relationship exists between reconstructed NPJ position and historical (1700-1850) fire activity in the Sierra Nevada, with increased (decreased) fire activity after winters with an anomalously northerly (southerly) NPJ position. *Valerie Trouet, University of Arizona*
- Local Adaptation, Habitat Connectivity, and Gene Flow:** Tactical landscape analysis is guiding a landscape genomics approach to infer how local adaptation and gene flow interact to affect the capacity of *Plethodon welleri*, an endemic, montane salamander of conservation concern, to respond to fragmented and warming habitats. This analysis, widely applicable across taxa, improves understanding of the capacity of species to adapt to changing conditions and what actions will be most effective to conserve salamander biodiversity under global change. *Brenna Forester, Duke University*. See Brenna's BREVIA on page 44.
- Snow-Albedo Feedback:** As climate warms over mid-latitude mountain ranges, loss of mountain snow cover exposes a darker land surface, leading to additional surface absorption of shortwave radiation and surface warming. This is an expression of the snow-albedo feedback (SAF). In simulations of climate change over the Rocky Mountains the SAF dominates the spatial structure of the warming pattern, strongly enhancing warming in specific locations focused on the lateral margins of the snow pack. Linear feedback analysis can quantify the physical controls on the SAF and how it varies seasonally and with model configuration. *Justin Minder, State University of New York Albany*
- Adaptations for Hydroclimate Variability:** Water year classifications categorize water years into similar types, allowing water managers to quantify years, visualize variability, and guide water operations. Classification frameworks were designed assuming stationary climate conditions. Climate-driven hydrologic models can identify alternative methods to adapt historical water year classification methods for nonstationary climates. *Sarah Null, Utah State University*



Homestead Resort.

A topic of current interest and yet little comprehensive understanding was the feature of an invited panel: Accelerated Warming at High Elevations (Elevation Dependent Warming, EDW) and Implications for Climate Adaptation.

- **Effect of Fine-Scale Factors:** Topographic position (one's height relative to the surrounding terrain) can dramatically alter the temporal variations of temperature at both daily and monthly time steps. The culprit is the relationship between topographic position and exposure to cold air pools, which play an important role in how temperature responds to changes in synoptic flow patterns in the upper atmosphere. The magnitude of this divergence might equal or exceed that of the projected temperature change itself. *Chris Daly, Oregon State University*
- **Physical Mechanisms Responsible for EDW:** The Arctic is well known to show amplification of current warming. Many of the same mechanisms (snow and surface albedo feedback, increased sensitivity of temperature change to radiative forcing at low temperatures and increased influence of specific humidity on down-welling longwave radiation) are also at work at high elevation. Thus we would expect warming to be amplified in mountain regions. However topographic complexity causes strong local and microclimates that in part conceal a universal global signal in the sparse observational dataset. We need to improve our understanding of EDW through improved surface stations, satellite data and modelling efforts. *Nick Pepin, University of Portsmouth, UK*
- **Insights from Climate Models:** Global Climate Models (GCMs) mostly provide grossly inadequate representation of high elevation regions as well as simulation of climate processes forced by the "elevation" and "complex topographical" factor. Nonetheless, if examined selectively, they have the potential to help us understand "broad-scale" nature of climate responses dependent upon the differential sensitivities and processes facilitated by the elevation factor. GCMs, under specific conditions (e.g., seasonally or diurnally), project relatively strong sensitivities and climate response to the anthropogenic climate forcing at high elevations. *Rangwala Imtiaz, CIRES, Earth System Lab, NOAA*
- **Regional Climate Modeling.** High-resolution regional climate model (RCM) simulations (horizontal grid spacing of 10's of km or less) are required to simulate the physical processes that potentially lead to elevation-dependent warming. RCM simulations over the Rocky Mountains indicate that the snow albedo feedback is the dominant mechanism producing elevation-dependent warming. Accordingly, warming is focused on elevations near the rain snow boundary during the spring (at mid elevations) and early summer (at high elevations). *Justin Minder, State University of New York at Albany*



MtnClim 2014 session. Photo: Scotty Strachan

Evening programs included a special 10th Anniversary performance of an original work, *Mountain Storm*, by local dancer, Michelle Sorensen, and an overview of research projects in the American Climber Science Program:

- *The American Climber Science Program* (ACSP) is an integrated environmental initiative to study mountains of the world, such as the Himalaya of Nepal and the Cordillera Blanca range in Peru. The ACSP collects a variety of integrated data to support the development of sustainable environmental management and sustainable livelihoods in mountain regions (www.climberscience.com; www.mountainscience.org). John All, University of Eastern Kentucky

Presentations in contributed oral and poster sessions added breadth and depth to the overall program. In addition to traditional sessions, we took the opportunity to honor CIRMOUNT scientists who have received recognition in the last two years including Kelly Redmond as the 2014 John Tyndall

Lecturer for AGU, Mike Dettinger as AGU Fellow, Jill Baron as 2014 President of the Ecological Society of America, and David Inouye as 2015 President. Post-MtnClim 2014 workshops included a Workshop for Natural Resource Managers (see page 19), and a work group meeting on alpine and arctic treeline ecotones (see page 64 for further discussion).

Information about *MtnClim 2014* and Conference Archives

The *MtnClim 2014* program includes the agenda with speakers, presentation titles, and affiliations, and abstracts, as well as a list of participants and contact info: www.fs.fed.us/psw/mtnclim/program/Program2014_FINAL.pdf.

Pdf versions of oral and poster presentations for invited and contributed sessions are archived on the *MtnClim 2014* website: <http://www.fs.fed.us/psw/mtnclim/talks/>



Cloud reflections on Walker Lake, Nevada. Photo: Kelly Redmond

Post-MtnClim Workshop for Resource Managers Midway, Utah; September 18, 2014

Holly Hadley

USDA Forest Service, Dixie National Forest, Cedar City, Utah

As part of the *MtnClim 2014*, 10th Anniversary Conference, a Post-MtnClim Workshop was held for natural resource managers. The workshop was open to all interested practitioners and scientists, and was held Thursday, September 18, after the main conference had adjourned. The goals of the half-day workshop were to provide state-of-science updates on the effects of climate change, and to discuss climate-smart management. Presentations focused on:

- Vegetation and water
- Identifying management concerns and priorities
- Focusing on sensitive resources and locations
- Discussing options for adapting to changing resource conditions

Organizers were Dave Peterson, USDA Forest Service, PNW Research Station, Seattle Washington; Natalie Little, USDA Forest Service, Region 4, Ogden, Utah; and Steve Jackson, DOI SW Climate Science Center, Tucson, Arizona.

The workshop began with science presentations on Water, Vegetation, and Adaptation, including the following.

Charlie Luce, USDA Forest Service Research, Boise, Idaho, presented on “Water Resources and Climate Change: Trends and Projections” Charlie’s presentation proposed that because of the rise in temperatures due to climate change, snow will not last as long and April snowpack will mostly decline (Fig. 1). He discussed the uncertainties associated with annual flows and flood magnitude.

Dave Peterson presented on “Climate Change Effects on Vegetation and Disturbance”. Dave showed how studies of historical and projected temperature indicate that maximum temperatures will increase at a faster rate in the future, thus affecting vegetation and disturbance. He displayed how extremes matter (Fig. 2). Dave discussed the possibility of increasing bark beetle outbreaks, as well as how climate change will affect wildfire. Other stressors such as fungal pathogens and invasive species may add to the challenges faced by mountain ecosystems in the future. Dave concluded by stating the time to take action is now!

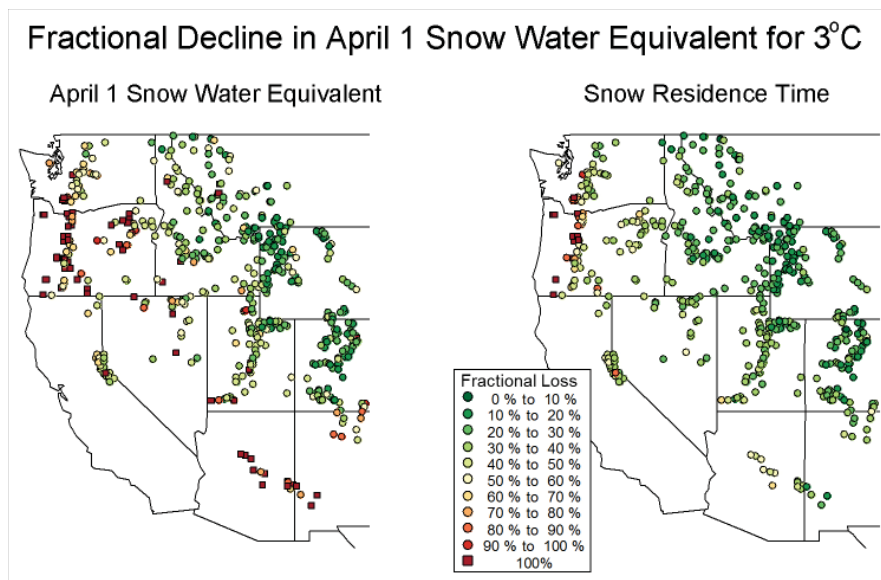


Figure 1. Expected change in snow water equivalent and residence time (Luce presentation).

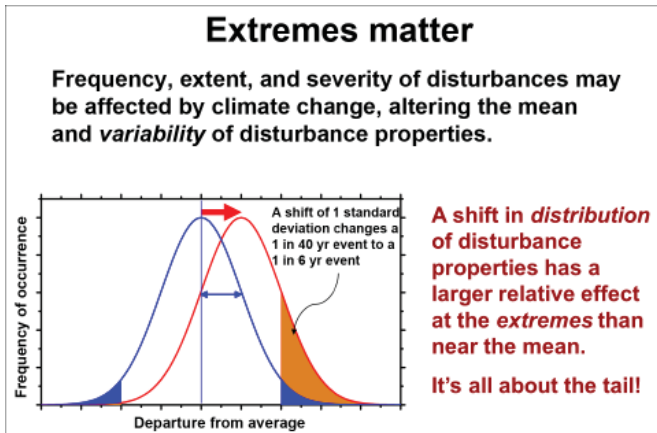


Figure 2. Importance of extremes for vegetation and disturbance (Peterson presentation).

Jill Baron of the US Geological Survey, Fort Collins, Colorado presented thoughts on adaptation. She said “there are wonderful experts who think about processes and science,” but what needs to happen is for that information to be put in simple terms so land managers can take action. “No action” in the face of climate change is a decision that may carry the greatest risk. Climate change effects will occur concurrently with contemporary resource problems. We need scenario planning, vulnerability assessments, and adaptive management in order to begin taking action. We also need to work together and build trust across political and disciplinary boundaries.

Steve Jackson addressed challenges to land managers. He said “we need to mobilize in many fronts and in as many ways as we can.” Land managers need to use the resources available to them from the universities, and everyone needs to bridge the chasm between science and management.

After the scientific presentations, the attendees participated in a talking circle and discussed challenges that land managers are facing in regards to climate change science. Some of the main concerns voiced were:

- Language barriers between scientists and land managers.
- Ease of access to scientific information.
- Communication between land managers who value climate change science and their superiors who don't.
- Superiors make decisions based on politics.
- Education for line officers and superiors is needed.
- Time and budget constrain capacity.
- Science needs to be incorporated in agency planning documents.

The participants then broke into four groups to discuss a number of concerns further, including:

1. From a research point of view, what are the most relevant topics to study, and who do scientists talk to at the agencies?
2. Feedback on vulnerability, adaptation, and monitoring assessments.
3. Embedding climate specialists in agencies.
4. Climate change refugia

Dave Peterson closed with additional thoughts on climate change and implementation. He said the complexities are growing. We are pioneers in making ecosystems more resilient. "Don't let your kids say that your generation let everything decline – take action so you can say you did your part in reducing climate change impacts."

Summary of Summaries: Key Messages from the Global Fair and Workshop on Long-Term Observatories on Mountain Social-Ecological Systems

Greg Greenwood

Mountain Research Initiative, Bern, Switzerland



The *Global Fair and Workshop on Long-Term Observatories on Mountain Social-Ecological Systems* held on 16-19 July 2014 at the University of Nevada at Reno brought together nearly 200 people to discuss the state of the art of mountain observation: where are we now and where would we like to go in the future? The Fair and Workshop was not designed to produce an output of a specific form but rather to provide a tour de horizon of the issues involved in a proposed global mountain observatory.



Greg Greenwood convenes the *Observatories* conference.
Photo: Claudia Drexler

The following report crystallizes key messages from the Fair and Workshop in order to frame better the emerging features and challenges of a global mountain observatory. The report draws from the Mountain Observatories blog (<http://www.mountainobservatories.net/>) to which many but not all session and ateliers chairs posted summaries of their events. Contents of that blog are portrayed below as bulleted italics with the main messages shown in bold headings and in plain text, numbered or otherwise, beneath headings.

What to Monitor?

1. The key features of mountains worthy of monitoring were indicated first of all by the sessions proposed for the Fair and Workshop. Within these broad themes, participants often noted key specific variables, but in general all of the sessions stopped short of lists of master variables.

Session Themes:

- *Climate and the Water Cycle*
- *Biogeochemistry*
- *Species, Ecosystems, and Paleo Environments*
- *Land Use and Tourism Social System*

2. These features of a given mountain social-ecological systems can be bound together in part or in whole through the use of models.



Climate monitoring station in the Pine Grove Mountains, Nevada.
Photo: Scotty Strachan

3. These features also exist within both temporal and spatial contexts. Understanding the past history of a system and its connections to large spatial domains is extremely useful for understanding the operation of the system as shown by monitoring data.



Doug Clark cores buried ice in the South Fork rock glacier, Sierra Nevada, CA. Photo: C. Millar

Climate and the Water Cycle

1. Sessions and ateliers on climate, meteorology and hydrology emphasized standard climate variables as well as additional variables necessary for understanding energy and water balances.

- *Comprehensive water balance measurements are needed across a variety of climate/geologic regimes to understand the processes controlling the water balance.*
- *Understanding of basin response to changes in climate is limited by a lack of comprehensive measurements across gradients in elevation, latitude, and continentality.*
- *Most platforms monitor temperature, humidity, and wind, while others also measure a wider range of variables: irradiance, snow depth, precipitation, soil moisture, etc. Temperature is the climate variable most studied.*
- *Streams are monitored in terms on how they respond to changes in precipitation regimes.*

2. While the sessions did not generate a concise list of basic variables to be monitored, creating such a list with additional variants for specific problems appeared to be a logical next step.

- *Identifying other key climate/environmental variables (in addition to temperature, i.e., snowpack properties, glacier elevation, water budget variables, wind, precipitation) to add to existing platforms is one area of improvement.*

3. Seasonal snow pack and the ratio of rain to snow were particularly important.

- *Changes in climate and precipitation type (from snow to rain) have unrealized impact to water yield from high elevation catchments.*
- *The following parameters seem to be very important with decreasing significance in view of the participants:*
 - o *SWE,*
 - o *Phase/snowfall,*
 - o *snow temperature and snow structure, and finally*
 - o *snow height.*

4. Temporal resolution is a concern.

- *While point measurements of these parameters are somehow of high quality, the temporal resolution is insufficient if they are based on manual measurements.*

5. More effective integration of remotely sensed data, ground measurements, and spatial models is needed to address the challenges noted above.

Biogeochemistry

The sessions demonstrated a specific concern with pollutants and nutrient inputs, and less about biogeochemical cycles, with the exceptions of those of carbon and water.

- *Accurate monitoring or measuring elements from atmospheric deposition or other sources.*
- *More attention on atmospheric deposited pollutants such as heavy metals, POC, etc., not only in mountain lakes but also in mountain soils.*

Species, Ecosystems and Paleo-Environments

1. Sessions validated the GLORIA approach and saw promise in expanding such plot and transect based approaches by incorporating additional variables and taxa, and by extending down below the alpine.

- *Extend vegetation monitoring efforts downslope of the summits in an effort to enhance our capability for early*

detection of elevational shifts by taxa.

- *Plant functional traits along an elevational gradient.*
- *Vegetation structure in addition to species composition.*
- *Preliminary evidence of rapid arthropod response to alpine environmental change. Arthropod sampling can be done rapidly.*

2. Particular plant and animal species of economic importance could also be included.

- *Invasives and plants useful to traditional cultures are two classes, perhaps occasionally overlapping, of economically and cultural important plant species.*
- *Changing environmental conditions may also disrupt interactions between pest taxa and their natural predators, thus exacerbating pest spread.*



Manipulating forest structure through harvest. Kandertal, Switzerland. Photo: C. Millar

3. Montane forests are important features and often require different levels of monitoring.

- *Field methods for monitoring montane forest structure and functioning, the methods emphasize measuring tree and basal area turnover, forest dynamics, precipitation and temperature.*
- *Remote sensing methods include sensors that utilize the NIR and IR bands, and historical black and white and recent panchromatic aerial photography.*

4. Aquatic habitats were mentioned but less frequently than terrestrial habitats and with few specifics.

- *Lakes in mountain regions are monitored in terms of water quality, biochemistry, biodiversity, physical chemical, and “lake-uses” in terms of tourism, fishing, etc.*
- *Streams are monitored in terms on how they respond to changes in precipitation regimes.*

5. Trophic levels are of interest as are exchanges between trophic and physical levels.

- *Inclusion of decomposers and consumers in addition to primary producers.*
- *Vertical and reciprocal exchanges.*

6. Paleo-ecology and refugia, while not strictly subjects of monitoring, are nonetheless important to understand current distribution.

- *Paleo-ecology and refugia.*
- *Presence and location of habitat refugia may be key.*

Land Cover and Tourism

1. Land cover emerged as a key point of contact between social and ecological systems.

- *Do we need to aim for a consistent land cover change product, or does one already exist? If one already exists (I suspect that this is true) should we consider a project to verify the product against ground data for mountain regions?*
- *What is the current state-of-the-art regarding the translation of land cover change into impacts in ecosystem services?*
- *Urban growth in high mountain areas.*

2. Tourism was called out as a particularly important feature in mountains.

- *Numbers, types, and (environmental) impacts of tourists, to be used to design management strategies (e.g., based on evaluation of carrying capacities, behaviours).*
- *A need to monitor tourists’ perceptions, to understand what they appreciate.*

Social System

1. Social monitoring needs to address both structure and agency.

- *All agree that institutions are important channels for human behavior, but most (all?) would also agree that humans are not automata but act with intention, within or around existing*



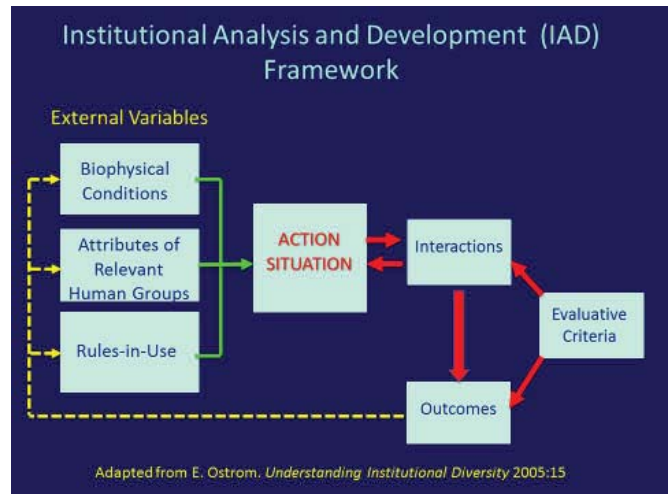
Mountain hotel at Gemmi Pass, Switzerland. Photo: C. Millar

institutions, even to the point of altering those institutions. (We need not only information on the (observable) behavior and institutions but also on those (unobservable but certainly reportable) interior states that underlie behavior.

- Are we attempting to find a critical point of agency [e.g. individual, households, etc.] and link to structure [e.g. rural-urban linkages in mountain areas]?

2. Participants identified the following kinds of data as important (in no particular order).

- Well-being
- Adaptive capacity
- Resilience
- Institutional arrangements
- Values
- Trust/legitimacy
- Ecosystem services (including cultural services)
- Government
- Economy
- Prices as drivers
- Demography, population movements
- Identity
- Perception
- Land use
- New technologies, leadership in the resources governance, social linkages etc. that are key drivers of changes in communities socio economic perspectives and ecosystems.
- The community perception on natural resources as commodities and commons, governance mechanism and



IAD framework explained by Catherine Tucker. *MtnClim* 2014 presentation.

management regimes, policies and externalities in terms of new and innovative entrepreneurs (orchards, tourism in protected areas etc.).

3. These “common core data” should be complemented by contextual information (e.g. histories), stretched as needed over space and time and open to elaboration by participants in the social ecological system.

- Oral histories (*Mountain Voices Project*); Media revisiting; Survey data; etc.

The Role of Modeling

Modeling can serve as a focal point to organize monitoring.

- Simulation of water and carbon distribution in mountain regions using suitable data should be verified, calibrated and widely used to figure out other elements distribution.
- Should every mountain monitoring station attempt “data assimilation” (meaning an on-going mixture of monitoring and modeling) of water and carbon?
- Can we develop coupled (SES) models?

Historical and Paleo-Reconstructions

Reconstructions of the recent and distant past provide a context for current and future monitoring.

- (T)he qualitative narrative of a place provides important information. And, interpretation of quantitative or qualitative data at any point in time may be completely inaccurate if not

placed in historical (and spatial) context. This recognition allows history and humanities to contribute data for a given place.

