

MOUNTAIN VIEWS

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



Informing the Mountain Research Community

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Sparks Lake and Mt. Bachelor, Oregon. Photo: J. Blanchard

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Front Cover: Six-year old ram of Sierra Nevada Bighorn Sheep with the backdrop of Mt. Williamson, one of the locations of the original and enduring herd units in the southern Sierra Nevada, California. Painting by Jane Kim, courtesy of INK-DWELL.

Back Cover: Group of Sierra Nevada Bighorn Sheep ewes in Pine Creek Canyon, Sierra Nevada. Photo: Courtesy of Pete Yeager and California Department of Fish & Wildlife.

Read about the contributing artists on page 72.

Mountain Views

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

CIRMOUNT

Volume 7, No 1, June 2013

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

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The Mountain Views Newsletter (MVN)

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 science studies, *Brevia* of recently published articles, mountain climate news and announcements, a remarkable contribution on cold-air-drainage by two elementary school students who live in rural Sierra Nevada, and our seasonal round-up of mountain artwork.

On behalf of the CIRMOUNT coordinators, I extend an invitation to attend *MtnClim 2014*, the seventh biennial mountain-climate conference sponsored by CIRMOUNT. The meeting will convene September 15-18, 2014 at the Homestead Resort in Midway, UT, in the Wasatch Range near Salt Lake City. We anticipate the typical *MtnClim* schedule, starting on the evening of the first day and adjourning at noon on the last day. As in the past, we intend to organize a specific event for resource managers, and likely a field trip. Dr. Andrea Brunelle, Department of Geography, Utah State University, is assisting with the program and local details. The *MtnClim* meetings are an opportunity to convene additional satellite work-group meetings. If you'd like to do so, feel free to contact me and I can help with logistics. We will be developing the conference website (follow www.fs.fed.us/psw/cirmount/meetings/mtnclim) over summer 2013, and, as program and registration details become available, I'll send further announcements.

The newsletter front and back covers feature artwork highlighting the conservation status and restoration efforts of the Sierra Nevada Bighorn Sheep, a species under recovery implementation by the US Fish and Wildlife Service and California Department of Fish and Wildlife. This long-running and highly successful program models the value and application of a dedicated research program and science basis for conservation actions, as you can read in an interview with Dr. John Wehausen, lead scientist (pg. 48). Progress toward restoration goals are on-track for delisting as outlined in the recovery plan.

For the *Voices in the Wind* section, I posed a question about the treeline ecotone as a climate-research model system. CIRMOUNT colleagues contributed valuable insight through their replies (pg. 53). We hope to incorporate these ideas in the framework of the evolving North American Treeline Network.

CIRMOUNT also sponsors mountain-climate sessions at the annual Fall Meeting of the American Geophysical Union (AGU) in San Francisco. AGU convenes this year December 9-13. Please consider submitting an abstract (deadline Aug 6) to our session, "Climate change and wildfire: drivers, interactions, consequences".

On behalf of the CIRMOUNT coordinators, I send best wishes for the coming summer: enjoy the mountains and learn their secrets!

-- Connie Millar, Editor



Photo: J. Blanchard

A 21st Century Vision for Observations of Western U.S. Extreme Storms

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In 2011, the Western States Water Council (WSWC) asked some of us who had worked on design and implementations of a new Extreme Storms Observations Network (White et al. in press) for the California Department of Water Resources Enhanced Flood Response and Emergency Preparedness program to develop the underlying principles still further in order to provide a monitoring vision for the entire Western States region. The result has been a vision of 21st Century observations for tracking, predicting, and ultimately managing the occurrence and impacts of major storms in the western United States. It builds on lessons learned from field experiments, such as NOAA's Hydrometeorology Testbed

(HMT; hmt.noaa.gov) and studies of emergency preparedness and response, and of the impacts of extreme precipitation and flooding. The vision is described in a 74-page vision statement by a group of 27 contributors from 21 organizations, and recommends innovations and enhancements to existing monitoring networks for rain, snow, snowmelt, flood and their hydrometeorological precursor conditions over land and ocean (Ralph et al. 2011). The basic concepts underlying the proposed network are described in Figure 1; and a broad conceptual design, suggesting numbers of new instrument sites more than specific locations, is shown in Figure 2.

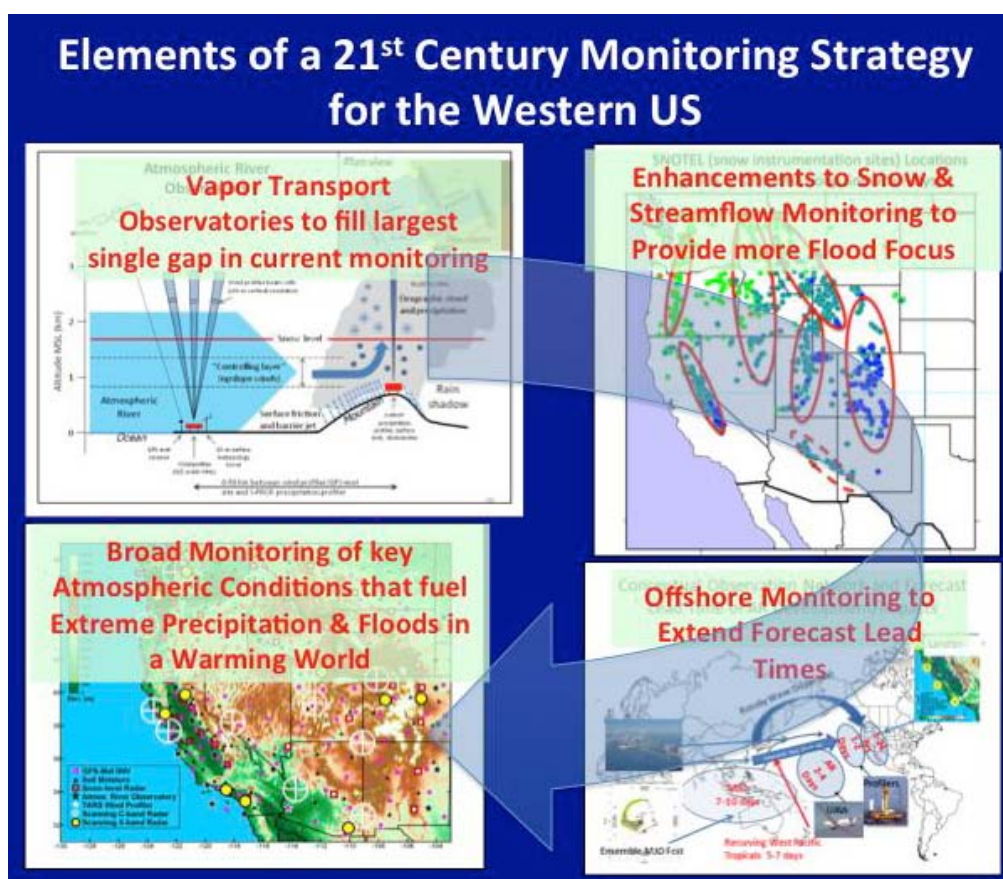


Figure 1. Conceptual elements underlying the vision for monitoring of major storm mechanisms and events.