- *As part of a proposed template for a proposed mountain monitoring program, should we emphasize the development of a history of observation for each site (i.e., to identify early organized observations) and a commitment at least to consider revisiting and remeasuring?*



Mountain lakes preserve historic physical and biological records in sediments. Oeschinensee, Switzerland. Photo: C. Millar

- *Lakes can preserve also paleo-information on past relationships between mountain environments, natural hazards (i.e. earthquakes, landslides) and human pressures (pollution, deforestation).*
- *Time series of discharge, or at least, a time series of floods, however defined.*
- *Describe the statistical population of floods.*
- *Temporal and spatial distribution of extreme floods as well as the triggering processes.*
- *A more general call for paleo-information on mountain sites.*
- *Uncertainty about the relative importance of extreme events versus gradual change (forests).*
- *The understanding of the past land use changes allows us to model the future landscapes.*
- *Can revisiting studies fill data gaps in monitoring programmes?*

Spatial Context

As sites are embedded in the past, so too are they embedded in larger spatial domains, data on which provide additional context.

- *The connection of surface-based stations to upper air (i.e., free tropospheric) atmospheric data and larger-scale atmospheric circulation patterns is rarely considered.*
- *Remote sensing methods include sensors that utilize the NIR and IR bands, and historical black and white and recent panchromatic aerial photography.*
- *What kinds of global data should we collect to understand the drivers and constraints on land cover/land use change? Should we be thinking of, for instance, a global land tenure coverage?*
- *Basic hydrographic datasets for mountain areas (e.g. HydroSHEDS).*
- *Other global datasets that could be valuable additions to SES studies in mountains include:*
 - o *Protected areas*
 - o *Indigenous territories*
 - o *Demographic variables (e.g. <http://sedac.ciesin.columbia.edu/>)*
 - o *Additional key socioeconomic variables summarized per political-administrative units at the sub-national level. The challenge is to build regional/global datasets from national sources, but precedents of this approach exist (e.g. in the Andean region).*



Global data, such as those collected in the international GLORIA Program take the pulse of broad mountain responses to climate change. Photo: C. Millar

Issues and Challenges in Monitoring

The success of a global mountain observatory depends on dealing with a number of key issues and challenges.

Improvements in Sensor Design



Technology improvements enable *Observatories* fieldtrip participants to beam in the World Cup Finals atop Mt. Washington (3200 m) in the Snake Range, NV thanks to the telecommunications capacity of the NevCan Climate Stations. Photo: Scotty Strachan

A global mountain observatory would benefit greatly from improved sensors.

- *More robust instrument technology and energy solutions should be developed.*
- *Expert knowledge about the specific sensor set-up to be used as well as basic information about the to be investigated process or phenomenon is essential.*
- *Are there references that might be useful for helping researchers address this issue?*
- *Appropriate maintenance of the hardware and accuracy assessment/recalibration is mandatory to get reliable datasets.*
- *Are there standards for these actions?*

Data Management and Information Technology

1. A global mountain observatory needs a well developed data management plan.

- *Basic QA/QC checks (lower level data products) then published through NEON's data portal rapidly after collection.*

- *Develop document of montane environmental observing and metadata standards, perform data and metadata QC, and build website to host metadata and data source links*

2. A global mountain observatory needs to take advantage of current information technology.

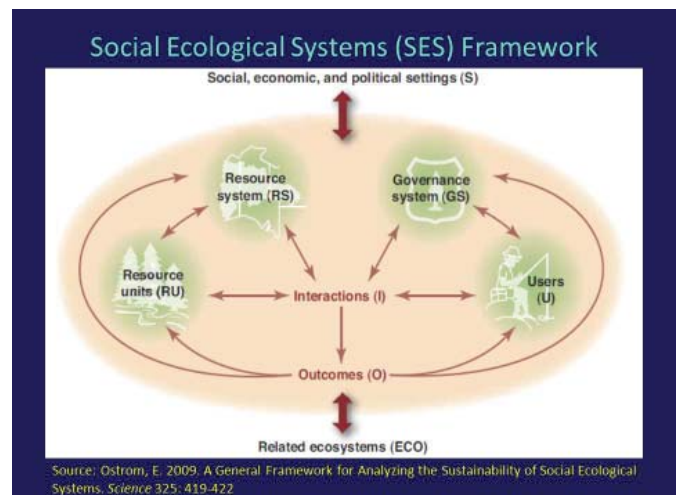
- *E-infrastructures are beginning to achieve their potential.*
- *Many projects don't have a dedicated data manager.*
- *Access to high-performance computing through cloud services promises a simpler approach.*
- *Best approached by organizing some kind of summer course for mountain researchers and site managers (e-infrastructures)?*

3. Sharing of data may require multiple methodologies.

- *Sharing of data is a good idea, but if it may work well only for quantitative data gathered through mechanical/technical data-gathering solutions. The exchange of direct observation qualitative data is a greater challenge.*
- *Knowledge repositories and facilitating data sharing.*
- *The need to continue to share experiences from seemingly very different contexts.*
- *Core data and principles with flexibility for context sensitivity.*

Social-Ecological System (SES) Framework

To make sense of the various data types, we need the overarching framework of SES with particular attention to the links between social and ecological systems.



The SES Framework elaborated by Catherine Tucker. *MtnClim* 2014 presentation

- *A common conceptual framework is needed that guides research questions and provides shared goals, and methods. In this context is important to have a common language (definitions and concepts).*
- *Approaches used to link the social and ecological components of the studied systems are less structured and vary from case to case.*
- *A combination of qualitative and quantitative methods is applied but this is not necessarily translated into a clear integration of social and environmental processes.*
- *A true SES monitoring approach should focus on the linkages between the ecological and social components of a system. An ecosystem good & services (E-G&S) approach may offer a starting point, but not all services are relevant under different contexts.*

Scaling

A global mountain observatory must address scaling issues if site-based data are to inform larger or adjacent domains.

- *Most everything is embedded in a web of relationships from the individual to the family to local to regional to national to international. For example, understanding the behavior of a given actor at point X may require data pertaining to political arrangements in the Capitol or to commodity markets in Chicago or London.*
- *A robust approach to monitoring SES in the long term has to incorporate the effects of local and extra-local processes that operate at different scales*
- *Scaling up from specific observatory sites to broader regions is challenging.*
- *Extrapolating point data to an area was identified as an ongoing main issue. Therefore a combination of in situ observations as “ground truth” and remote sensing techniques or reanalysis data for the second and third dimension was suggested.*
- *Uneven spatial distribution of point data.*
- *The approach of representative basins.*
- *A huge problem is the regionalization of these point measurements in space.*
- *What form would these take (e.g. a daily? weekly? or monthly? time series for SWE)?*

Engagement and Commitment

A successful observatory requires engagement and commitment among researchers for an extended period of time.

- *For those in the developing world (South/East) an obligation to make their data available to the global community. Way too much information lies in cupboards or on personal computers.*
- *North/West should have a strong commitment to facilitate collaboration with the South/East in order to obtain a truly global data set upon which responsible decision-making can be based.*
- *Coordination without centralization.*

Transdisciplinarity

A sustainable observatory that informs social change requires engagement with stakeholders and policy makers.

- *Our knowledge of mountain SES will improve to the degree that we engage participants in the SES in the very creation of knowledge, knowing full well that we and they are not involved in a strictly epistemological exercise.*
- *Likely require engaging actors inside and outside the academy (e.g. local governments, advocacy groups).*
- *Better involvement of stakeholders, better knowledge of decisions by local population about land use (e.g. South America, Himalaya region).*
- *An important challenge is to generate and maintain relationships based on trust. In many cases, barriers persist to share information, methods and expertise in a more open way.*
- *To strengthen the links between the scientific knowledge and tools that are being generated, and the relevant decision-making processes.*

Useful Next Steps

The next steps in creating a global mountain observatory include the following.

Due Diligence on What's Already Been Done

1. A global mountain observatory should identify and engage other pertinent observational activities.

- Consult with NEON, NPS I&M, GEOS and others regarding the implementation of principles.
- Review WMO, GIVD, IPCC, and other guides of observation.
- Talk with WMO and other organizations for guidance on a protocol for establishing new mountain observing standards.
- If such a minimum set has been defined, are there extant data portals for such data? And if those exist, what would help increase their use (i.e., increase the deposition of data on such portals)?
- Publish review paper about problem and vision of action.
- New satellite missions will bring opportunities for better monitoring of land use.

2. A global mountain observatory should identify relevant existing data.

- Should we have a project that clips land cover change projects to specific mountain regions (for instance, the GMBA mountain range polygon coverage) and then delivers them, for discussion and refinement, to stakeholders in those mountain regions?
- Two strategies could render important information:
 - 1) identify and systematically compare continental/global LUC (Land Use Cover) datasets to assess their potential uses in mountain areas, and
 - 2) for key land cover datasets, quantify their thematic accuracy. This last activity could be done with a crowdsourcing approach in which regional/local experts feed a centralized validation dataset.

Networking

Information exchange and the development of a global mountain observatory community will be required.

- It is important for the general community to come together and share solutions. Compiling best practices and systems used in successful deployment at a variety of funding scales is important.
- One such emerging community is the EnviroSensing Cluster (http://wiki.esipfed.org/index.php/EnviroSensing_Cluster) within the Federation for Earth Science Information Partners (ESIP, <http://www.esipfed.org/>), mostly populated by LTER scientists: would it be useful to try to convene potential members of the observatory network at the next ESIP meeting?

- Paul Campbell's company must have some kind of client network that it uses to improve its products. Could we call on him?
- Where might (a forum to prioritize) happen? The mountain community has its own meeting in Perth Scotland 4-8 Oct 2015.



Banner from website of PERTH III conference. www.perth.uhi.ac.uk/specialistcentres/cms/Conferences/Perth2015/Pages/default.aspx

- There is OBFS meeting in Woods Hole in September.
- There is the AGU where MRI could set up a side event to work on this topic.
- What are the existing fora via which we could pursue these topics: FRIEND, PUB, CUASHI, CZO, IAHS? Should we be proposing sessions at the AGU, EGU?
- A network of climate scientists and instrumentation technicians is needed for the purpose of sharing expertise in the design, installation, and maintenance of environmental monitoring stations.
- Create a network of scientists working in BRs, to complement the existing networks of the MAB programme and also to create opportunities for collaborative projects.

Protocol Compilation and Development

The compilation of protocols for the measurement of variables is a key next technical step.

- Reference to key paleo-reconstruction methods.
- Catalog the methods that one could use to generate such a flood time series.
- What are the standard methodologies? Can we create a comprehensive but finite list of methodologies that generate different kinds of information (e.g., biomass standing crop vs. demography) for different life forms (e.g. alpine tundra, treeline, montane forest)?
- Maintain raw data collected with accurate meta-data.
- Are there standard approaches to analyzing the diversity and evolution of local institutions? How can these methods be incorporated into a monitoring strategy?

- *Calling the conferences and congresses on the terms and definitions; translation of the key books which was instrumental in the forming of the existing monitoring, preparation and publication of manuals for the different methods to make the methods of one side more apprehensible to the other side.*
- *Organizational: creating a workgroup on the development of method integration.*
- *Workgroups must move beyond intention to taking action, such as publishing a book that outlines guidelines for data-gathering.*



Climate monitoring in the Bernese Oberland, Switzerland.
Photo: C. Millar

collaborative methods for funding and standardizing such instrumentation.

- *It is through the test bed idea that most-effective methodologies can be created.*

Framing

A global mountain observatory can be advanced via linkages to other activities.

- *Global: appealing to the government for the International Ecology Year– an initiative similar to the International Geophysical Year, International Polar Year or International Mountain Year.*
- *It is anticipated that the new strategy and action plan for the MAB programme (2015-2021) will have an increased emphasis on research, probably as a contribution to Future Earth. Does this represent an opportunity for the development of a coordinated programme of monitoring in mountain BRs?*

Further Information

Information on the Global Fair and Workshop is at: <http://mri.scnatweb.ch/en/homepage>

For details of blog discussions, visit: <http://www.mountainobservatories.net/>

Model Sites

The engagement of existing observing sites is central to a bottom-up approach to a global mountain observatory.

- *Experimental: test bed solution: creating of the test beds in the developing countries (to determine how well the eastern system may work in the different conditions and how it can improve quality of the monitoring there) and the unified (e.g. USA-Russia) test bed for testing of the integration solutions at the relatively close conditions (e.g. Altai-Alaska).*
- *Workgroups must be constituted by people who agree at the outset to apply the methods at their respective sites.*
- *A forum to prioritize these key climate/environmental variables would be a beneficial method to engage mountain observatories in the decision-making process and identify*



Active discussion during the Observatories conference.
Photo: Claudia Drexler

BREVIA

Obtaining Downscaled Versions of the Latest Climate-Change Scenarios

Mike Dettinger

US Geological Survey and University of California
 Scripps Institution of Oceanography, La Jolla, California

Maurer, E.P., Brekke, L., Pruitt, T., Thrasher, B., Long, J., Duffy, P., Dettinger, M., Cayan, D., and Arnold, J. 2014. *An enhanced archive facilitating climate impact analysis: Bulletin of American Meteorological Society* 95:1011-1019, DOI:10.1175/BAMS-D-13-00126.1

At the *MtnClim 2014* Conference in October this year, Andy Bunn, Western Washington State University, asked whether downscaled climate-change scenarios from the latest IPCC Fifth Assessment Report are available yet. The global-model versions of these scenarios are collected at, and distributed through, the Coupled Model Intercomparison Project (CMIP5) at Lawrence Livermore National Lab. However, the spatial resolutions of those scenarios are still far too coarse for use in mountainous

settings (and most others) unless some interpolation of the results to higher resolutions (called downscaling) is applied (Fig. 1). Ed Maurer, Santa Clara University, and Levi Brekke, US Bureau of Reclamation, have been leading a team of us in an effort to apply several different statistical downscaling methods to the CMIP5 projections (as well as the previous generation of projections, CMIP3). The results are now freely available in a new archive at:

http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

We are serving up hundreds of downscaled climate projections there, with downscaling by several different methods, from the past two generations of IPCC assessments, and including (this time) hydrologic simulations based on some of the downscaled projections. Whole CONUS fields can be downloaded, or several regional or user-specified subsets can be obtained from the archive. Spatial resolutions of the downscaled fields are currently $1/8^\circ$ (approximately 12 km) but $1/16^\circ$ (~ 6 km) versions are being constructed already. Monthly- and daily-scale projections are available. Downscaling is still very much a research endeavor, so efforts are already well underway to improve on products here with even newer methods, but there is already enough in this archive to keep you busy for a long time.

The archive has recently been described in the paper cited above. A personal-use copy is available at:

http://tenaya.ucsd.edu/~dettinge/BAMS-Maurer_2014.pdf

The paper also describes the process of developing such products and serving them, and gives some history regarding the many uses that have been made of a previous edition of this archive.

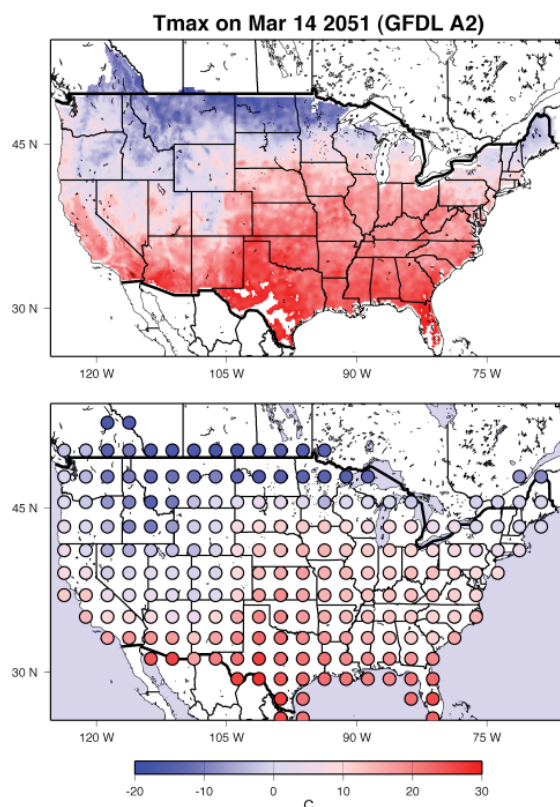


Figure 1. Comparison of the daily maximum temperature projection for a particular future day in a particular simulation by the GFDL model under A2 emissions scenario, as (bottom) simulated by the global model and (top) in its statistically downscaled, 12-km form.

BREVIA

A 2000-Year Reconstruction of Air Temperature in the Great Basin of the United States with Specific Reference to the Medieval Climatic Anomaly

Scott A. Reinemann¹, David F. Porinchu², Glen M. MacDonald³,
Bryan G. Mark¹ and James Q. DeGrand¹

¹ Department of Geography, The Ohio State University, Columbus, Ohio

² Department of Geography, University of Georgia, Athens Georgia

³ Institute of the Environment and Sustainability and Department of Geography,
University of California, Los Angeles, California

Reinemann, S.A., Porinchu, D.F., MacDonald, G.M., Mark, B.G., and DeGrand, J.Q. 2014. A 2000 year reconstruction of air temperature in the Great Basin of the United States with specific reference to the Medieval Climatic Anomaly. *Quaternary Research* 82:309-317. DOI: 10.1016/j.yqres.2014.06.002

Elevated temperature and decreases in effective moisture over recent decades in the mountainous western United States has motivated researchers to access proxy climate records to gain longer time perspective (Mensing et al. 2008, Williams et al. 2010). Although hydroclimate variability in the Great Basin and adjacent regions during the last two millennia has been well documented (MacDonald 2007, Mensing et al. 2008, Woodhouse et al. 2010, Routson et al. 2011), much of this research has been focused upon reconstructions of the two ‘mega droughts’ identified by Stine (1994) and the precipitation anomalies that occurred during the Medieval Climate Anomaly (MCA) (AD 900 – 1300). The MCA is characterized by a spatially heterogeneous response in moisture and temperature; however, the MCA is generally associated with warmer conditions in the Northern Hemisphere (Hughes and Diaz 1994, Mann et al. 2008, Diaz et al. 2011). Unfortunately, as noted by Woodhouse et al. (2010) and Rouston et al. (2011), quantitative, high-resolution temperature reconstructions spanning the last two millennia in the Great Basin of the United States are sparse, making it difficult to explicitly identify the sensitivity of the region to hemispheric temperature patterns and the degree to which temperature changes contributed to intensifying regional aridity over this interval.

The hydroclimate of arid and semi-arid environments such as the southwestern United States and the Great Basin is greatly influenced by temperature, with temperature playing a critical role in controlling effective moisture and exacerbating drought through its influence on snowpack extent and timing of spring run-off (Shinker and Bartlein 2010, Woodhouse et

al. 2010). Nevertheless, proxy-based and modeled temperature reconstructions from the Great Basin that span the last two millennia are qualitative, limited in their temporal resolution, or have large sample specific errors (Louderback and Rhode 2009). We were thus motivated to develop a high-resolution, quantitative temperature reconstruction spanning the last two millennia for the central Great Basin. Increasing the number of lengthy and detailed quantitative records describing the regional response of Great Basin climate and vegetation to past climate perturbations, with a specific emphasis placed on prolonged warm intervals, will expand our knowledge of the mechanisms driving climate variability in the Great Basin under warmer conditions and possibly provide insight into future conditions at a regional scale (Mock and Brunelle-Daines 1999, Woodhouse et al. 2010).

We applied a chironomid-based inference model for mean July air temperature (MJAT) (Porinchu et al. 2010) and developed a detailed, sub-centennial, quantitative reconstruction of thermal conditions for Stella Lake in Great Basin National Park (GBNP) (Figs. 1, 2) that spans the last two millennia. We used a form of indirect gradient analysis, detrended correspondence analysis (DCA), to assess the degree of compositional turnover between samples. Lastly, we used loss-on-ignition (LOI) to make qualitative inferences of lake productivity. This study expands on our earlier work describing Holocene Thermal Maximum (HTM) conditions in GBNP (Reinemann et al. 2009) and provides a much needed, well-constrained (sub-centennial resolution), paleo-temperature record for the central Great Basin. This quantitative reconstruction improves our understanding of the temporal patterns of past climate change during the MCA, an interval characterized by significant regional hydroclimate variability. We compare results from Stella Lake to existing paleoclimate reconstructions from the Great Basin and hemispheric temperature compilations.

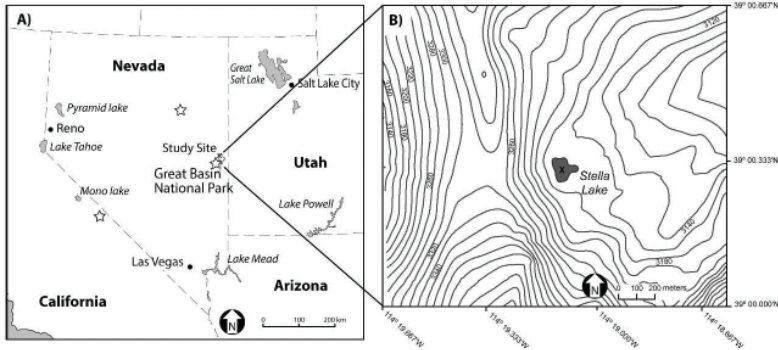


Figure 2. Stella Lake, looking south, in Great Basin National Park, Nevada. Photo: Scott Reinemann.

Sub-Fossil Chironomid Assemblages

The sub-fossil midge assemblage data and the results from the DCA indicate that the midge community in Stella Lake underwent major shifts in composition during the last two thousand years (Fig. 3). DCA axis 1 identifies the existence of a strong correspondence between the midge community composition and the MJAT estimates. The most prominent change evidenced in the sub-fossil midge stratigraphy of Stella Lake is the dramatic reorganization of the midge community between AD 600 and AD 1600. The portion of the record between AD 600 and AD 1300 is characterized by a large and rapid increase in *P. semicirculatus/sordidellus* and *Pentaneurini*. These taxa have relatively high MJAT optima in the Intermountain West

training set (Porinchu et al. 2010). The interval between AD 1300 and AD 1600 is characterized by a rapid faunal turnover, with fluctuations in *Cladotanytarsus mancus* group, a taxon with a relatively low MJAT optima in the Intermountain West training set (Porinchu et al. 2010), largely driving the changes observed in the midge assemblages during this interval. The shifts in head capsule concentrations observed in the Stella Lake record likely reflect variations in sedimentation and lake productivity, with the elevated concentration of head capsules at the base of the record indicating low sedimentation and high lake productivity (AD 600 - AD 1000). The Stella Lake midge community is characterized by limited faunal turnover between AD 0 and AD 500 and AD 1600 to present, suggesting these were relatively stable intervals.

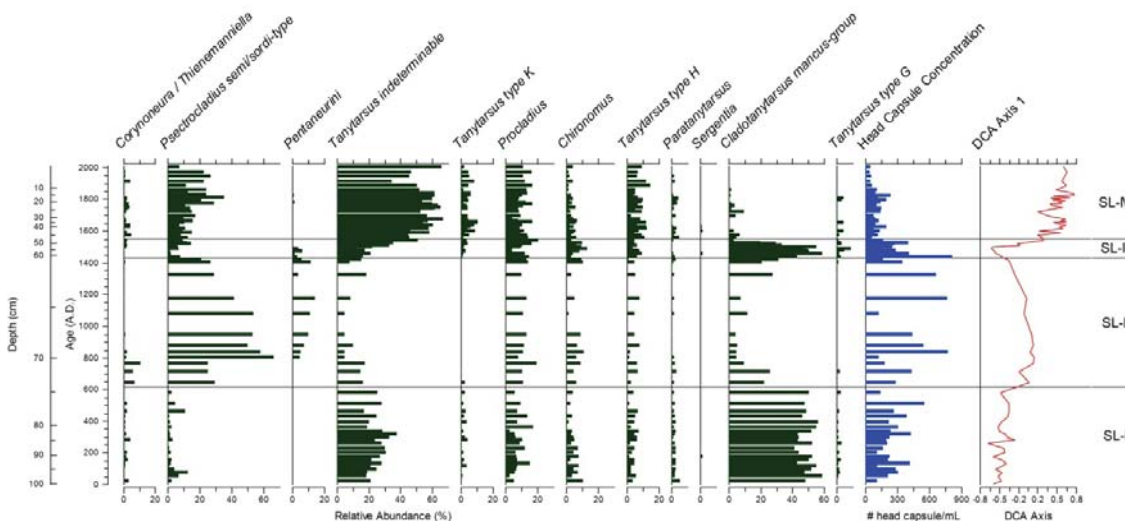


Figure 3. Chironomid relative abundance diagram for Stella Lake. Taxa have been arranged according to their MJAT optima, with decreasing optima temperature from left to right. *Psectrocladius semi/sordid-type* = *Psectrocladius semicirculatus/sordidellus*. The blue bars are head capsule concentrations, given as the number of head capsules per mL. The red line represents DCA axis 1 scores.

Elevated Temperatures Corresponding to the MCA

Chironomid-inferred temperatures at Stella Lake reach a core minimum of approximately 1.0°C below the late Holocene average between AD 0 and AD 700. The timing of the depressed MJAT recorded at Stella Lake broadly corresponds to compilations of environmental change from the northern hemisphere indicating that the interval between AD 200 and AD 900 (Fig. 4) was generally characterized by below average temperature (Moberg et al. 2005, Mann et al. 2008, Christiansen and Ljungqvist 2012, Moinuddin et al. 2013). The timing of the increase in inferred temperatures at Stella Lake, which begins at approximately AD 700, corresponds to the warming documented in Northern Hemisphere reconstructions (Fig. 4) (Moberg et al. 2005, Mann et al. 2008, Christiansen and Ljungqvist 2012) and pollen-based reconstructions for North America (Moinuddin et al. 2013). A more recent study by Salzer et al. (2014), focusing on tree-ring records, indicates that the central Great Basin during the MCA is characterized by a positive temperature anomaly of $+0.4^{\circ}\text{C}$. It is difficult to directly compare the Salzer et al. (2014) reconstruction to our record due to the difference in temporal resolution; however, it is interesting to note that the Salzer et al. (2014) reconstruction indicates that the warming during the most recent century is larger than the inferred warming during

the MCA. A similar pattern exists in the midge-based Stella Lake MJAT reconstruction. The interval between AD 900 and AD 1300, corresponding to the MCA, is distinguished by a local maximum in chironomid-inferred temperatures at Stella Lake of approximately 0.4°C above the late Holocene average, with peak chironomid-inferred MJAT occurring between AD 800 and AD 950. The elevated temperatures at Stella Lake during the late 1st millennium correspond to the warming evidenced in the recent pollen-based temperature reconstruction for North America (Moinuddin et al. 2013).

Near the end of the MCA and extending into the Little Ice Age (LIA), Stella Lake experienced a gradual decrease in MJAT to levels of $\sim 1.0^{\circ}\text{C}$ below the 2000 year mean temperature. The drop in temperature documented at Stella Lake corresponds to reconstructed northern hemisphere compilations and regional temperature records, which indicate that decreases in hemispheric and regional temperature began at approximately AD 1000 and continued to AD 1600 (Fig. 4). The lowest temperature during the second millennium occurs at approximately AD 1500, matching the timing of the greatest negative hemispheric temperature anomaly during the last 2000 years, associated with a volcanic-solar downturn (Moinuddin et al. 2013). The cooling trend observed in Stella Lake between AD 1300 and

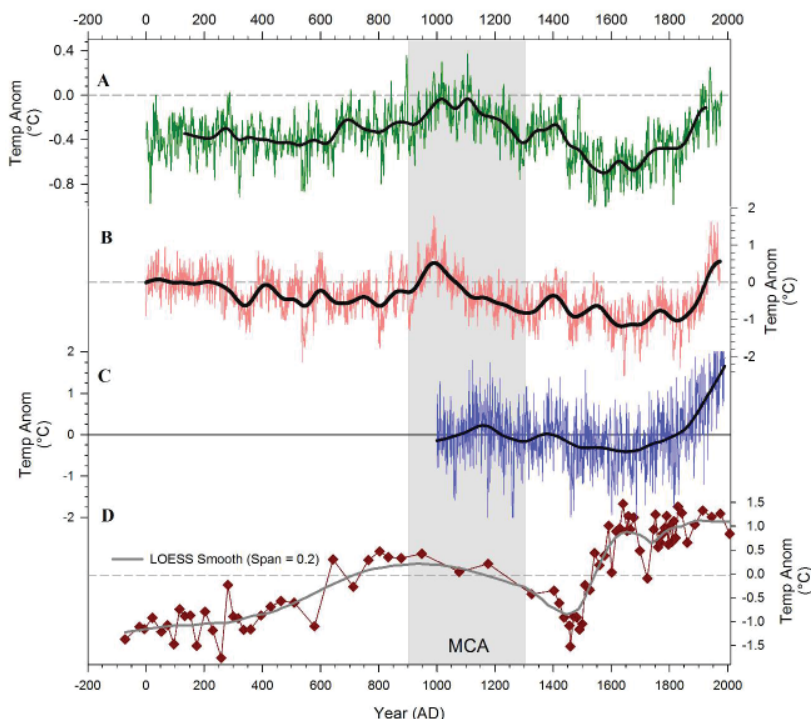


Figure 4. Summary diagram of select hemispheric and regional temperature reconstructions based on model and paleo-proxy data and data from Stella Lake: (A) Northern Hemisphere mean temperature variations (green) and its >80-yr component (black) with respect to AD 1961-90 average. (Moberg et al. 2005); (B) reconstruction of extra-tropical Northern Hemisphere mean temperature variations (red) and 50-yr smooth (black) with respect to AD 1880-1960. (Christiansen and Ljungqvist 2012); (C) mean temperature deviations from 1000-1990 mean of the southwestern United States (box bounded by 40°N , 34°N and 104°W , 124°W) based on ECHO-G forcing 2 model (blue) and loess smooth (span = 0.2) (black); and (D) Stella Lake chironomid-inferred MJAT anomalies (maroon) and loess smooth (span = 0.2) (grey). Gray shading represents the MCA interval (AD 900 – 1300).

AD 1600 matches well with the reduced bristlecone pine ring-widths measured at a number of sites in the Great Basin (Salzer et al. 2009). The depressed temperatures at Stella Lake during the very end of the MCA and beginning of the LIA also corresponds to records from the Sierra Nevada that suggest the possible occurrence of a glacial advance during this time interval (Bowerman and Clark 2011). This cold phase was followed by a rapid increase in inferred MJAT beginning at ~ AD 1600 and reaching a plateau at ~ AD 1800.

Chironomid-inferred MJAT increased from ~ 1.0°C below to ~0.8° C above the long-term average during this interval. The timing of the increase in temperature at Stella Lake appears to closely correspond to the timing of rise in hemispheric temperature, which begins at approximately AD 1600 (Moinuddin et al. 2013). However, the most recent warming plateau occurs earlier than in many other records (Fig. 4). This ‘smearing’ of the recent warming signal may reflect age model uncertainty at the top of the core with the upper portion of the core not being as well constrained. It is notable that the recent warming, which exceeds MCA conditions, is in agreement with large-scale reconstructions for the past 1000 to 2000 years (Fig. 4; Moberg et al. 2005, Christiansen and Ljungqvist 2012). Overall, there is a notable correspondence between the Stella Lake MJAT reconstruction over the last two millennia and both regional and hemispheric compilations of temperature change (Moberg et al. 2005, Mann et al. 2008, Moinuddin et al. 2013). This is true not only in the timing of the MCA and LIA, but also in the 0.5°C to 1.0° C amplitude of temperature deviations observed at Stella Lake and these other reconstructions.

In conclusion, our quantitative sub-centennial chironomid-based temperature reconstruction from Stella Lake provides a much needed new temperature proxy covering the last two millennia in the central Great Basin, a region with very few quantitative temperature records. The Stella Lake record establishes that:

- 1) the MCA in the Great Basin was characterized by a notable fluctuation in thermal conditions;
- 2) the iconic Medieval megadroughts occurred during intervals of above average MJAT;
- 3) the subsequent LIA was not only moister, but also cooler;
- and 4) recent warming may have exceeded MCA conditions.

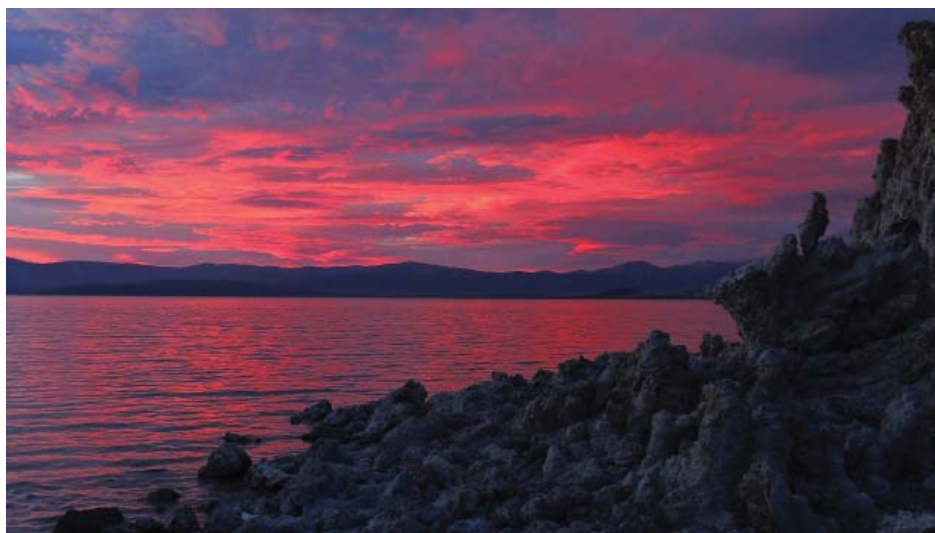
The results of this study supports using the MCA as a potential analogue for future scenarios in which elevated temperature is expected to contribute to exacerbating and intensifying aridity in the arid and semi-arid Intermountain West of the United States during the 21st century (Seager et al. 2007). The 21st century has already been exceptionally warm and dry in the Great Basin and Southwest (MacDonald 2010). The paleoclimatic records present here and from elsewhere in the region

suggest continued, and perhaps increased aridity are within the realm of possibility as future scenarios for the Great Basin (MacDonald 2010, Woodhouse et al. 2010). Identifying the role played by temperature in intensifying the aridity associated with the Medieval droughts and earlier drought intervals must be an area of active of research (Woodhouse et al. 2010, Routson et al. 2011). Further documentation of the temperature-aridity relationship will improve our ability to describe and model future hydroclimate variability in the Great Basin and assist in planning for the sustainable management of freshwater resources in the Great Basin.

References

- Bowerman, N.D., Clark, D.H. 2011. Holocene glaciation of the central Sierra Nevada, California. *Quaternary Science Reviews* 30:1067–1085.
- Christiansen, B., Ljungqvist, F.C. 2012. The extra-tropical Northern Hemisphere temperature in the last two millennia: reconstructions of low-frequency variability. *Climate of the Past* 8:765–786.
- Diaz, H.F., Trigo, R., Hughes, M.K., Mann, M.E., Xoplaki, E., Barriopedro, D. 2011. Spatial and temporal characteristics of climate in Medieval Times revisited. *Bulletin of the American Meteorological Society* 92:1487.
- Hughes, M.K., Diaz, H.F. 1994. Was There A Medieval Warm Period, and if so, Where and When. *Climatic Change* 26:109–142.
- Louderback, L.A., Rhode, D.E. 2009. 15,000 Years of vegetation change in the Bonneville basin: the Blue Lake pollen record. *Quaternary Science Reviews* 28:308–326.
- MacDonald, G.M. 2010. Water, climate change, and sustainability in the Southwest. *Proceedings of the National Academy of Sciences* 107:21256–21262.
- MacDonald, G.M. 2007. Severe and sustained drought in southern California and the West: Present conditions and insights from the past on causes and impacts. *Quaternary International* 173:87–100.
- Mann, M.E., Zhang, Z.H., Hughes, M.K., Bradley, R.S., Miller, S.K., Rutherford, S., Ni, F.B. 2008. Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proceedings of the National Academy of Sciences of the United States of America* 105:13252–13257.
- Mensing, S., Smith, J., Norman, K.B., Allan, M. 2008. Extended drought in the Great Basin of western North America in the last two millennia reconstructed from pollen records. *Quaternary International* 188:79–89.

- Moberg, A., Sonechkin, D.M., Holmgren, K., Datsenko, N.M., Karlen, W. 2005. Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. *Nature* 433: 613–617.
- Mock, C.J., Brunelle-Daines, A.R. 1999. A modern analogue of western United States summer palaeoclimate at 6000 years before present. *Holocene* 9:541–545.
- Moinuddin, A., Anchukaitis, K.J., Asrat, A., Borgaonkar, H.P., Braida, M., et al. 2013. Continental-scale temperature variability during the past two millennia. *Nature Geoscience* .
- Porinchu, D.F., Reinemann, S., Mark, B.G., Box, J.E., Rolland, N. 2010. Application of a midge-based inference model for air temperature reveals evidence of late-20th century warming in sub-alpine lakes in the central Great Basin, United States. *Quaternary International* 215:15–26.
- Reinemann, S.A., Porinchu, D.F., Bloom, A.M., Mark, B.G., Box, J.E. 2009. A multi-proxy paleolimnological reconstruction of Holocene climate conditions in the Great Basin, United States. *Quaternary Research* 72:347–358.
- Routson, C.C., Woodhouse, C.A., Overpeck, J.T. 2011. Second century megadrought in the Rio Grande headwaters, Colorado: How unusual was medieval drought? *Geophysical Research Letters* 38:5.
- Salzer, M.W., Bunn, A.G., Graham, N.E., Hughes, M.K. 2014. Five millennia of paleotemperature from tree-rings in the Great Basin, USA. *Climate Dynamics* 42:1517–1526.
- Salzer, M.W., Hughes, M.K., Bunn, A.G., Kipfmüller, K.F. 2009. Recent unprecedented tree-ring growth in bristlecone pine at the highest elevations and possible causes. *Proceedings of the National Academy of Sciences of the United States of America* 106:20348–20353.
- Seager, R., Ting, M.F., Held, I., Kushnir, Y., Lu, J., Vecchi, G., Huang, H.P., Harnik, N., Leetmaa, A., Lau, N.C., Li, C.H., Velez, J., Naik, N. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. *Science* 316:1181–1184.
- Shinker, J.J., Bartlein, P.J. 2010. Spatial variations of effective moisture in the western United States. *Geophysical Research Letters* 37:5.
- Stine, S. 1994. Extreme and Persistent Drought in California and Patagonia During the Medieval Time. *Nature* 369:546–549.
- Williams, A.P., Allen, C.D., Millar, C.I., Swetnam, T.W., Michaelsen, J., Still, C.J., Leavitt, S.W. 2010. Forest responses to increasing aridity and warmth in the southwestern United States. *Proceedings of the National Academy of Sciences* 107:21289–21294.
- Woodhouse, C.A., Meko, D.M., MacDonald, G.M., Stahle, D.W., Cook, E.R. 2010. A 1,200-year perspective of 21st century drought in southwestern North America. *Proceedings of the National Academy of Sciences* 107:21283–21288.



Sunset over Mono Lake, California. Photo: Kelly Redmond

BREVIA

Hotter, Drier Climate Leads to More Tree Deaths from Fire

Phillip van Mantgem

U.S. Geological Survey, Western Ecological Research Center,
Redwood Field Station, Arcata California

van Mantgem, P., Nesmith, J. C. B. Keifer, M., Knapp, E., Flint, A. L., and Flint, L.E. 2013. Climatic stress increases forest fire severity across the western United States. *Ecology Letters* 16:1151-1156.

There is a growing realization that current warming trends may be contributing to increasing forest fire size, frequency, and severity (the number of trees killed) across the western United States (Westerling et al. 2006, Dillon et al. 2011, Williams et al. 2012, Mallek et al. 2013; but see Miller et al. 2012). The mechanism whereby fire severity increases in response to warming is presumed to be through greater probabilities of severe fire weather (higher air temperature and lower relative humidity resulting in lower fuel moisture) (Fried et al. 2008).

While likely true, this view discounts the biological context of the fire event. Our recently published article in *Ecology Letters* shows that trees subject to drought stress are more sensitive to subsequent fire damage (van Mantgem et al. 2013, above), implying that recent warming trends may lead to a de facto increase in fire severity (higher probability of tree mortality), separate from changes that may increase fire intensity (the amount of heat released during a fire).

We assembled observations of individual tree injury and mortality following prescribed fire from the FFI database (FEAT/FIREMON Integrated, www.frames.gov/ffi) from across western NPS units (National Parks, Monuments and Recreation Areas) (Fig. 1). Prescribed fire data are particularly well suited to exploring the relationship between climate and fire severity because prescribed fires are conducted over a relatively narrow range of fire weather but over a potentially wide range of inter-annual climatic conditions. We merged these data with downscaled estimates of climate from the Basin Characterization Model (Flint et al. 2013), using estimates of the climatic water deficit as our index of drought.

Models of post-fire tree mortality suggested pre-fire climatic water deficit exacerbated the effects of fire-caused injuries

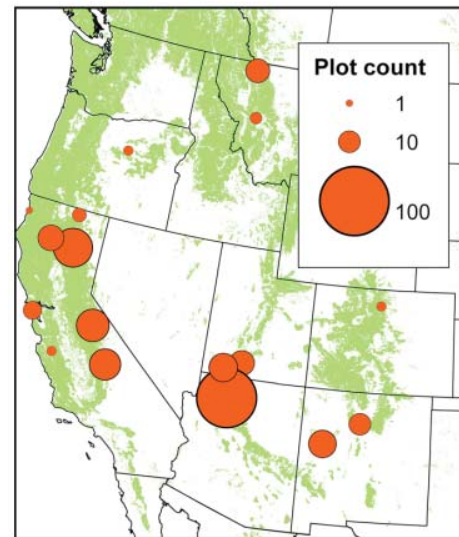


Figure 1. Locations of management units with qualifying pre- and post-burn data. Symbol size is scaled to the number of monitoring plots per management unit. Forest cover is shown in green.

(crown scorch and char height) (Fig. 2). These findings support recent physiological evidence showing that both drought and heating from fire can impair xylem conductivity (Kavanagh et al. 2010, McDowell 2011, Michaletz et al. 2012). Climate and fire interactions did not vary substantially across geographical regions, major genera and tree sizes.

Our analysis did not consider other factors that could also exacerbate climatic warming effects on tree deaths, such as tree pathogens and insect pests. Also, the forest data were solely drawn from prescribed fire events.

Disturbance is a common feature of natural systems, but escalating rates of tree mortality via drought-fire interactions may lead to substantial changes in forest structure and function, including increased carbon emissions (Meigs et al. 2009). Our results can inform forest management decisions. Increasing climatic stress and subsequent fire-caused mortality may lead to prescribed fires with unintentionally more severe effects than expected, so managers may wish to incorporate this drought-

fire relationship in their prescribed fire planning (Reinhardt et al. 1997). Higher severity may not be a negative outcome in all cases. If forest managers wish to reduce the density of an overstocked forest, prescribed burning might actually be more effective when done during drier than normal periods.

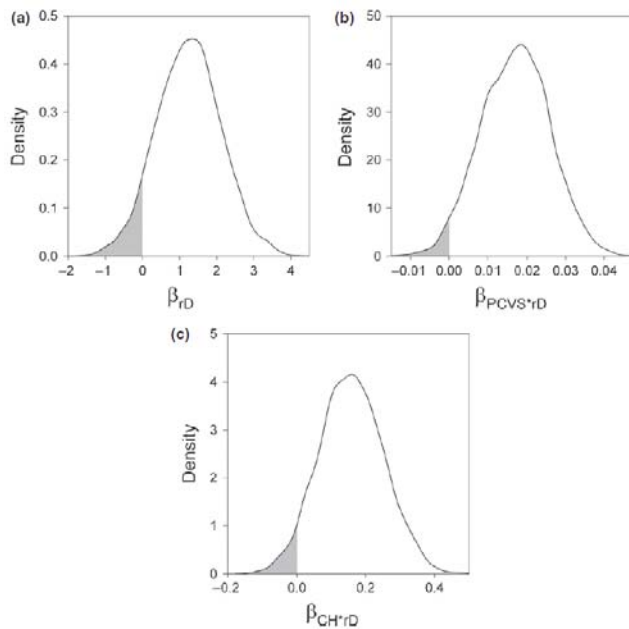


Figure 2. Densities of 3000 samples from the posterior distributions of generalized nonlinear mixed model parameters (β) relating post-fire tree mortality probability to pre-fire average climatic water deficit, relative to the 30 year average (rD). The main effect (β_{rD}) had 93% of samples > 0 (a), while density distributions for interactions between percentage crown volume scorched and pre-fire rD ($\beta_{PCVS*rD}$) (b) and stem char height and pre-fire rD (β_{CH*rD}) (c) had over 95% of samples > 0 . Grey regions show density of samples where $\beta < 0$.

Acknowledgements

This project was supported by grants from the Joint Fire Science Program (JFSP project number 09-3-01-68). Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Dillon, G. K., Z. A. Holden, P. Morgan, M. A. Crimmins, E. K. Heyerdahl, and C. H. Luce. 2011. Both topography and climate affected forest and woodland burn severity in two regions of the western US, 1984 to 2006. *Ecosphere* 2:art130.

Flint, L. E., A. L. Flint, J. H. Thorne, and R. Boynton. 2013. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. *Ecological Processes* 2:1-21.

Fried, J., J. Gilles, W. Riley, T. Moody, C. Simon de Blas, K. Hayhoe, M. Moritz, S. Stephens, and M. Torn. 2008. Predicting the effect of climate change on wildfire behavior and initial attack success. *Climatic Change* 87:251-264.

Kavanagh, K. L., M. B. Dickinson, and A. S. Bova. 2010. A way forward for fire-caused tree mortality prediction: modeling a physiological consequence of fire. *Fire Ecology* 6:80-94.

Mallek, C., H. Safford, J. Viers, and J. Miller. 2013. Modern departures in fire severity and area vary by forest type, Sierra Nevada and southern Cascades, California, USA. *Ecosphere* 4:art153.

McDowell, N. G. 2011. Mechanisms linking drought, hydraulics, carbon metabolism, and vegetation mortality. *Plant Physiology* 155:1051-1059.

Meigs, G., D. Donato, J. Campbell, J. Martin, and B. Law. 2009. Forest fire impacts on carbon uptake, storage, and emission: The role of burn severity in the eastern Cascades, Oregon. *Ecosystems* 12:1246-1267.

Michaletz, S. T., E. A. Johnson, and M. T. Tyree. 2012. Moving beyond the cambium necrosis hypothesis of post-fire tree mortality: cavitation and deformation of xylem in forest fires. *New Phytologist* 194:254-263.

Miller, J., C. Skinner, H. Safford, E. E. Knapp, and C. Ramirez. 2012. Trends and causes of severity, size, and number of fires in northwestern California, USA. *Ecological Applications* 22:184-203.

Reinhardt, E. D., R. E. Keane, and J. K. Brown. 1997. First Order Fire Effects Model: FOFEM 4. 0, User's Guide, USDA Forest Service, INT-GTR-344, Ogden, UT.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313:940-943.

Williams, A. P., C. D. Allen, A. K. Macalady, D. Griffin, C. A. Woodhouse, D. M. Meko, T. W. Swetnam, S. A. Rauscher, R. Seager, H. D. Grissino-Mayer, J. S. Dean, E. R. Cook, C. Gangodagamage, M. Cai, and N. G. McDowell. 2012. Temperature as a potent driver of regional forest drought stress and tree mortality. *Nature Climate Change* 3:292-297.

BREVIA

Climatic Changes in Mountain Regions: A Review of Historical Changes and Future Outlook in the American Cordillera and the Tropics

Henry F. Diaz

NOAA/CIRES, University of Colorado, Boulder, Colorado

Diaz, H. F., Bradley, R.S., and Ning, L. In press (Nov, 2014). Climatic changes in mountain regions of the American Cordillera and the Tropics. Arctic, Antarctic, and Alpine Research.

A review of climatic changes occurring in the American Cordillera and the Tropics over the past half-century and a discussion of potential future climate changes due to global warming toward the end of this century is the subject of paper in press cited above. Key aspects of climatic variability and trends in these regions are the amplification of surface warming trends with height, and the strong modulation of temperature trends by tropical sea surface temperature, largely controlled by changes in El Niño/Southern Oscillation on multiple time scales. The paper also considers impacts associated with several aspects of the climate trends that include an increase in a critical plant growth temperature threshold, a rise in the freezing level surface, and the possibility of enhanced subtropical drying. Anthropogenic global warming projections indicate a strong likelihood for enhancement of these observed changes.

Mountain regions cover about one-fifth of the earth's continental areas providing basic life support directly for close to 10% of the world's population, and indirectly to over half. They play a crucial role in supplying freshwater resources to many regions, both within the mountains themselves, and in the broader regions downslope. Ecosystems along mountain slopes are closely stacked due to sharp vertical temperature and precipitation gradients, and are particularly sensitive to anthropogenic climatic change (Beniston 1994, Diaz and Graham 1996, Messerli et al. 2004, Beniston et al. 1997, Decker and Bugmann 1999, Diaz et al. 2003a, Huber et al. 2005, Bradley et al. 2006, 2009).

With the additional pressures of land use change and habitat fragmentation, such regions are especially vulnerable. While these issues are of general concern throughout the Tropics, they are particularly problematical on tropical and sub-tropical islands, as well as on isolated mountains on the continents, where the opportunities for species migration are obviously severely

constrained. In addition to the exceptional loss of habitat due to deforestation, encroaching urbanization and the introduction of invasive species in recent decades has only exacerbated the situation.

The freezing level height in the atmosphere is an important geophysical threshold, potentially affecting a range of hydrological and ecological processes. The freezing level height occurs at ~4500 m throughout the tropical belt. A study of freezing level height (FLH) changes along the American Cordillera by Diaz et al. (2003b; cf. their Fig. 2) examined upper air data from 1948–2000. In this region of the Tropics, FLH increased by ~73 m (1.43 m/year) over the study period, with a slightly lower rate of increase from 1958–2000 (~53 m, 1.17 m/year). The latter difference is due possibly to a prolonged period of cool tropical Pacific SST, or perhaps due to biases in the early years of the reanalysis product, or both. Interestingly, in a recently published paper that looked at millennial-scale changes in upper treeline in high mountain ranges of the Great Basin of the western U.S., changes in the mean position of the treeline scaled to ~60 m shifts per degree Celsius change in mean annual temperature (Salzer et al. 2013).

Over the last 100 years, global surface temperature has increased by ~0.8° C, more than half of it occurring in the last 40 years (Hansen et al. 2010, O’Gorman and Singh 2013). Based on NCEP reanalysis data the tropical free air temperature has increased by ~0.5° C over the last 4 decades at both the 700 mb level (~3 km) and at the 400 mb level (~7 km). In both instances there is considerable spatial variability, with some regions in the vicinity of the tropical warm pools exhibiting warming that exceeds 0.8° C (Pepin and Lundquist 2008, Rangwalla and Miller 2012).

Figure 1 shows projected 100-year temperature changes from the surface to ~9 km height along a meridional transect along the American Cordillera with doubled levels of CO₂, based on 10 general circulation model simulations of future climate from the IPCC Fifth Assessment Report. Projections are shown for

mean annual temperature in the respective hemispheres under the RCP4.5 concentration trajectory scenario. The results are consistent with previous results reported by Bradley et al. (2004, 2006) using an earlier suite of GCMs—namely a future with greater total warming with increasing elevation. A significant rise in the freezing level surface is evident, particularly in tropical latitudes.

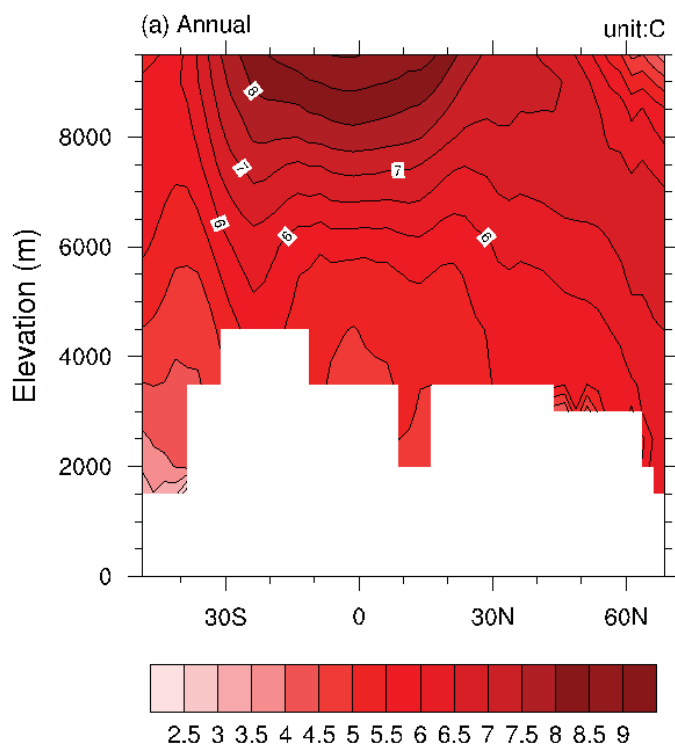


Figure 1. The mean change in free air temperature for the RCP 8.5 emissions scenario: Differences are calculated for the period 2081–2100 minus 1981–2000; average of 10 CMIP5 GCMs. Source: Diaz et al. 2014.

In summary, the global climate models used in the latest IPCC Assessments project late 21st-century global surface temperature increase of $\sim 3.5^{\circ}\text{C}$. Warmer oceans will lead to an enhanced hydrologic cycle, an increase of latent heat input to the atmosphere, and hence greater warming with elevation (Ohmura 2012). The study by Ohmura (2012) evaluated long-term surface temperature records for multiple sets of station records using high and low elevation pairs to assess differences in trends. The author found that in about 60% of the areas analyzed there was a significant amplification of recent warming trends at the higher elevations. A similar large-scale comparison of surface temperature trends for stations at different elevations around the globe also indicates greater warming trends at higher elevations compared to lower elevation sites.

Some important atmospheric surfaces, such as the freezing level height and an approximate minimum growth temperature threshold for tree growth exhibit large upward shifts in the past half-century. A rise of $\sim 200\text{ m}$ in the 6.5°C surface, assuming a typical vertical temperature lapse rate of $\sim 6.5^{\circ}\text{C/km}$ translates to an approximate warming at the nominal altitude of this surface of $\sim 1.3^{\circ}\text{C}$. Ecosystem changes are already occurring in many regions, and are having a significant impact on tree stand mortality, and fire occurrence and intensity (Westerling et al. 2006, Allen et al. 2010, Williams et al. 2013).

The high spatial heterogeneity of mountain climates and environments, and the scarcity of on-the-ground measurements, challenges our ability to document current rates of change, and to model the specific changes that can be expected under future climate scenarios. As societal pressures on mountain ecosystems increase, in order to plan for sustainable development in these regions, as well as downstream areas, which depend on them, more detailed scenarios of future climate changes (with high spatial resolution) are needed for realistic assessments of their environmental consequences. Changes in the alpine cryosphere are already clearly visible, and represent some of the earliest signs of large-scale climate change. A reduction in the area covered by snow and ice not only serves as an indicator of change but also provides powerful feedbacks through changes in albedo. In addition, melting of permafrost destabilizes slopes in areas of high relief, leading to landslides, rockfalls and other climate-related geomorphic hazards, such as the formation of unstable proglacial lakes, which may lead to potentially catastrophic flooding (Milly et al. 2002) and other significant hazards in many places (Allamano et al. 2009), as has already occurred in the tropical Andes (Bradley et al. 2006, Vuille et al. 2008).

Changes in hydrological variability, precipitation, and snow cover impact a broad range of socio-economic sectors, including hydropower generation (Barnett et al. 2004), ecosystem health (Breshears et al. 2005, 2008, Williams et al. 2013), water resources for irrigation and civil supply (Messerli et al. 2004, Coudrain et al. 2005, Knowles et al. 2006, Milly et al. 2008, Wi et al. 2012) and tourism-related industries (Bradley et al. 2006, Rosenzweig et al. 2007, Orlove et al., 2008). Decision-makers in these different sectors need more accurate data on current and future conditions in the high mountains for effective resource management planning. This requires more investment in environmental monitoring within high mountain regions, and further research on future climate scenarios using regional climate models that can be linked to glaciological, hydrological, and ecological models (Diaz et al. 2006).

References

- Allamano, P., Claps, P., and Laio, F. 2009. Global warming increases flood risk in mountainous areas. *Geophys. Res. Lett.* 36:L24404, doi:10.1029/2009GL041395.
- Allen, C. D. and Coauthors. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management* 259:660–684.
- Barnett, T. R. Malone, W. Pennell, D. Stammer, B. Semtner and W. Washington. 2004. The effects of climate change on water resources in the West: Introduction and overview. *Climatic Change* 62:1–11.
- Beniston, M. (Ed.). 1994. *Mountain Environments in Changing Climates*. Routledge, London, 461 pp.
- Beniston, M., H. F. Diaz, and R. S. Bradley. 1997. Climatic change at high elevation sites: An overview. *Climatic Change* 36:233–251.
- Bradley, R.S., F.T. Keimig, and H.F. Diaz. 2004. Projected temperature changes along the American Cordillera and the planned GCOS Network. *Geophys. Res. Lett.* 31: doi:10.1029/2004GL020229.
- Bradley, R.S., M. Vuille, H.F. Diaz, and W. Vergara. 2006. Threats to water supply in the Tropical Andes. *Science* 312:1755–1756.
- Bradley, R. S., F. T. Keimig, H. F. Diaz, and D. R. Hardy. 2009. Recent changes in freezing level heights in the Tropics with implications for the deglaciation of high mountain regions. *Geophys. Res. Lett.* 36:L17701, doi:10.1029/2009GL037712.
- Breshears, D.D. and Coauthors. 2005. Regional vegetation die-off in response to global-change-type drought. *Proc. of the Natl. Acad. of Sci. of the USA* 102:15144–15148.
- Breshears, D.D., T.E. Huxman, H.D. Adams, C.B. Zou, and J.E. Davison. 2008. Vegetation synchronously leans upslope as climate warms. *Proc. of the Natl. Acad. of Sci. of the USA* 105:11591–11592.
- Coudrain, A., B. Francou, and Z.W. Kundewicz. 2005. Glacier shrinkage in the Andes and consequences for water resources. *Hydrol. Sci. Journal* 50:925–932.
- Decker, A., and H. K. Bugmann (Eds.). 1999. *Global change and mountain regions*, Report 49, 85 pp., Int. Geosphere-Biosphere Program.
- Diaz, H. F., and N. E. Graham. 1996. Recent changes in tropical freezing heights and the role of sea surface temperature. *Nature* 383:152–155.
- Diaz, H. F., Eischeid, J. K., Duncan, C., and Bradley, R. S. 2003b. Variability of freezing levels, melting season indicators, and snow cover for selected high-elevation and continental regions in the last 50 years. *Climatic Change* 59:33–52.
- Diaz, H. F., Grosjean, M., and L. Graumlich, L. 2003a. Climate variability and change in high elevation regions: past, present and future. *Climatic Change* 59:1–4.
- Diaz, H. F., R. Villalba, G. Greenwood, and R.S. Bradley. 2006. The Impact of Climate Change in the American Cordillera. *EOS* 87:315.
- Hansen, J., Ruedy, R., Sato, M., and Lo, K. 2010. Global surface temperature change, *Rev. Geophys.* 48:RG4004, doi:10.1029/2010RG000345.
- Huber, U., Reasoner, M., and Bugmann, H. (Eds.). 2005. *Global Change and Mountain Regions, A State of Knowledge Overview*. Dordrecht: Kluwer Academic Publishers, 652 pp.
- IPCC. 2013. *Climate Change 2013 — The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC*. Cambridge University Press, Cambridge, UK, 1535 pp.
- Knowles N, Dettinger M, Cayan D. 2006. Trends in snowfall versus rainfall in the Western United States. *Journal of Climate* 19:4545–4559.
- Messerli, B., Viviroli, D., and Weingartner, R. 2004. Mountains of the world: Vulnerable water towers for the 21st Century. *Ambio*, Special Report No. 13:29–34. <http://www.jstor.org/stable/25094585>.
- Milly P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R., Kundzewicz, Z., Lettenmaier, D., and Stouffer, R. 2008. Stationarity is dead—Whither water management? *Science* 319:573–574. doi:10.1126/science.1151915.
- O’Gorman, P. A., and Singh, M.S. 2013. Vertical structure of warming consistent with an upward shift in the middle and upper troposphere. *Geophys. Res. Lett.* 40:1838–1842, doi:10.1002/grl.50328.
- Ohmura, A. 2012. Enhanced temperature variability in high-altitude climate change. *Theoretical & Applied Climatology* 110:499–508.
- Orlove, B., Wiegandt, E., and B. H. Luckman (Eds.). 2008. *Darkening peaks: Glacial retreat, science and society*. Berkeley: University of California Press, 282 pp.
- Pepin, N. C., and Lundquist, J. D. 2008. Temperature trends at high elevations: Patterns across the globe. *Geophys. Res. Lett.* 35:L14701, doi:10.1029/2008GL034026.

Rangwalla, I., and J. R. Miller. 2012. Climate change in mountains: a review of elevation-dependent warming and its possible causes. *Clim. Chg.* 114:527–547.

Rosenzweig et al. 2007. Assessment of observed changes and responses in natural and managed systems. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the 4th Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge Univ. Press, Cambridge, UK, 79–131.

Salzer, M. W., Bunn, A. G., Graham, N. E., and Hughes, M. K. 2013. Five millennia of paleotemperature from tree-rings in the Great Basin, USA. *Climate Dynamics*, DOI: 10.1007/s00382-013-1911-9.

Vuille, M., Francou, B., Wagnon, P., Juen, I., Kaser, G., Mark, B. G., Bradley, R. S. 2008. Climate change and tropical Andean glaciers: Past, present and future. *Earth-Science Reviews* 89:79–96.

Westerling, A. L., Hidalgo, H. G., Cayan, D. R., and Swetnam, T. W. 2006. Warming and earlier spring increase in U.S. forest wildfire activity. *Science* 313:940–943.

Wi, S., Dominguez, F., Durcik, M., Valdes, J., Diaz H. F., and Castro, C. L. 2012. Climate change projections of snowfall in the Colorado River Basin using dynamical downscaling, *Water Resour. Res.* 48:W05504, doi:10.1029/2011WR010674.

Williams, A. P., and Coauthors. 2013. Temperature as a potent driver of regional forest drought stress and tree mortality. *Nature Climate Change* 3:292–297.



Greetings, earthlings, from the east end of the Extraterrestrial Highway, Nevada Route 375, near Hiko Nevada.
Photo: Kelly Redmond

BREVIA

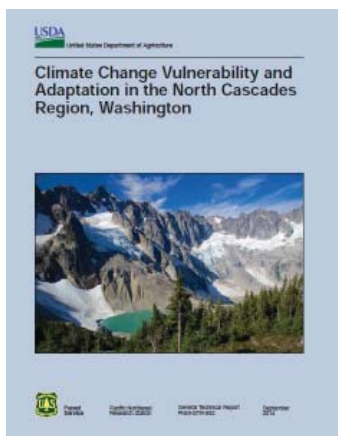
Floods, Fire, and More—Climate Change Effects and Adaptation in the North Cascades

David L. Peterson

USDA Forest Service, Pacific Northwest Research Station, Seattle, Washington

Raymond, C.L., D.L. Peterson, and R.M. Rochefort (eds.).

2014. *Climate change vulnerability and adaptation in the North Cascades region. USDA Forest Service General Technical Report PNW-GTR-892. Pacific Northwest Research Station, Portland, OR.*



The North Cascadia Adaptation Partnership (NCAP) is a science-management partnership consisting of the U.S. Forest Service Pacific Northwest Research Station, Mount Baker-Snoqualmie National Forest, Okanogan-Wenatchee National Forest, North Cascades National Park Complex, Mount Rainier National Park, and University of Washington Climate Impacts Group. These organizations worked with 30 stakeholders over 2 years to identify climate-change issues relevant to resource management in the North Cascades region of Washington state, and to find solutions that will facilitate transition of the diverse ecosystems of this region to a warmer climate. The NCAP provided education, conducted a climate change vulnerability assessment, and developed adaptation options for federal agencies that manage 2.4 million hectares in north-central Washington.

As the climate continues to warm, hydrologic systems in North Cascades watersheds will become increasingly rain dominated, rather than snow dominated, resulting in more autumn/winter flooding, higher peak flows, and lower summer flows (Fig. 1). This will greatly affect the extensive road network in the North Cascades (longer than 16,000 km), making it difficult to maintain access for recreational users and resource managers.



Figure 1. A warmer climate is expected to increase peak flows and flooding in autumn and winter in streams on the west side of the North Cascade Range. This trend is already apparent as a result of reduced snowpack caused by warmer temperatures. Flooding, as shown here for the Stehekin River, causes costly damage to roads and other infrastructure and reduces access to federal lands. Photo: National Park Service

It will also greatly reduce suitable fish habitat, especially as stream temperatures increase above critical thresholds. In forest ecosystems, higher temperatures will increase stress and lower the growth and productivity of lower elevation tree species on both the western and eastern sides of the Cascade crest, although growth of high-elevation tree species is expected to increase. Distribution and abundance of plant species may change over the long term, and increased disturbance (wildfire, insects, and invasive species) will cause rapid changes in ecosystem structure and function across broad landscapes, especially on the east side. This in turn will alter habitat for a wide range of animal species by potentially reducing connectivity and late-successional forest structure.

Coping with and adapting to the effects of an altered climate will become increasingly difficult after the mid-21st century, although adaptation strategies and tactics are available to ease the transition to a warmer climate. For roads and infrastructure, tactics for increasing resistance and resilience to higher peak



Figure 2. A warmer climate is expected to increase the duration of fire season and annual area burned in dry forests on the east side of the North Cascade Range. Although wildfires cannot be stopped, their intensity can be reduced through assertive management of forest stand densities and surface fuels, thus increasing resilience and protecting large overstory trees. Photo: U.S. Forest Service

flows include installing hardened stream crossings, stabilizing streambanks, designing culverts for projected peak flows, and upgrading bridges and increasing their height. For fisheries, tactics for increasing resilience of salmon to altered hydrology and higher stream temperature include restoring stream and floodplain complexity, reducing road density near streams, increasing forest cover to retain snow and decrease snow melt, and identifying and protecting cold-water refugia. For vegetation, tactics for increasing resilience to higher temperature and increased disturbance include accelerating development

of late-successional forest conditions by reducing density and diversifying forest structure, managing for future range of variability in structure and species, including invasive species prevention strategies in all projects, and monitoring changes in tree distribution and establishment at tree line. For wildlife, tactics for increasing resilience to altered habitat include increasing diversity of age classes and restoring a patch mosaic, increasing fuel reduction treatments in dry forests (Fig. 2), using conservation easements to maintain habitat connectivity, and removing exotic fish species to protect amphibian populations.

The NCAP facilitated the largest climate change adaptation effort on federal lands to date by including many participants from other organizations to promote an all-lands approach to addressing climate change. It achieved specific elements of national climate change strategies for the U.S. Forest Service and National Park Service, providing a scientific foundation for resource management and planning in the North Cascades region. The NCAP process has already catalyzed the development of several additional projects that address the effects of climate change on hydrologic function, fisheries, access, and habitat connectivity, expanding the capacity of regional institutions to incorporate climate change in planning and management. Continued implementation of adaptation in sustainable resource management will enhance the potential for North Cascades ecosystems to maintain long-term functionality in future decades.

The publication can be downloaded here <http://www.treesearch.fs.fed.us/pubs/47131>.

Printed copies can be ordered here <http://www.fs.fed.us/pnw/publications/index.shtml>.

While the studies and results described below have not yet been submitted for publication, on the basis of her invited talk in the Early Career session at MtnClim 2014, I asked Brenna to develop a BREVIA for Mountain Views. Research such as studies Brenna and her colleagues are undertaking with landscape genomic approaches to investigate adaptation processes and develop conservation strategies for climate change are sparsely represented in the CIRMOUNT community. I anticipate (and hope) we will see more studies in the future such as Brenna is conducting. -- Editor

BREVIA

Mountains, Climate Change, and Conservation: The Role of Landscape Genomics

Brenna R. Forester¹, Dean L. Urban², Thomas F. Schultz²,
Jennifer J. Wernegreen², and Rob R. Dunn³

¹University Program in Ecology, Nicholas School of the Environment,
Duke University, Durham, North Carolina

²Nicholas School of the Environment, Duke University, Durham, North Carolina

³Department of Biological Sciences, North Carolina State University, Raleigh, North Carolina

Faced with climate change, organisms either adapt in place or move—or they go extinct. Relative to dispersal, adaptation in response to environmental change remains poorly understood (Hoffmann and Sgro 2011). Fortunately the recent development of molecular techniques for detecting local adaptation in wild populations has made it easier to evaluate this response (Schoville et al 2012, Harrisson et al. 2014). When these molecular methods are integrated with landscape and spatial analyses, they offer important benefits for conservation practice in a dynamic world, since expanding adaptive capacity in wild populations can improve their ability to persist under the synergistic effects of climate change and habitat fragmentation.

Our research is based in the expanding field of landscape genetics, which addresses the interaction of landscape features and microevolutionary processes (Manel and Holderegger 2013). Our approach to genetic analyses places this work more specifically in the realm of landscape genomics, in which high-throughput sequencing is used to develop a large number of neutral and potentially adaptive molecular markers. In combination with geospatial and environmental data, these molecular markers are used to identify and understand spatial patterns and environmental drivers of local adaptation and gene flow. This approach lies at the interface of landscape ecology, population genomics, spatial statistics, and bioinformatics.

Species living in montane systems are an excellent choice for landscape genomic analyses. Mountains provide replicated elevational gradients for assessing local adaptation, as well as environmental clines that are steep relative to the dispersal capacity of many organisms. This allows us to assess the

joint effects of local adaptation and gene flow in a replicated framework (Keller et al. 2013a).

We are investigating the interaction of local adaptation and gene flow in *Plethodon welleri*, an endemic, montane species of conservation concern (Fig. 1). This salamander has a restricted range in the Southern Appalachian Mountains (Fig. 2), a global hotspot for salamander biodiversity. The fully terrestrial woodland salamanders (genus *Plethodon*) contribute heavily to the biodiversity and endemism of this region, however these salamanders are under threat from a diversity of causes, most of which are not well understood (Highton 2005, Caruso and Lips 2013). These animals have limited dispersal capabilities, narrow physiological tolerances, and are highly sensitive to changes in climate, specifically the interaction of temperature and moisture (Bernardo and Spotila 2006).



Figure 1. *Plethodon welleri*. Photo: Katherine Cain.

Climate change is expected to result in habitat loss and increased isolation for high-elevation Plethodontid salamanders in the Southern Appalachians (Milanovich et al 2010). The presence of warm-adapted populations at low elevation range limits has important consequences for the potential of montane species, such as *P. welleri*, to adapt to rapid warming. Our research is quantifying how local adaptation and gene flow interact to affect the genetics and ecology of these salamanders in fragmented and warming habitats. We are asking a number of questions, including:

1. To what extent are salamander populations separated by geographic distance also genetically different? This is the isolation by distance effect (IBD), in which neutral genetic differentiation increases as a function of distance due to the interaction of genetic drift and restricted gene flow (Wright 1943, Slatkin 1993). An extension of this question includes how neutral markers covary with environment, independent of geographic distance (termed “isolation by environment”; Wang and Bradburd 2014).

2. To what extent are salamander populations adapted to different climates? This addresses the incidence of local adaptation to microclimate. We are currently testing a suite of novel multivariate approaches to detect molecular markers potentially under selection; these markers help us identify and understand the drivers of local adaptation by determining how the spatial distribution of markers under selection covaries with environment.

3. To what extent does dispersal facilitate or isolation impede the ability of salamander populations to track or adapt to local microclimatic variability? Answers to this question are provided by instances where populations are maladapted to their local microclimate, perhaps because warming (due to climate change or forest loss) has occurred faster than the population could adapt. Conversely, gene flow from nearby habitats might subsidize a population with better-adapted genotypes. We are addressing this question by investigating relationships among neutral and adaptive molecular markers, microclimate variables, and separation distances.

As indicated in the questions above, our research uses a number of data sources and methods to identify the environmental drivers and spatial patterns of local adaptation and gene flow (Fig. 3). Briefly, we:

1. Sample at least 30 salamanders per mountain peak, stratifying individual samples across elevation and aspect. We record basic salamander and habitat data before taking 5 mm tail snips using an aseptic technique; salamanders are then released at their point of capture.
2. Collect high-resolution temperature and relative humidity data across the study area; these data are used to model environmental covariates relevant to salamander habitat use and physiology.
3. Genotype individuals at thousands of single nucleotide polymorphism (SNP) markers using double digest restriction site associated DNA sequencing (RAD-seq; Peterson et al. 2012). RAD-seq has become a powerful tool for conservation genomics because it does not require a sequenced genome and can readily be used to study local adaptation in wild populations (Keller et al. 2013b; White et al. 2013).
4. Reconstruct genotypes *de novo* (without a reference genome) using the program Stacks (Catchen et al. 2011).
5. Partition neutral and potentially adaptive SNP markers using novel individual-based genotype-environment outlier detection methods, including constrained ordinations.
6. Integrate data sets using a Bayesian approach (BEDASSLE) that allows us to quantify the relative contributions of space and environment to neutral and adaptive genetic differentiation while accommodating spatial autocorrelation in the data (Bradburd et al. 2013).

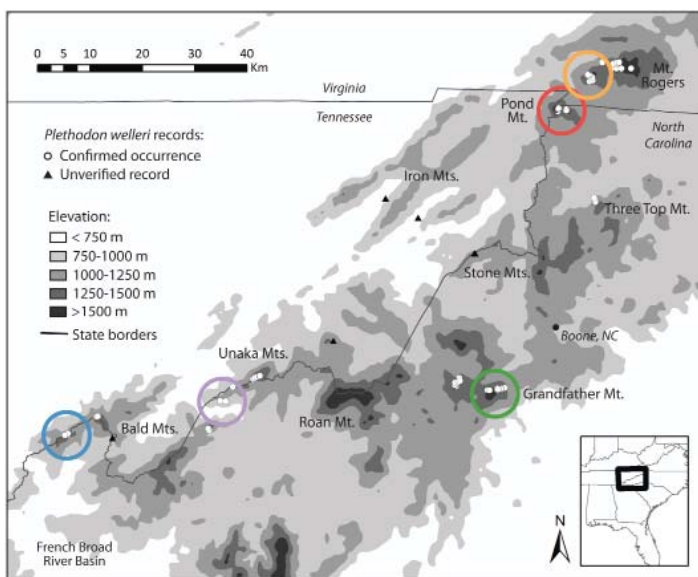


Figure 2. Full range of *Plethodon welleri* in the Southern Appalachian Mountains, and distribution of confirmed and unverified presence records. The five areas circled match colors used to delineate populations in the principle component analysis (Fig.4).

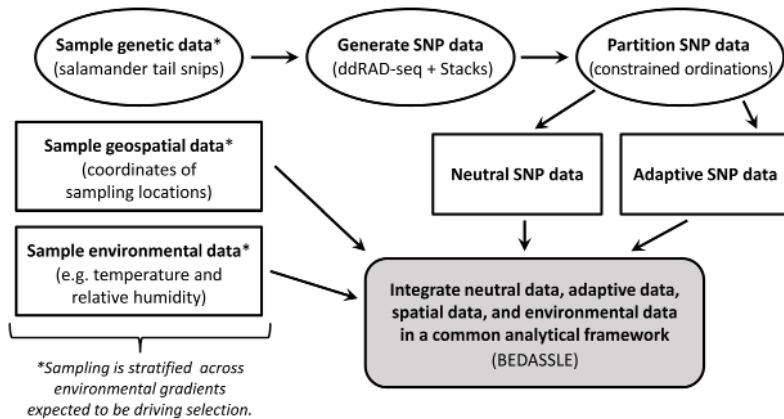


Figure 3. Flowchart of methods used for landscape genomic analyses of *Plethodon welleri*. Circles represent intermediate data products, with completed data products in rectangles. The shaded rectangle represents the final integrative step.

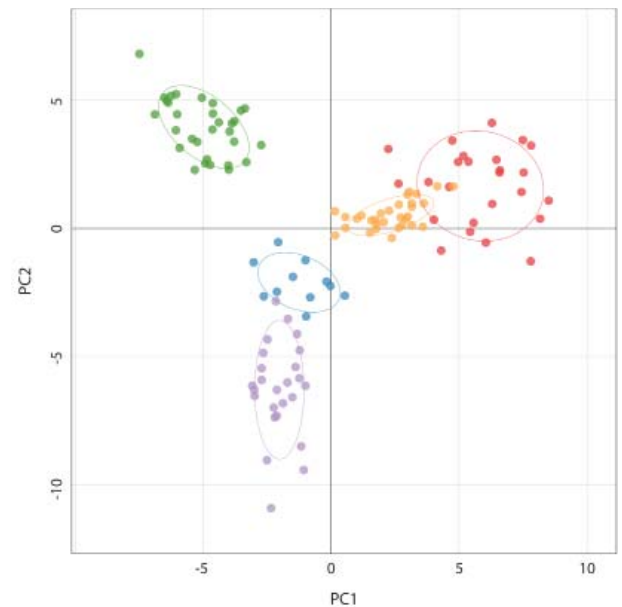


Figure 4. Principle component analysis of neutral genotypes of 123 *Plethodon welleri* individuals (points) in five populations (colors – see location of populations in Fig. 2); ellipses encircle two-thirds of the individuals in each population.

Highlights of our Research Results to Date

- *Plethodon welleri* populations show significant IBD at neutral SNP markers both across mountain peaks and within elevation gradients indicating restricted gene flow likely due to dispersal limitation (Fig. 4).
- *Plethodon welleri* populations show evidence of local adaptation at SNP markers potentially under selection based on temperature proxies, both along elevation gradients and across populations (latitudinally).
- RAD-seq can successfully be used to identify thousands of SNP markers across the genome of *P. welleri*: we identified 642,000 RAD tags (short reads) across 128 individual *P. welleri* in five populations, and genotyped 31,584 markers with a maximum of 3 SNPs per tag in at least 80% of the individuals.
- Multivariate approaches (e.g. constrained ordinations) are computationally efficient and highly effective methods for differentiating neutral from potentially adaptive molecular markers in very large genomic data sets (Forester et al., *in prep*). These methods maintain high power to detect markers under selection while simultaneously controlling for demographic signals in neutral markers that produce high false positive rates.

Landscape genomic tools are applicable across all taxa, even those for which there is no prior genomic information. These methods are especially valuable in mountain systems, which harbor a large proportion of endemic species that are especially vulnerable to climate change and habitat fragmentation.

Landscape genomic analyses such as ours provide information of high conservation value, including quantifying the “adaptability” of populations (identifying genetic material from provenances that match future climate, Steane et al. 2014), as well as their “evolutionary resilience” (the ability of populations to undergo evolutionary adaptation in response to changing environmental conditions, Sgro et al. 2011). Our novel analytic approach will help us better understand the capacity of species to adapt to changing conditions, and what actions will be most effective to conserve biodiversity under global change.

References

- Bernardo J, Spotila JR. 2006. Physiological constraints on organismal response to global warming: mechanistic insights from clinally varying populations and implications for assessing endangerment. *Biol Lett* 2:135–139.
- Bradburd GS, Ralph PL, Coop GM. 2013. Disentangling the effects of geographic and ecological isolation on genetic differentiation. *Evolution* 67:3258–3273.
- Caruso NM, Lips KR. 2013. Truly enigmatic declines in terrestrial salamander populations in Great Smoky Mountains National Park. *Divers Distrib* 19:38–48.
- Catchen J, Amores A, Hohenlohe P, et al. 2011. Stacks: building and genotyping loci *de novo* from short-read sequences. *G3 Genes Genomes Genet* 1:171–182.

Forester BR, Jones MR, Joost S, Landguth EL, Lasky J. *In prep.* Detection of loci under selection across spatially complex landscapes using multivariate methods to effectively control for population structure.

Harrisson KA, Pavlova A, Telonis-Scott M, Sunnucks P. 2014. Using genomics to characterize evolutionary potential for conservation of wild populations. *Evol Appl*. doi: 10.1111/eva.12149

Highton R. 2005. Declines of eastern North American woodland salamanders *Plethodon*. In: Lanoo M (ed) *Amphibian Declines: Conservation Status of United States*. University of California Press, pp 34–46.

Hoffmann AA, Sgro CM. 2011. Climate change and evolutionary adaptation. *Nature* 470:479–485.

Keller I, Alexander JM, Holderegger R, Edwards PJ. 2013a. Widespread phenotypic and genetic divergence along altitudinal gradients in animals. *J Evol Biol* 26:2527–2543.

Keller I, Wagner CE, Greuter L, et al. 2013b. Population genomic signatures of divergent adaptation, gene flow and hybrid speciation in the rapid radiation of Lake Victoria cichlid fishes. *Mol Ecol* 22:2848–2863.

Manel S, Holderegger R. 2013. Ten years of landscape genetics. *Trends Ecol Evol* 28:614–621.

Milanovich JR, Peterman WE, Nibbelink NP, Maerz JC. 2010. Projected loss of a salamander diversity hotspot as a consequence of projected global climate change. *PLoS ONE* 5:e12189.

Peterson BK, Weber JN, Kay EH, et al. 2012. Double digest RADseq: an inexpensive method for *de novo* SNP discovery and genotyping in model and non-model species. *PLoS ONE* 7:e37135.

Schoville SD, Bonin A, François O, et al. 2012. Adaptive genetic variation on the landscape: methods and cases. *Annu Rev Ecol Evol Syst* 43:23–43.

Sgro C, Lowe A, Hoffmann A. 2011. Building evolutionary resilience for conserving biodiversity under climate change. *Evol Appl* 4:326–337.

Slatkin M. 1993. Isolation by distance in equilibrium and non-equilibrium populations. *Evolution* 47:264–279.

Steane DA, Potts BM, McLean E, et al. 2014. Genome-wide scans detect adaptation to aridity in a widespread forest tree species. *Mol Ecol* 23:2500–2513.

Wang IJ, Bradburd GS. 2014. Isolation by environment. *Mol Ecol*. doi: 10.1111/mec.12938

White TA, Perkins SE, Heckel G, Searle JB. 2013. Adaptive evolution during an ongoing range expansion: the invasive bank vole (*Myodes glareolus*) in Ireland. *Mol Ecol* 22:2971–2985.

Wright S. 1943. Isolation by distance. *Genetics* 28:114–138.



Tufa towers at Mono Lake, California. Photo: Kelly Redmond

An Interview with Kelly Redmond; 2014 Awardee of the Tyndall History of Global Environmental Change Lecturer, American Geophysical Union

Kelly Redmond is Regional Climatologist and Deputy Director of the Western Regional Climate Center, and Research Professor in climatology at the Desert Research Institute, Reno, NV. This summer he was selected as the "Tyndall History of Global Environmental Change Lecturer" for the Fall 2014 meeting of the American Geophysical Union in San Francisco. This award recognizes the life and work of physicist (also mountaineer), John Tyndall, whose measurements in the late 1850s and early 1860s verified the importance of the greenhouse effect that had been proposed by Fourier in 1824. Kelly was selected as Tyndall Lecturer in recognition of his outstanding contributions to understanding of global environmental change. Specifically, this lecture focuses on the development of the science underlying global environmental change and provides a historical perspective. Kelly will deliver his lecture during the December meeting (Thursday afternoon, Dec. 18), which will also be available as a webcast and as an archived presentation on the AGU website. As a founder and key coordinator of CIRMOUNT we are tremendously excited about this award, proud of Kelly, and offer our sincere congratulations. We look forward to his thoughts in the Tyndall lecture as we do his insights on all things climatological during the many other lectures Kelly presents annually.

-- Editor

KELLY REDMOND



"THE WIND IS A MUSICAL INSTRUMENT WITH A CERTAIN RANGE OF TONES, BEYOND WHICH IN BOTH DIRECTIONS WE HAVE AN INFINITE SILENCE"

-- JOHN TYNDALL

Connie: Give us some personal history – what first got you interested in climate as a research focus and what motivated your passion to communicate climate information and knowledge so broadly?

Kelly: I grew up in Southwest Montana in Belgrade, next to the Bozeman Airport, where my dad worked for the FAA for 27 years as a Flight Service Specialist. He also recorded the official weather records for BZN airport during this time. In Montana, everybody a) is interested in the weather, or b) is dead. My dad had a lot of weather material from his training, and I memorized it all. I remember well a 5th-grade science project on clouds. My freshman advisor at MIT, Fred Sanders, was a highly respected and motivated meteorologist. As a physics major (astrophysics, which I still follow closely) I took some courses in meteorology, and hung around the map room often. My undergraduate advisor, Rainier Weiss, who along with Kip Thorne was one of the two co-founders of today's LIGO project, told me that he considered climate prediction to be among the hardest problems in science. This just totally intrigued me, because I love hard problems. Astronomers are often clouded out; rather than look *through* the atmosphere, I decided to look *at* the atmosphere. Further, I am interested in every part of Nature, and climate eventually touches all other earth science disciplines, has deep connections to fundamental processes, is strongly nonlinear, and is hugely important to society, so this appeals very strongly to me. My basic affliction is an interest in everything, something that Richard Feynmann called "the pleasure of finding things out."

As state climatologist for Oregon for 7 years, I had about 35,000 one-on-one conversations with people from every walk of life about nearly every facet of climate. Maybe 10-20 of these conversations were about climate change; the large majority was just about the ongoing effects of climate variability. I always

received a lot of positive feedback from these encounters, and spent more and more time giving talks and presentations, always very well received, which provided further encouragement. Also, I feel very strongly that society does not support science and climate studies just so that we can indulge our personal passions (although, it should for that reason as well), but so that it will receive useful payback on its investment. Also, it is a wonderful challenge to learn how to transfer intact a thought from one mind to another. It helps greatly that the public has a direct and intimate connection with climate and weather, a natural and major advantage for our profession.

Connie: OK, great. Like John Tyndall, mountains are clearly important in your work. In what ways do you find mountain climates – their process, patterns, and challenges -- so compelling?

Kelly: I grew up in the beautiful Gallatin Valley, something I would not trade for anything, surrounded by mountains on every horizon, spent many days in them with my four brothers and my mom and dad. I was fascinated by the way mountain weather could be so different from that out in the middle of the valley. Mountains make their own weather, and modify much of the rest of weather. There are exceptionally sharp spatial gradients in so many atmospheric and climatic properties, something not widely appreciated by those who do not live, work, and play in such surroundings. My job covers the 11 western states and Alaska and Hawaii, with mountains galore and complex topography a defining property of that entire region. It's one of many reasons why I really love this job. Throughout the West, we are strongly affected by mountains, even if we do not directly live in them. And there is the simple fact of how inspiring they are. Meteorology becomes far more complex in such terrain, and more difficult to observe. We specialize in observations, and mountain observations probably take 2-3 times, or more, effort and resources to produce successful high quality measurements. We also suffer from insufficient density of long-term high quality observations, because of the many difficulties involved.

Connie: What do you see as urgent problems to be tackled or needs to be addressed in the near future in relation to our work in mountain climates and ecosystems in order to make important progress on societally critical issues of anthropogenic global warming?

Kelly: We need to learn how mountain climates work, fundamentally, in the absence of climate change. Climate change is simply another source or type of variability. An important issue is how large-scale patterns (global, continental) of atmospheric variability translate to the small-scale realm (meters



Kelly shares a light moment with Chris Daly at the recent *MtnClim 2014* conference. Photo: Scotty Strachan.

to a few kilometers) in complex environments. Orographic enhancement of precipitation is affected by topographic details, wind patterns, vertical stability, and other subtle factors, a subject about which we need to learn more. Elevation and aspect effects on insect pests and pathogens are still in need of further understanding. Mountains reach up and "grab" water from the sky, and serve as reservoirs that meter this water out over the warm season and maintain base flows for streams. How will this function be affected by changes in temperature and precipitation? A big challenge is to close the surface water budget on scales of a kilometer or less. Especially important is assigning better numbers to groundwater flows and reservoirs, and better understanding the physical processes by which this is accomplished.

Mountains were once regarded as largely unapproachable and forbidding environments (e.g., read Mary Shelley's *Frankenstein*). Improved physical, and now electronic, access has greatly changed this attitude. Now, by contrast with the past, mountains are increasingly being populated, with pushes to higher elevations, and the wildland-urban interface, and the exurbs, are leading to fire and wildlife issues in places where formerly few people lived. Climate change, and warming temperatures, may act as a force driving people to higher and cooler elevations. For much of human history, mountains were regarded as mysterious and sacred places. In my own view, this latter distinction may have decreased, even though (again, my view) we should be regarding all of Nature, all biomes and climates and settings, as sacred.

Connie: How would you suggest CIRMOUNT scientists can contribute best to these challenges?

Kelly: The MtnClim Conferences are one great tradition to keep going. We might be ready for a next rendition of Mapping New Terrain [CIRMOUNT's early document], though many things in that publication are still relevant and timely. Keep up a tradition of interdisciplinary communication. Mountain Views Newsletter is one of those forms of communications, and you all have given an excellent start and example to that. Continue to advocate for monitoring.

Connie: So what about the El Niño we hear about for winter 2014? Isn't summer too early to be predicting ENSO? [I had asked this question earlier this year to Kelly]

Kelly: As of this writing (early Nov 2014) a weak to moderate El Niño still seems on track. This year a potential El Niño for winter 2014-15 was suggested at a very early lead time (May or so, highly unusual), leading to much speculation about a possible strong El Niño come winter. Then the situation slipped during summer as El Niño, especially a strong version, appeared much less likely. In the last few months, models and other signs have

consistently pointed to about a 2/3 probability of a weak to moderate El Niño. The ocean temperatures have been showing mildly warm conditions in the ENSO area on the equator, giving credence to expectations of a minimal to modest El Niño. As we have pointed out in a recent fact sheet, various indicators caution us not to expect a savior on a white horse in the form of El Niño to end the severe drought conditions. El Niño is only one factor that can affect western U.S. winter climate.

Connie: Anything else to add in light of your Tyndall Award and its significance?

Kelly: I am very much honored and surprised by this. It's an excellent fit to my interests. Tyndall worked on three main facets: the physics of radiative transfer in the atmosphere (CO₂ effect), he was a lifelong accomplished mountaineer and has a peak named after him in the Sierra Nevada, and most importantly he felt a duty to translate science to the citizenry and took this responsibility very seriously. This award gives me motivation to expand my thinking on several fronts, and the talk will be something of an experiment.



Kelly atop Hardscramble Peak looking northwest. Bridger Mountains, Montana. Photo: Patrick Redmond.

An Interview with Mike Dettinger; 2014 Fellow of the American Geophysical Union

Mike Dettinger, Research Hydrologist with the U.S. Geological Survey and University of California Scripps, Institution of Oceanography at La Jolla, California, was elected this year to the 2014 Class of Fellows of the American Geophysical Union (AGU). In that Mike is a founder and key leader of CIRMOUNT, we in the mountain-science community send Mike our congratulations and share in the pride of this honor. Mike will be recognized with other 2014 Fellows during the annual Fall Meeting of the AGU on Wednesday evening, December 17, 2014 in San Francisco, California. My admiration for Mike's incisive mind and for his many critical scientific contributions added incentive to pin Mike down with the following questions.

-- Editor

MIKE DETTINGER



Photo: Nicholas Barrett

"THE MOST SUCCESSFUL SCIENTIST THINKS LIKE A POET—WIDE-RANGING, SOMETIMES FANTASTICAL—AND WORKS LIKE A BOOKKEEPER."

-- E.O. WILSON

Connie: Your recent critical body of research on atmospheric rivers has brought clarity and systematic rigor to what had been a poorly understood climatological process of significant implications. What got you started on this line of research?

Mike: Interestingly, it was a PACLIM [Pacific Climate] Workshop back in the days when I was running that show that led me into this atmospheric rivers stuff. It was the year when we wanted to look at paleo records of multi-decadal droughts and such (sounds like any PACLIM, but in those days this was a special theme for that particular year...I think I still have the t-shirt). I rather cantankerously was concerned that some of the isotope-based discussions would devolve into long strings of attributing various isotopic excursions in various proxies to "El Niño supplies a

bunch of tropically fed precipitation here, and La Niña does more over there", and so on, without anyone having actually looked to see what ENSO and PDO and so forth actually do to the movements of water vapor around the world. I realized that I was in a position to derive a 50-yr record of daily vapor transports globally using modern meteorological data sets (re-analyses) to preempt the gap in the discussion that I was anticipating, and also immediately realized that if I made such a data set, there would be a ton of other uses for it too. So much of what we did was based on inferring how moisture (and heat) is transported from various proxies, like pressure fields and such. I realized that with the (then) modern data, I could go directly to what I so often really wanted to know: where was this water I was studying coming from, on any given day, month, year, whatever.

One of the things I did with the dataset once I'd constructed it (besides a poster session on ENSO/PDO/annual patterns of vapor transport for that PACLIM) was to track down and document every pineapple express storm on the west coast since 1948. That led me into conversations with the folks, like Marty Ralph, at NOAA, who had recently been flying around in such storms, and who were calling them "atmospheric rivers". I won't deny that I pretty quickly recognized the sex appeal of that term (coined earlier by Yong Zhu and Reginald Newell of MIT) and equally quickly realized that these things really are the guts of the atmospheric arm of the water cycle. Honestly the global (atmospheric) water cycle has always been a very attractive topic for me...I've often felt that meteorologists and climatologists weren't giving it the attention it deserves as a basis for land hydrology, and that hydrologists (who should know the right questions to ask) had effectively ceded all attention of it to the climate folks.

The upshot is that, since then, I've worked closely with those guys from NOAA (and elsewhere) to better document and understand atmospheric rivers as a phenomenon. My main roles

have been to provide the long-view perspective on these storms in order to augment the more case-study perspective that had dominated much of the work previously. My other role has been to hunt down and document the on-the-land practical implications and impacts, both good and bad, of these “rivers” in the sky for California and the West.

Connie: OK, let me generalize my question: Your career has been characterized by a succession of key climate studies on distinct, if related, climate problems. How in general do you make decisions about selecting research topics and directions along the way, given that there are so many interesting and seemingly important problems you could follow?

Mike: Dan Cayan has in the past referred to his pursuits (and mine) in terms of us being “old timey naturalists”, indicating that we both pursue topics stoked by very wide-ranging, none-too-stovepiped curiosities. So, yes, there is an almost limitless range of topics that I am tempted to pursue. The good news is that there is still a ton of good science lurking in existing meteorological data sets from the past 50-60 years, science just waiting to be extracted and explored. (So don’t ever imagine that all the good stuff is done, nor that ONLY with new data can new science get done.) Thus topics are pretty easy to come by, results are all around, and the operative question really is “what are the most useful problems to pursue and address?”

It’s a combination of a gnawing curiosity and, like all of us, an underlying desire to make a societal difference with my work that determines which questions I pursue. I like to think that I have a good instinct for what is a fruitful set of questions, and I strategically tend to pursue ones that I know will set me up with tools to answer other later questions in other areas too. The vapor-transport analysis mentioned above is an example of what I mean: I thought it would be useful to do that original PACLIM analysis but probably wouldn’t have if I hadn’t realized that, once I had that particular data set compiled for the PACLIM poster, a large number of other equally interesting but different questions would suddenly become address-able in new ways (like long-term orographic precipitation variations and like the history and future of pineapple expresses, and so on). So I choose strategically, looking forward a couple of studies, when possible.

I guess I’d also say it’s really useful to value/develop the skills, tools, and datasets that allow you to analyze quickly. That may seem obvious, but in this context I mean mostly that, for me, interesting ideas are cheap and easy. But most of mine are wrong. However, because I have valued work that yields tools and datasets that make the next study and the one after that easier and

faster, I am pretty quick. Thus I am able to pursue a lot of faulty ideas in order to root out my few good ones. If I were slower, I’d never get through all my bad ideas to the good ones, and I wouldn’t seem to have any good ones. You wouldn’t believe how many dead ends I visit in my travels.

Connie: What is it about mountain environments that has attracted your research interest and attention?

Mike: I just love them personally. I make all sorts of justifications for why they are important to study (like in “Mapping New Terrains” [CIRMOUNT’s early position document]), but really I just love the mountains. It’s an odd mix of their tremendous scale and quiet, combined with the fact that our western mountains are these huge landscapes made up of small human-sized alcoves. I like the grandeur, but even more I like the small settings that are scaled like something that I fantasize I could someday really understand.

Connie: What key research problems or questions in coming years do you hope to tackle, and that you hope to motivate others also to work on?

Mike: Okay, so to be honest, the other thing that drives my selection of research topics is a tendency to prefer to work on issues that are important before they are too popular. I studied groundwater issues a step before they became the most heavily pursued issues in western hydrology (a few decades ago). I jumped off of that and onto hydroclimate variability topics back when there weren’t many of us, when Dan Cayan was still chumming the waters with all his remarkable early discoveries, when students in that area were precious few and jealously guarded. I didn’t exactly jump onto the climate-change topic but rather was pulled onto it by a few key (historical) findings and a lot of interest from key agencies in California, back when it wasn’t the most popular topic around. More recently, I recognized that atmospheric rivers had the potential to prove critical to understanding a lot of problems that I’d been mystified by for much of my career...in particular, I realized that they might be just the piece that was needed to fill in the gap between weather events and climate variations of many shapes and sizes. That realization continues to yield fruit, with recent connections that I’ve found tying California’s droughts (a mystifying climate scale phenomenon) almost exclusively to the largest few atmospheric rivers, or lack thereof.

But indeed as with all the previous topics, I am struggling now because atmospheric rivers have become a hot topic, and the number of folks working on them has burgeoned in the past

couple of years...to the point where I am feeling a bit antsy. Honestly, I am sort of scanning the horizon wondering what might be the next good, less populated topic to pursue.

I have lots of commitments re: atmospheric rivers, so it's not like I'll stop doing that but, right now, I am thinking about two attractive directions, bearing in mind that—let's face it—I don't have time for too many more switches in my career: (i) I started down the road towards trying to do syntheses of the atmospheric arm of the water cycle, how it works and varies at essentially global scales, how understanding those workings might allow us to better understand, forecast, and track water processes on land. But I got diverted (in a very good way) onto this specific phenomenon, atmospheric rivers. I have been thinking lately about how to step back and re-engage with those original, even-larger scale processes that I thought I was going to pursue initially.

(ii) On the completely other end of the space scale, I have been increasingly attracted to issues up in the Lake Tahoe Basin. It

seems to me that Tahoe has the benefit of being the one place in the whole of the Sierra Nevada—and maybe of the whole West—where lots of people live in the mountains in one place and with at least some attempts to do right by it. I know it's an urban lake at this point, but it seems to me that if I really do want to contribute to how people live with mountains, Tahoe is sort of ground zero.

Of course, the problem is that, if you'd asked me a couple of years ago, I was already starting to feel a bit antsy, and I had two other new directions I was thinking about (very different and way off the track). The catch is that I simply don't have the skill sets to make real contributions in those areas and, yes, I have explored them long enough to find that out for sure. They were goooood ideas, but not for me. Regrouping, the two above feel like directions that I am actually suited for, so they are my best guesses as to "what's next" I think. I hope.



Mike in Yosemite National Park. Photo: Julia Dettinger

Voices in the Wind

In this section of Mountain Views Newsletter, we query members of the CIRMOUNT community for their perspective on a question of current discussion. At the recent MtnClim 2014 Conference in Midway, Utah, we heard emphasis on mountains as “fractured landscapes”, emphasizing their highly heterogeneous environments, that mountains are “not just high, flat places”, and that climates and ecosystems respond at diverse scales. In the spirit of this important issue, I posed the following question to a handful of colleagues.

— Editor

What aspects of topo- and/or micro-scale processes – climatic, hydrologic, ecologic, or social – do you think are especially important to study?

Chris Daly, PRISM Climate Group, Northwest Alliance for Computational Science and Engineering Oregon State University, Corvallis, OR



At the *MtnClim 2014* conference I used the term “fractured landscapes” to refer to the idea that under a changing regional climate, local responses across a mountainous landscape may not happen in lock-step, but instead break into pieces, based on topographic position, solar radiation exposure, proximity to riparian zones, snow cover,

soil moisture availability, and other factors that vary in scale from meters to kilometers. These factors cause complicated, but somewhat predictable, patterns in today’s mean climate, but there is more to the story. For us to understand how a landscape will respond to a changing climate, we need to remember that the mean condition is made up of responses to individual weather patterns. For example, an exposed hill slope at high elevation may have a mean annual temperature that is similar to that of an adjacent dark, moist, low-elevation valley, but has a radically different response to a change in the weather from, say, a cloudy, stormy condition to a sunny, calm condition. In the HJ Andrews Experimental Forest in the Oregon Cascades, our measurements show that such a weather pattern change typically causes the hill slope to warm considerably as the regional air mass warms and the sun comes out. But the shady valley changes very little, as light levels remain relatively constant, and the formation of a cold air pool decouples the site from the warming air mass. Differences in response are likely played out at scales as small as the north and south side of a rock, one in shade and one in sun, but we are lacking good measurements at that scale.

Sarah Null, Department of Watershed Sciences, Utah State University, Logan, UT

The differential hydrologic response of river reaches and watersheds to climate change is particularly interesting. We know in general that climate is warming, snowfall will shift to rainfall, and snowpack will be reduced in mountain regions. However, micro-scale processes vary considerably within and across mountain river systems. So big research questions include which rivers, watersheds, elevations, and aquatic habitats are most vulnerable to climate change and why?



Many mountain river systems have also been altered by dam building, water diversions, invasive species, and poor water quality - creating barriers within river systems. Hydrologic and ecologic connectivity is already greatly changed from natural conditions, but how will it be further altered with climate change? Are novel ecosystems - new combinations of organisms in highly altered habitats - more likely for some habitat types or in specific watersheds? Can we manage dam releases or remove some barriers to improve habitats and connectivity? These research questions are multi-disciplinary and ultimately require linking climatic, hydrologic, ecologic, and social processes to improve our understanding of complex and heterogeneous mountain river systems.

Imtiaz Rangwala, Western Water Assessment, University of Colorado-Boulder, and Physical Sciences Division, NOAA Earth System Research Lab, Boulder, CO

Mountain systems are often referred as the “water towers” on a continental landmass because they capture a large bulk of ocean moisture in a very concentrated region. However, these regions can experience large water stress, and associated ecosystem impacts, because of climate change primarily through changes and loss in water storage capacity and the intensification of the regional hydrologic cycle, i.e., shorter duration of mountain snowpack; greater proportion of moisture delivered in extreme precipitation events; and higher rates of evapotranspiration. Landscape-scale strategies to slow down the flow of water and spread it around may greatly help to mitigate the regional water stress. Topographical complexity of mountain terrain facilitates a multitude of coupled ecological-geological-hydrological environments along and across the elevation gradient that could collectively play the role of a “sponge”. To that effect, understanding and identifying critical ecosystems, and quantifying their hydrological controls within a mountain system or a specific basin would be a useful research. This would also further the cause for improving and maintaining the functionality of these critical ecosystems.



Karen Pope, USDA Forest Service, Pacific Southwest Research Station, Arcata, CA



Climatic heterogeneity across small spatial and temporal scales can greatly influence an organism’s ability to survive given the earth’s changing climate and other associated stressors. When the organism relies on aquatic habitats, then it becomes important to understand how climatic, hydrologic and ecologic processes interact at the scales appropriate to that organism.

As an amphibian ecologist, I have been amazed at how fine a resolution we must go to predict whether a population of

montane frogs will persist within a particular landscape. Many of our montane amphibians are in peril due to a fungal disease, chytridiomycosis, caused by the pathogen *Batrachochytrium dendrobatidis* (Bd), which happens to be highly sensitive to water temperature. Bd has a higher likelihood of killing frogs at low temperatures compared to high temperatures, likely because host resistance to infection is reduced at low temperatures and Bd does not survive sustained temperatures above 30°C. Within a population, frogs that bask in shallow mountain pools warmed by the sun have a higher chance of survival than frogs in deep, shaded pools or mountain springs. An easy conclusion would be that climate warming is therefore good for persistence of our mountain frogs. However, shallow pools under the hot sun tend to dry out quickly preventing tadpoles from successfully metamorphosing. Without recruitment, populations are in peril. It seems that heterogeneity in water temperature and hydroperiod at very small scales determines population persistence when these two conflicting stressors collide. Whether or not climate change positively or negatively affects population persistence in the long run will be determined at small scales.

Steve Kroiss, Department of Biology, University of Washington, Seattle, WA

Variation in topography (ridges and valleys) and vegetation structure (forest canopy gaps) can cause dramatic shifts in climate over remarkably short distances, suggesting that microhabitats may allow species’ ranges to track climate change over the course of a few meters rather than hundreds of meters or kilometers upward or poleward. Future research efforts should focus



on characterizing these cool or buffered microhabitats in an effort to determine their abundance at the local and regional scale. Furthermore, species population dynamics and plant community composition should be monitored within these microhabitats in an effort to predict long-term community composition shifts. Together, these avenues of research should allow us to understand the degree to which microhabitats may buffer the negative effects of global climate change.

Jared Oyler, Numerical Terradynamic Simulation Group,
University of Montana, Missoula, MT



Spatially, climate varies on the global and hemispheric scale, synoptic scale (≥ 1000 km), mesoscale (5 to 100s of km), topoclimatic scale (one to several km), and microscale (meters). Nonetheless, is there an optimal climate spatial scale for a specific region? Using traditional geostatistical methods, there have been attempts to quantify an optimal spatial scale for analyzing climate in specific regions,

but such analyses are confounded by the periodic spatial drift and non-stationarity of most climate variables. In the ecological literature, recent attention has focused on large variations in climate at extremely small spatial scales. It is thought that such variation can help to buffer climate change impacts to biodiversity. While this is likely true, for landscape ecological and hydrological studies, is it necessary to quantify climate variability at extremely fine scales (< 30 m) or will 1 km, 4 km or even coarser be suitable? We need to develop better quantitative approaches that take into account both local topographic and biophysical influences and synoptic atmospheric circulation patterns to determine an optimal climate spatial scale for a specific region and research question. Additionally, most small scale studies only examine the spatial variability in climate means and not how climate temporal variability varies spatially. For instance, will climate change in the same way across a specific region or will there be significant spatial variation in the changes? As shown in research on elevation-dependent warming, the answer to this question is highly uncertain. Recent attention has focused on the ability of areas with cold air drainage to lessen changes in climate and act as refugia, but our understanding of this is really only conceptual. We should continue work on quantifying the processes that could cause landscape-scale variation in climate trends and if such processes will continue to be important in the context of a warming climate.

Monica Buhler, National Park Service, Devils Postpile National Monument, CA



I think that it is important to realize the limitations of predictive models and recognize this when using them to guide land management. Because mountains are heterogeneous, the response to changing climate will not be uniform across the landscape and microclimates and local processes such as cold air pooling may be a key contributor to maintaining refugia. We, as managers, have a tendency to always act and want to fix things but we must first try to understand the physical and biological processes that create and maintain current conditions. I think that we must be cautious when identifying refugia; who is it for, is it isolated, what makes it a refugium; and proposing management actions that are limited by the extent of our understanding. Rather than thinking about manipulating or managing these area for a particular condition or species, I think that we should focus on doing anything that we can to ecologically protect, restore and maintain function and structure to improve resilient and resistance. As a restoration ecologist practitioner, I have always learned something new during and after an ecological restoration project and am awed by the size of plants after a fire, the new species that pops up after asphalt is removed, the flow of water after a large rainstorm – things that were unexpected. Although the rate of climate change is certainly unprecedented, I have some faith that the natural world and how species respond will surprise us, if we are patient and learn before acting.

Alina Cansler, School of Environmental and Forest Sciences,
University of Washington, Seattle, WA



I think we have made great advances in representing the highly variable physical environment in mountain ecosystems. Higher resolution geospatial data sets, such as temperature and climate data available from PRISM, 10 meter DEMs, LIDAR mapping of topography and vegetation, have greatly improved our ability to do this over the last

decade. I think we are also learning a lot about how “drivers” of process change in importance across different scales – think about how additional processes, such as diurnal canyon winds and temperature inversions in valleys have been integrated into high resolution gridded temperature and precipitation, improving accuracy in mountainous terrain. I think what we are still struggling to do is model cases where the pattern and processes at large scale cannot be adequately represented without considering the local-scale variation. One way to address this is to try to include everything in a large-scale model (impossible!) Another tactic—and one I’ve taken in my research on fire regimes—is to examine how the unique properties of mountain ecosystems, such as their complex topography and high habitat variability result in emergent properties at large scales. Testing the theory that mountains contain more climate refugia, or, in my case, whether areas with complex topography have greater variation in fire severity and thus are more resistant to developing large severe fires, are examples of ways to look at emergent properties at large scales. I think our biggest challenge, now, is determine if feedbacks between different processes—say between weather, hydrology, vegetation distributions, and disturbance—attenuate or amplify the patterns and relationships we have observed. The former, attenuation, may indicate resilience in ecosystems to changes in climate, while the latter, amplification, may be indicative of abrupt non-linear changes even with a linear change in climate.

Dave Porinchu and son Maty, Department of Geography,
University of Georgia, Athens, GA



Our recent work has documented the importance of hydroclimate and topography in shaping and influencing the atmospheric deposition of pollutants (spheroidal carbonaceous particles [SCPs], Hg) and midge communities in alpine and sub-alpine lakes in the western United States. One study investigating historical changes in the deposition of SCPs and Hg, which identified the existence of spatial and temporal correspondence in Hg flux amongst a series of high elevation lakes in the central Great Basin, highlighted the important role that topographic position and sheltering plays on controlling Hg flux ratios to some of the study sites. Documenting variations in the midge assemblages at these same lakes not only identified the existence of a coherent regional signal, with midge communities responding the elevated air temperatures in recent decades, but also the importance of site-specific hydrology in controlling midge community composition. Substantial faunal turnover occurred at all study sites during the 20th century, with the exception of Teresa Lake (Great Basin National Park). Teresa Lake is fed largely by groundwater, some of which emanates from the Wheeler Peak rock glacier, and has a constant temperature of ~1.5°C throughout the summer. The influx of cold groundwater may serve to decouple water temperature from fluctuations in air temperature and help to buffer the midge community at Teresa Lake from the effects of recent climate change. These studies, together with data obtained from an embedded micro-logger sensor network in Great Basin National Park, highlight the control of topo- and micro-scale processes on hydroclimate, which in turn has the potential to greatly influence the structure and function of mountain ecosystems.

David Inouye, New President of the Ecological Society of America



Photo: Martha and David Inouye

August at the 99th Annual Meeting of ESA in Sacramento, California.

David has undertaken pollinator and wildflower research encompassing pollination biology, flowering phenology, plant demography and plant-animal interactions in both the US and abroad since 1971. Over his 44-year tenure at the Rocky Mountain Biological Lab near Crested Butte, Colorado, David has discovered that the wildflower growing season has increased by 35 days since the 1970s. His long-term studies of flowering phenology and plant demography provide key insights into the effects of climate change at high altitudes.

David Inouye, plant ecologist and professor emeritus of the Department of Biology at the University of Maryland (UMD), College Park, and longtime participant in CIRMOUNT, was elected president of the Ecological Society of America (ESA) for the 2014-15 year. Inouye stepped into the post in

In addition, David is a lead author for the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) fast-track assessment of pollinators, pollination and food production, sits on the governing boards of the North American Pollinator Protection Campaign and the USA-National Phenology Network, is a member of the National Academy of Sciences Roundtable on Public Information in the Life Sciences, and serves on many scientific publication editorial boards.

David taught courses in ecology and conservation biology at UMD and also instructed at the University of Colorado's Mountain Research Station, the Rocky Mountain Biological Laboratory, and with the Organization for Tropical Studies.

David follows another key CIRMOUNT coordinator, Jill Baron, USGS, who was ESA President for the 2013-2014 year. Congratulations, David, and thank you, Jill!



Exposed tufa towers on the south shore of Mono Lake with Bodie Mountains in the distance.
Photo: Kelly Redmond

Mountain Research Initiative Convenes Meeting of New Science Leadership Council Kandersteg, Switzerland: October 19-21, 2014

— Connie Millar, USDA Forest Service

The Mountain Research Initiative (MRI: <http://mri.scnatweb.ch/en/>) is an international science program developed to promote and coordinate global change research in mountain regions of the world. Established in 2004, MRI is funded by the Swiss National Science Foundation, endorsed by the International Geosphere-Biosphere Programme, International Human Dimensions Programme on Global Environmental Change, Global Land Project, Global Terrestrial Monitoring System, and UNESCO Man and the Biosphere Programme, and hosted at the Institute of Geography at the University of Bern, Switzerland. In that many of MRI's goals and actions are similar to those to which CIRMOUNT aspires — if on more modest scales — the activities of MRI serve as models and examples for our community. As important to mentoring and communication, Greg Greenwood, Executive Director of MRI, is also a founding father and key coordinator of CIRMOUNT, meaning that our networks are indeed tied at the hip.

More specifically, MRI's vision is to be a global change scientific program that detects signals of global environmental change in mountain environments, defines the consequences of global environmental change for mountain regions as well as lowland systems dependent on mountain resources, and informs sustainable land, water, and resource management for mountain regions at local to regional scales. MRI pursues its goals through actions at global and regional levels. These actions — initiation, implementation, integration, and information (the 4 "I's"; Fig. 1) — describe the different stages of work needed to achieve the goals.



Kandersteg and view to Blümlisalp.

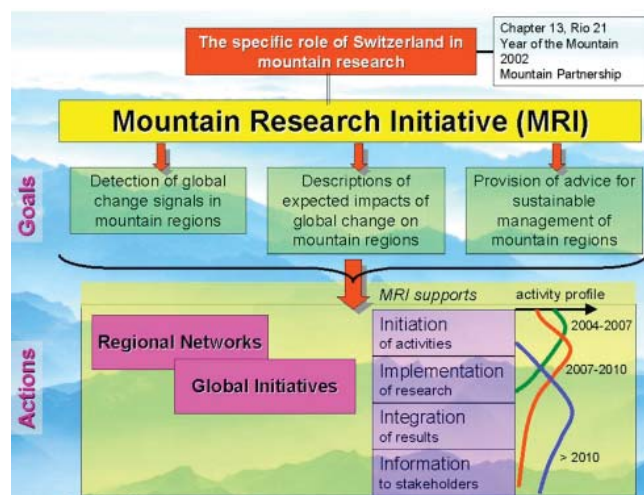


Figure 1. Overall framework of the Mountain Research Initiative. From the MRI website.

The first decade of MRI was devoted to identifying active researchers around the world, discerning common interests, and creating forums for common action; in short, creating a functioning community from disparate individuals. Since the early 2010s, MRI expanded its work to include more long-term community actions that are termed “Concerted Efforts” in the most recent proposal to the Swiss National Science Foundation for the period 2013-2016.

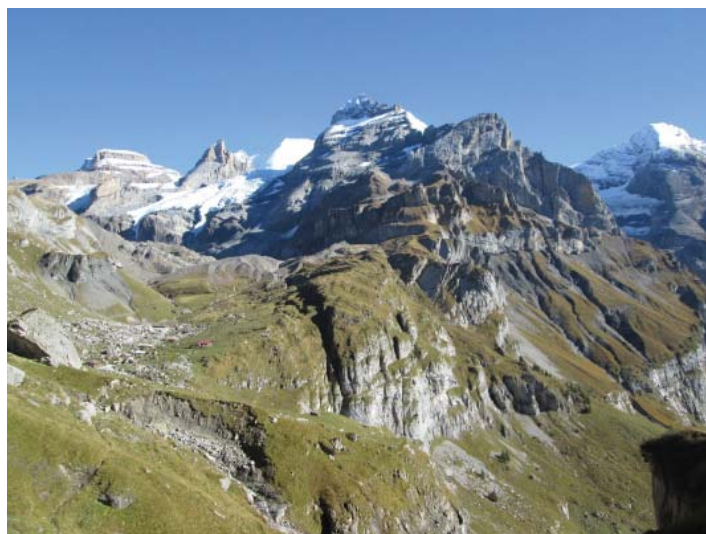
Now at the end of its 10th year, MRI, like CIRMOUNT, is looking forward to the next decade of program development. To help guide this effort, MRI formed a new Science Leadership Council, which comprises 18 members, drawn from mountain regions around the world, including several from CIRMOUNT. The Council's task is not only to provide advice to the MRI Coordinating Office, but also – and as importantly – to provide impetus for MRI's scientific activities. In that MRI is a global network of researchers, its progress is measured by the ability of its members to combine forces, resources and insights to advance understanding of global change in mountain social-ecological systems. Science Leadership Council members are tasked to provide guidance about how best to help members combine their efforts. Council members are also participants in global change research themselves, and thus by their own actions carry forward the MRI (as well as CIRMOUNT's) scientific agenda.

The first meeting of the Science Leadership Council took place October 19-21, 2014 in Kandersteg, Switzerland, in the Alps of the Berner Oberland. The objective of this meeting was to agree on an overall conceptual framework to guide MRI and initiate a strategic planning process based on the following steps:

1. Where Are We Now?
2. Where Do We Want To Be?
3. How Do We Get There?
4. What are the Next Steps?

Brainstorming at the meeting produced a list of issues from which MRI could select a few key for new concerted efforts. Similarly, the Council brainstormed specific actions addressed to these issues that MRI could entrain. These ranged from broad topics such as establishing a global network of mountain observing stations, improving understanding of coupled human-natural systems, and building community capacity for mountain research and sustainable development (i.e., getting mountains as entities into global research agendas) to specific action items about networking at conferences, developing a mentor program and grant opportunities for young researchers, and evaluating opportunities for partnership with Future Earth, AGU Thriving Earth Exchange (TEX), Protect our Winters (POW), and the NASA International Snow Remote Sensing Working Group (ISWGR).

The MRI Coordinating Office will continue to engage the Council to develop and flesh out topics for specific action during the coming year. The group next meets again formally during the PERTH III, *Mountains of Future Earth* Conference in Scotland, October. 2015.



Enroute to Hohtürli, above Kandersteg

Council members serve three-year terms and currently include:

Irasema Alcántara Ayala, Universidad Nacional Autónoma de México, Mexico

Jörg Balsiger, University of Geneva, Switzerland

Jill Baron, USGS, Colorado State University, USA

Raymond Bradley, University of Massachusetts, USA

Alexis Gunya, Russian Academy of Sciences, Russia

Lubos Halada, Slovak Academy of Sciences, Slovakia

Christian Huggel, University of Zurich, Switzerland

Julia Klein, Colorado State University, USA

Sandra Lavorel, Centre National de la Recherche Scientifique, France

Ruijun Long, Gansu Agricultural University, China

Rob Marchant, University of York, UK

Connie Millar, USDA Forest Service, USA

Andreas Muhar, Uni. Natural Resources & Life Sciences BOKU, Austria

Anne Nolin, Oregon State University, USA

Maria Shahgedanova, University of Reading, UK

Catherine Tucker, Indiana University, USA

Kenichi Ueno, University of Tsukuba, Japan

Veerle Vanacker, Universite Catholique de Louvain, Belgium

Information about the Science Leadership Council and its activities are on the MRI website at: <http://mri.scnatweb.ch/en/the-mri/team/scientific-leadership-council>



Landgasthof Ruedihus, Kandersteg

PERTH III: Mountains of our Future Earth Perth, Scotland; October 4-8, 2015

www.perthmountains2015.com

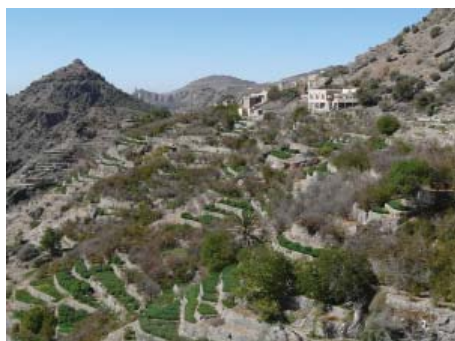
The Centre for Mountain Studies at Perth College, University of the Highlands & Islands, in collaboration with the Mountain Research Initiative and the Global Mountain Biodiversity Assessment is organizing a third conference – Perth III – on ‘Mountains of Our Future Earth’. The conference is a contribution to the global Future Earth program (www.futureearth.org/), a 10-year international research initiative that will develop the knowledge for responding effectively to the risks and opportunities of global environmental change and supporting transformation towards global sustainability in the coming decades. The three themes of Future Earth and of PERTH III are:

Dynamic Planet: Observing, explaining, understanding, projecting Earth, environmental and societal system trends, drivers and processes and their interactions; anticipating global thresholds and risks.

Global Sustainable Development: Knowledge for sustainable, secure and fair stewardship of biodiversity, food, water, health, energy, materials, and other ecosystem services.

Transformations towards Sustainability: Understanding transformation processes and options, assessing how these relate to human values, emerging technologies and social and economic development pathways, and evaluating strategies for governing and managing the global environment across sectors and scales.

This structure will permit the global change research community working in mountain areas to align itself more easily with the broader global change research framework established by Future Earth. Specific opportunities will be provided to strengthen ongoing research activities and to foster new collaborations, thematic and/or regional.



Terraces in Oman.
Photo: Martin Price



Oberaargletscher and Oberaarsee, Swiss Alps.
Photo: Martin Price

Aims

- 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 harmonize 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. An important starting point will be to evaluate case studies of both successful and unsuccessful collaborations.

Structure and Program

The conference will include field trips to the Scottish Highlands on October 4, keynote presentations, thematic and poster sessions, and roundtables.

A full list of session themes, to which abstracts may be submitted, is at: www.perth.uhi.ac.uk/specialistcentres/cms/Conferences/Perth2015/Pages/Sessions.aspx

Important Dates:

- | | |
|--------------|---|
| February 27: | Deadline for paper/poster submissions |
| August 14: | Deadline for submission of extended abstracts |
| August 31: | Deadline for registration |
| October 4: | Conference field trips (Scottish Highlands) |
| October 5-8: | PERTH III Conference |

Conference Website: www.perthmountains2015.com



MtnSEON, the Mountain Social Ecological Observatory Network; A Social Ecological Systems (SES) Research Coordination Network

— David Griffith, MtnSEON Leadership Team

The growing importance of understanding the relationships between humans and their mountain environments catalyzed development of the Mountain Social Ecological Observatory Network (MtnSEON). The focus of this research network is to advance social-ecological-systems (SES) approaches to assessing vulnerability and promoting sustainability in complex mountain landscapes. These approaches implemented through the MtnSEON integrate social, biophysical, and ecological sciences at every level, from long-term institutionalization projects to working groups focused on integrated solutions to specific issues. MtnSEON particularly emphasizes engaging Indigenous, government, and non-government actors to develop integrated solutions at multiple scales.

Mountain-valley environments are complex landscapes characterized by steep biophysical and land-use gradients. Across these gradients there is profound variation in socioeconomic transitions including rapid population growth and land-use change. Human-environment relationships in these landscapes are also affected by very large demographic changes, which in turn affect emerging amenity-oriented communities and communities with on-going legacies in extractive natural resources. Sustainability and resilience of these landscapes remains uncertain in the face of changing climate and social systems, and is a function of the ability of natural and human systems to

respond to change under shifting social, ecological, and economic forces. MtnSEON, an NSF-funded Research Coordination Networks (RCN) program, addresses the overarching issue: How can we reduce the vulnerability, improve resilience, and support sustainability of natural and human systems in complex mountain landscapes through research and education partnerships?

The main objectives of MtnSEON are threefold: to facilitate integration and synthesis of existing programs and studies regionally and internationally; to design collaborative research, education, and governance projects; and to create partnerships that will utilize new informatics to produce linked, scalable models and methods that will be better informed by management needs and help in decision-making affecting the resilience of mountain landscapes. MtnSEON activities include annual all-hands meetings, workshops on specific SES or mountain-related topics, and the establishment and funding of working groups. Working groups have been formed to stimulate research on specific issues ranging from SES dimensions of plant invasions, to socioecological patterns in the Blue Mountains, to the structure and processes of public decision making and the role of science in decision making in mountain environments, to the social and demographic patterns and tolerance of large carnivores in the Northern Rockies.



From The MtnSEON website, <http://webpages.uidaho.edu/mtnseon/>.

The current MtnSEON Working Groups include (but are not limited to): Social Ecological Systems Training and Education Program (SESTEP); Sociological Patterns and Processes in the Blue Mountains Ecoregion of the Pacific Northwest; Student Led Initiative on Mountain and Water Ecosystems; Bark Beetle Disturbances and Social Perspectives on High Severity Outbreaks; The Processes, Patterns, and Mechanisms of *Venttenata dubia* Invasion in Complex Western Landscapes; the Riverscapes Initiative; the Governance Working Group; the Large Lakes Initiative; and Science-based Solutions for Large Carnivore Conflicts in Mountain-Valley Ecosystems of the Western US.

The *MtnClim 2014* Conference included the Machida Session, which was co-sponsored by the Governance Working Group (Greg Greenwood, Mike Evans, Sandra Pinel), which invites western and international scholars and practitioners interested in how can we systematically understand the structure and processes of public decision making at multiple scales.

The current Leadership Team includes:

Jim Gosz, Primary Investigator
University of Idaho

Lilian Na'ia Alessa
Director of Alaska EPSCoR
University of Idaho

Ray Callaway
University of Montana

Bob Crabtree
Yellowstone Ecological Research
Center

Ed Galindo
University of Idaho

Colin Grier
Washington State University

David L. Griffith, Graduate
Student Representative to
Leadership Team
University of Idaho

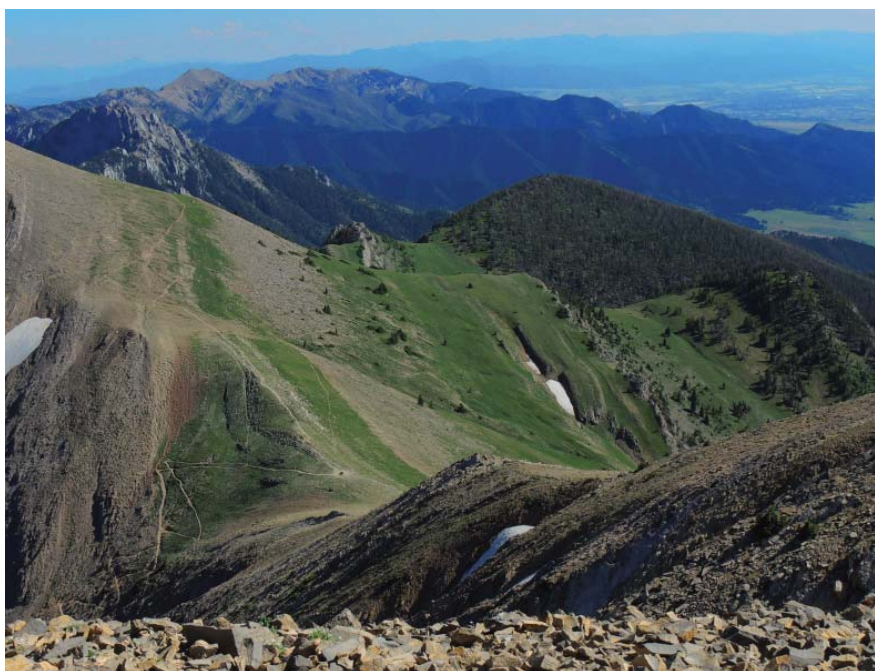
Art McKee, Project Coordinator
University of Montana

Todd Norton
Washington State University

Sandra Pinel, Prometeo and
Fulbright NEXUS Fellow
Universidad Tecnica Particular de
Loja, Ecuador

Jack Stanford
University of Montana

The MtnSEON website is <http://webpages.uidaho.edu/mtnseon/>. Information on working groups is available at: <http://webpages.uidaho.edu/mtnseon/workinggroups.html>. General inquiries on MtnSEON should be directed to mtnseon@uidaho.edu or to Art McKee at art.mckee@flbs.umt.edu.



Bridger Mountain Range, north of Belgrade, Montana. Photo: Kelly Redmond

Alpine and Arctic Treeline Ecotone Networking Activities

— Connie Millar, USDA Forest Service

As prior issues of *Mountain Views Newsletter* have described, a group of CIRMOUNT scientists interested in research issues of alpine and arctic treeline ecotones (AATE) continues to rally effort toward a coordinated and integrative research network. Spearheaded by Dave Cairns (Texas A & M), Lara Kueppers (Berkeley National Lab and University of California Merced), and myself, this effort has taken several tangible actions this year:

- In July, Dave Cairns, Lara Kueppers, and I submitted a proposal to the National Science Foundation's Research Coordination Network program on the topic of "Advancing integrated understanding of treeline response to environmental change: the alpine and arctic treeline ecotone network".
- Lara Kueppers, Dave Cairns, and Melanie Harsch (University of Washington) convened an Organized Oral Session at the annual meeting in August of the Ecological Society of America on "Advancing knowledge of alpine and arctic treeline ecotones and responses to environmental change".
- Pavel Cudlin (Global Change Research Center, Czech Republic) and I convened a session on "Vegetation shifts in

response to climate change" at the October World Congress of IUFRO (the International Union of Forest Research Organizations).

Upcoming activities include:

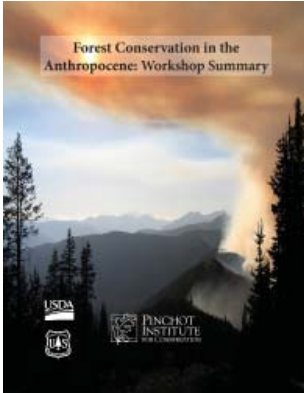
- Oral and poster sessions at the Fall meeting of the American Geophysical Union on "Responses of alpine and arctic treeline ecotones to environmental change", December 16, 2014, convened by Dave Cairns, Jeremy Littell (USGS), Matt Germino (USGS), and myself.
- Dave Cairns and I are organizing a theme session for the PERTH III — *Mountains of Future Earth* Conference in October 2015 on "Mountain treeline ecotones; threshold dynamics and climatic relationships".

If you are interested in any of these or other AATE topics, please join us for the upcoming sessions, participate in network strategizing, and send me a note (cmillar@fs.fed.us) so we can add you to our treeline ecotone email list.



Alpine treeline ecotone in the Toquima Range, Great Basin, NV. Photo: Connie Millar

New Book: *Forest Conservation and Management in the Anthropocene*



From the Pinchot Institute:

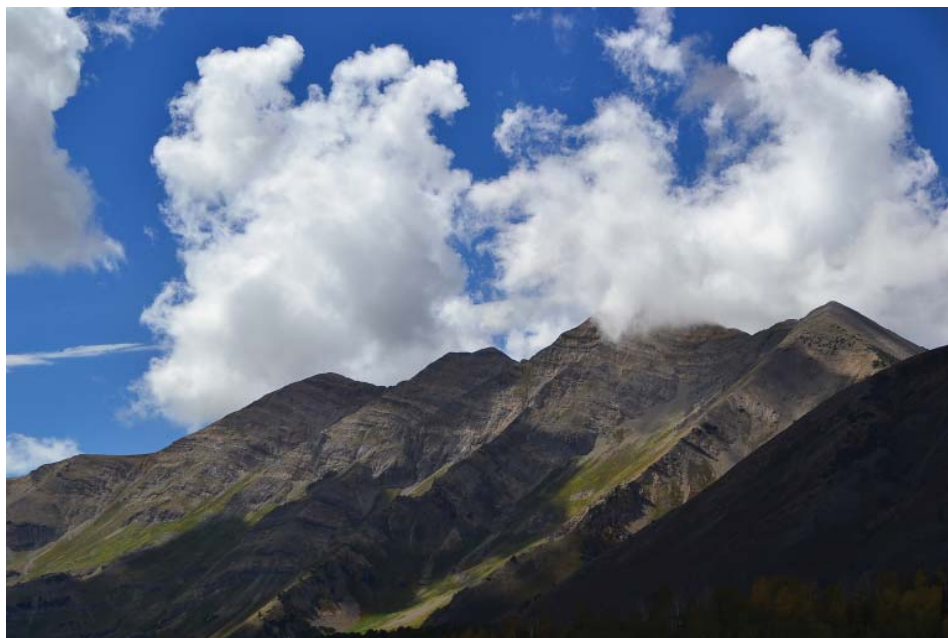
Strategies for wildlife conservation, water resource management, and biodiversity protection are undergoing major change as scientists and resource managers grapple with the uncertainties of climate change and its effects on forests. Wildfires and invasive species will redraw the face of America's forests,

which in some cases will not return to their original condition any time in the foreseeable future. Management policy is shifting from forest protection to managing risk, and to bolstering the resilience of forests as they confront changes that are unprecedented in human history.

These are among the findings in a new report from the Pinchot Institute highlighting the challenges of sustainable natural resource management in the Anthropocene epoch. *Forest Conservation and Management in the Anthropocene: Adaptation of Science, Policy, and Practices* includes contributions by leading scientists, resource managers, and policy specialists exploring the implications of climate change and other manifestations of the Anthropocene on the management of wildlife habitat, biodiversity, water, and other resources, with particular attention to the effects of wildfire. "We are facing a 'no-analog' future in which much of the existing science relating to the functioning and response of forest ecosystems must be reconsidered," said Al Sample, President of the Pinchot Institute.

Forest Conservation and Management in the Anthropocene is available online at Pinchot.org/Anthropocene,

or through the Rocky Mountain Research Station website at http://www.fs.fed.us/rm/pubs/rmrs_p071.html.



Mount Nebo, 11928 ft, southernmost and highest peak in the Wasatch Range, viewed from the east on Mt Nebo Scenic Byway. Photo: Kelly Redmond

Article: Coordinated, Distributed Experiments

Given the widespread interest to develop monitoring and other observation networks, this paper should be of broad interest.

*Lauchlan H Fraser, Hugh AL Henry, Cameron N Carlyle, Shannon R White, Carl Beierkuhnlein, James F Cahill Jr, Brenda B Casper, Elsa Cleland, Scott L Collins, Jeffrey S Dukes, Alan K Knapp, Eric Lind, Ruijun Long, Yiqi Luo, Peter B Reich, Melinda D Smith, Marcelo Sternberg, and Roy Turkington. 2013. Coordinated distributed experiments: An emerging tool for testing global hypotheses in ecology and environmental science. *Frontiers in Ecology and the Environment* 11:147–155, doi:10.1890/110279*

Abstract: There is a growing realization among scientists and policy makers that an increased understanding of today's environmental issues requires international collaboration and data synthesis. Meta-analyses have served this role in ecology for more than a decade, but the different experimental methodologies researchers use can limit the strength of the meta-analytic approach. Considering the global nature of many environmental issues, a new collaborative approach, which we call coordinated distributed experiments (CDEs), is needed that will control for both spatial and temporal scale, and that encompasses large geographic ranges. Ecological CDEs, involving standardized, controlled protocols, have the potential to advance our understanding of general principles in ecology and environmental science.



Scotty Strachan (Univ. Nevada, Reno) installing the climate-monitoring station in the Pine Grove Hills, NV. Photo: Time-lapsed selfie

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.

– Editor

Willow Rust: A New Outbreak in the Great Basin—or Just a Pathogen New to Me?

Connie Millar

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

I aspire to be an astute observer of nature—an old timey naturalist, as Mike Dettinger would say—and I know the trap of not seeing what you don't expect. For the first time two summers ago, I started looking intentionally for willow rust in the mountains of the Great Basin. I had never (consciously) met willow rust before, and was introduced to it in 2013 by Monica Buhler, ranger ecologist at the Devils Postpile National Monument in the Sierra Nevada of California. She showed me leaves on willows fringing the Monument meadows that looked to be dehiscing before autumn phenology would predict. The leaves were turning yellow and yellow-brown throughout portions of some willow crowns, while other willows nearby of the same species had the typical vibrant green leaves of high summer. Conspicuously dotting the backs of the yellow-brown leaves were abundant tell-tale spots of velvety orange rust (pustules) (Fig. 1).

That started me on a mission to look for yellow-browning leaves and pre-mature leaf dehiscence on willows throughout my field travels in the Great Basin, and, when I saw these, to check for rust on the leaves. As it turned out, I found many locations in 2013 with this situation, increasing from yellow leaves in mid-summer (Fig. 2, left) to brown and dehiscing leaves as the season wore toward autumn, occurring on several willow species (Fig. 2, right). Locations ranged from the canyons of the eastern Sierra Nevada, Sweetwater Mountains, and White Mountains of California, through the Wassuk Range, Toquima Mountains, and Pine Forest Range of central and northern NV, to the Snake Range, Ruby Mountains, and East Humboldt Mountains of eastern Nevada. Although I can't vouch for the identifications, nor did I voucher the plants, I believe the willows affected included the following taxa of *Salix*: *S. eastwoodiae*, *S. geyeriana*, *S. lemmonii*, *S. orestera*, and *S. petrophila* in California, and in Nevada, *S. exigua* and *S. geyeriana*.



Figure 1. Willow rust in the Sierra Nevada, 2013. Left: Rock Creek. Right: Lundy Canyon.



Figure 2. Willow rust in early and late summer 2013. Left: Virginia Canyon. Right: Warren Fork Canyon. Sierra Nevada.

Contexts for the affected shrubs varied, but included most wet or moist habitats in which willow occurs in the parts of the Great Basin I visited, including valley and mountain riparian communities, meadows, and lithic environments. In general the rust occurred from low to high (even into the high subalpine and treeline ecotone) elevations. I found willow rust less commonly on drier mountain slopes, where willow itself is less abundant.

During the early field season of 2014 I returned to many of these sites and was able to check the status of the spring bud flush. For many of the locations, although I hadn't marked the shrubs, or specifically labeled the branches bearing rust in 2013, the crowns that had been affected in 2013 generally appeared dead—their branch stems were jet black or silvery, and no live buds were on the stems (Fig. 3). Adjacent healthy plants were leafing out normally. Over the course of the 2014 warm season, I found more situations with rust on willows, many showing entire crowns of blackened stems (Fig. 4), which I interpreted to indicate rust the prior year, and many increasingly visible signs on still-live shrubs as yellow-brown leaves appearing by mid-summer. When I was able to check, rust pustules dotted the backs of leaves, and early leaf dehiscence was common. Although I did not return to all of the locations in 2014 where I'd observed rust in 2013, for those I did re-visit, all showed this pattern. I didn't see obvious environmental patterns within locations where the rust occurred, such as drier sites, specific aspect, or age relationships. Within shrubs, however, there seemed to be a tendency for outermost, exposed branches to have rust more than inner, lower ones.

One location in northeast Nevada that I observed for the first time in 2014 was along the Bruneau River south of the Jarbidge Mountains where a broad flat valley forms a wide riparian corridor of willow. For several miles along this zone, the willows



Figure 3. Willow communities in early summer 2014. Top: Blackened stem of affected shrub. Bottom: Affected riparian stand after leaf-out. Rock Creek, Sierra Nevada.



Figure 4. Mid summer 2014 appearance of willows affected by rust in prior years. Note sprouting green leaves at base of plants. Left: Lakeside willow stand in the upper subalpine forest. Right: Riparian stand in the mid subalpine forest. H.M. Hall Research Natural Area, Sierra Nevada.

near the river were almost entirely dead, again with blackened stems, although willows farther back from the center were often alive (Fig. 5). I did observe willow rust on leaves of live shrubs I examined, but I cannot be certain rust was the cause of the extensive mortality along the central corridor.

Melampsora Taxonomy and Life Cycle

Willow rusts are caused by species of *Melampsora* (Basidiomycetes, order Uredinales), which affect a large number of arctic and temperate willows, cottonwoods, and aspen (*Salicaceae*) throughout North America, northern Europe, and northeast Asia (Sinclair et al. 1987). The life cycle of these rusts is complex: they are macrocyclic, that is, they produce all five spore types/stages found in rusts, and heteroecious, meaning they require two unrelated hosts to complete their life cycle.

Melampsora epitea has long been considered the sole species complex affecting willows in North America (Smith et al. 2004). Recent studies have suggested, however, that phylogenetic divergence has been greater than previously assumed within the *Melampsora epitea* complex. Molecular and morphological studies of the rusts showed that arctic and temperate taxa in North America have evolved distinct traits that correspond to divergent willow lineages (Smith et al. 2004). In another molecular study of *Melampsora* on 19 species of *Salix* in the western United States, 14 phylogenetic species, or phylotypes, were apparent from nuclear rDNA sequencing of 140 collections or isolates (Bennett et al. 2011). Nuclear rDNA sequencing analyses further indicate that speciation has occurred in rusts that

affect North American versus Eurasian willows in that willow species from Eurasia showed resistance in field and inoculation experiments to North American *Melampsora*.

Primary, or aecial, hosts of the *Melampsora epitea* complex include conifer species -- hemlock (*Tsuga*), fir (*Abies*), and larch (*Larix*) -- and angiosperm currant shrubs (*Ribes*) and, likely, saxifrages (*Saxifraga*) (Pei et al. 1993, Sinclair et al. 1987, Smith et al. 2004). Teliospores overwinter on dead willow leaves on the ground. In the spring, teliospores germinate, producing wind-disseminated basidiospores that infect current year's conifer needles and cones or *Ribes/Saxafraga* leaves (Riffle et al. 1986). Spermatogonia (pycnia) and aecia (yellow pustules) develop within several weeks on the underside of needles. Orange-yellow aeciospores are dispersed in the wind to infect willow hosts. Conifer needles become necrotic, shrivel, and are shed shortly after sporulation, but otherwise damage on the telial host is usually minor. Infected willow leaves produce urediniospores that infect other leaves of the same species throughout the summer, intensifying the disease. In the fall, brown, crust-like telia form in place of uredinia. Mild temperatures (18-20 °C) and moist conditions (continuous moisture on leaf surface for 2-24 hours) are required for infection (Ziller 1974, Sinclair et al. 1987).

In general, impacts are more severe on willows than on the alternate hosts. Willow rust causes discoloration, shriveling, and premature dropping of willow leaves. Severe defoliation may reduce growth and increase susceptibility to other diseases or insects (Sinclair et al. 1987).

Ecological Significance in the Great Basin?

From my observations, I might be tempted to think that willow rust has been on the increase in the Great Basin over the past few years, and maybe even speculate a relation to recent and severe drought (although drought could also arguably reduce spread of spores). As such, a mortality wave might be expected to increase. An equally likely explanation for seeing rust on willow in the last two years is that I didn't look for it, or even look much at willows, before. In hopes of clarifying these options, I asked several of my pathology friends, none of whom, however, had observations or knowledge that shed light. Given the importance of riparian habitat in the arid Great Basin, the keystone role of willows to this habitat, and the pervasive use by domestic and native livestock in willow communities, monitoring the condition of willow rust seems prudent.

Pathologist Susan Frankel (USFS) led me to the fact that willow rust is rated a "C" pest in California, which means it is "A pest of known economic or environmental detriment and, if present in California, it is usually widespread. C-rated organisms are eligible to enter the state as long as the commodities with which they are associated conform to pest cleanliness standards when found in nursery stock shipments. If found in the state, they are subject to regulations designed to retard spread or to suppress at the discretion of the individual county agricultural commissioner. There is no state enforced action other than providing for pest cleanliness" (CDFA 2014).

I welcome comments or insights from anyone who knows about willow rusts and effects in these ecosystems.

References

- Bennett, C., Aime, M.C., and Newcombe, G. 2011. Molecular and pathogenic variation within *Melampsora* on *Salix* in western North America reveals numerous cryptic species. *Mycologia*, 103:1004–1018.
- CDFA (California Department of Food and Agriculture). 2014. Encycloweediea web pages, accessed November 7, 2014. http://www.cdffa.ca.gov/plant/ipc/encycloweediea/wininfo_weedratings.htm
- Pei M.H., Royle D.J., Hunter T. 1993. Identity and host alternation of some willow rusts (*Melampsora* spp.) in England. *Mycol Res* 97:845–851.
- Riffle, J.W., Peterson, G.W. (Eds). 1986. Diseases of trees in the Great Plains. Gen. Tech. Rep. RM-129. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 149 p.
- Sinclair, W.A., Lyon, H.H., Johnson, W.T. 1987. Diseases of trees and shrubs. Ithaca, NY: Cornell University Press. 576 p.
- Smith, J.A., Blanchette, R.A., Newcomb, G. 2004. Molecular and morphological characterization of the willow rust fungus, *Melampsora epitea*, from arctic and temperate hosts in North America. *Mycologia* 6:1330-1334.
- Ziller, W.G. 1974. The tree rusts of western Canada. Publication No. 1329. Victoria, BC: Canadian Forestry Service, Environment Canada. 272 p.



Figure 5. Extensive willow mortality in the riparian corridor, Bruneau River, northern Nevada. Left: Live willow in foreground; dead willow behind. Right: All willows dead (*Artemisia tridentata* shrubs in foreground). August 2014.

Contributing Artists

I am thrilled to include art and poetry in this issue by our two featured CIRMOUNT scientists, Kelly Redmond (page 48) and Mike Dettinger (page 51). Kelly has many years of photography experience; fortunately for us he keeps his camera at hand as he travels widely across the landscapes of the West. Photos in this issue include images from his homeland, the Bridger Mountains in Montana, as well as views from his trip to the *MtnClim 2014* conference. Mike Dettinger shared one of his poems with me, *World Sounds*, and I am honored to include it in *Mountain Visions*.

Two reproductions of new watercolor paintings are by Valerie Cohen, whose artwork we have featured in prior issues. Valerie is a nationally renowned landscape artist who lives and works

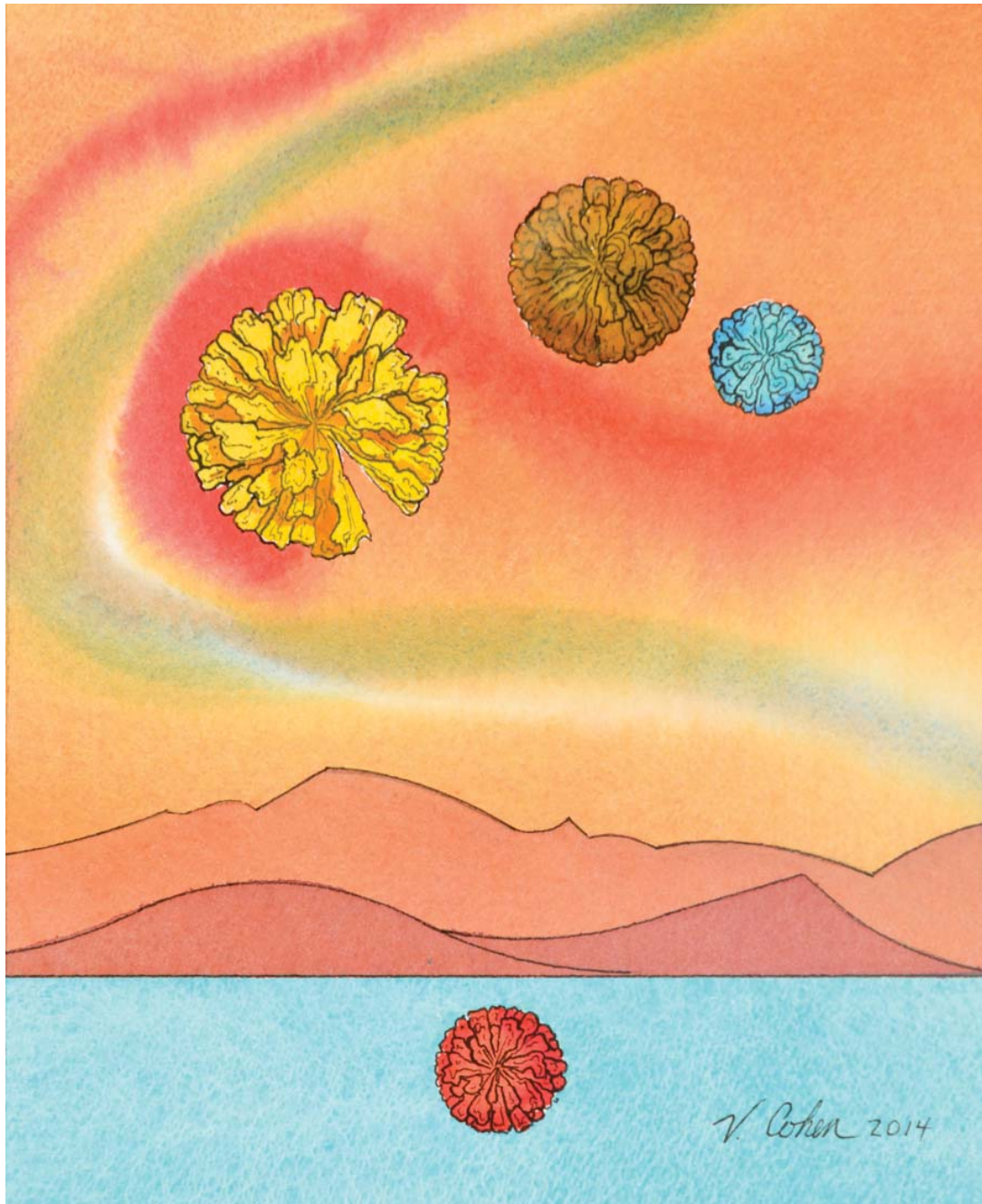
in the Sierra Nevada. She often joins us during the GLORIA expeditions in the high White Mountains, where we are fortunate to gain new insights into the plants, animals, and mountain terrain that we study through Valerie's remarkable artistry. See more of Valerie's work at: <http://valeriepcohen.com/>

Martha Apple (Montana Tech, Butte, MT) photographed the image of Piegan Pass featured on the Back Cover. When I expressed surprise that this was a photo, Martha explained: "We hiked up for the snowfield study, towering clouds built up, and I took that picture by pointing the camera almost into the sun, set it on aperture priority and used illustration mode, which drew the lines."



Valerie P. Cohen
"Giant Blazing Star"
Watercolor and Ink - 10" x 8"

Mountain Visions



Valerie P. Cohen
"Buckwheat Moons Over Mono"
Watercolor and Ink - 10" x 8"

World Sounds

There is a sound that is being made far and wide
 around the world each moment,
The sound of wind blowing in the tree tops
A sound ocean that no one of us can hear but that
 stitches the lands together,
 That forms vast, swirling harmonies washing
 over the world, back and forth, in heat driven tides
It stirs and wakes the green earth
and joins its forests into a music of the sphere
Like vast prayer flags over the land.

There is a sound that rings the globe like the geologic
 rings of fire,
Rising from the pale narrow band of crashing surf at the
 ocean's edge
 In the lacy fringe circling the earth circling the
 oceans circling every bay and strait.

The roar from the ocean's edge is far reaching, a global roar,
 So that Pacific storms a hundred years gone are measured still
 In dusty seismograms in the stacks of Harvard.

Like voices across the room,
These sounds connect the planet
 With a universal rustling of leaves
 And crashing of waves,
 Like prayers that bind all process and result together,
 Stirring the live and dead places,
 Stirring with invisible fingers.

But, from a pace or two beyond the world, the sounds rage
 and pound against the black silence of vacuum space.
Looking back from the Moon, the Earth a bright blue and white
 lantern of radiance and life
But not a sound reaches the seas of tranquility, not a rumble passes
 Earth's gates to cross the open space

No, the World Sounds are strictly for us here at home,
 strictly songs in the planet's skin and blood streams
 The winds, the surf, the encompassing sounds
 are only for our corner of the universe,
 our living realm.

Stirrings that give life, stirrings that signify life,
 but only within the planet's living skin,
 Stirring it with invisible fingers.

—Michael Dettinger



Clouds on Piegan Pass, Glacier National Park, Montana. Photo: Martha Apple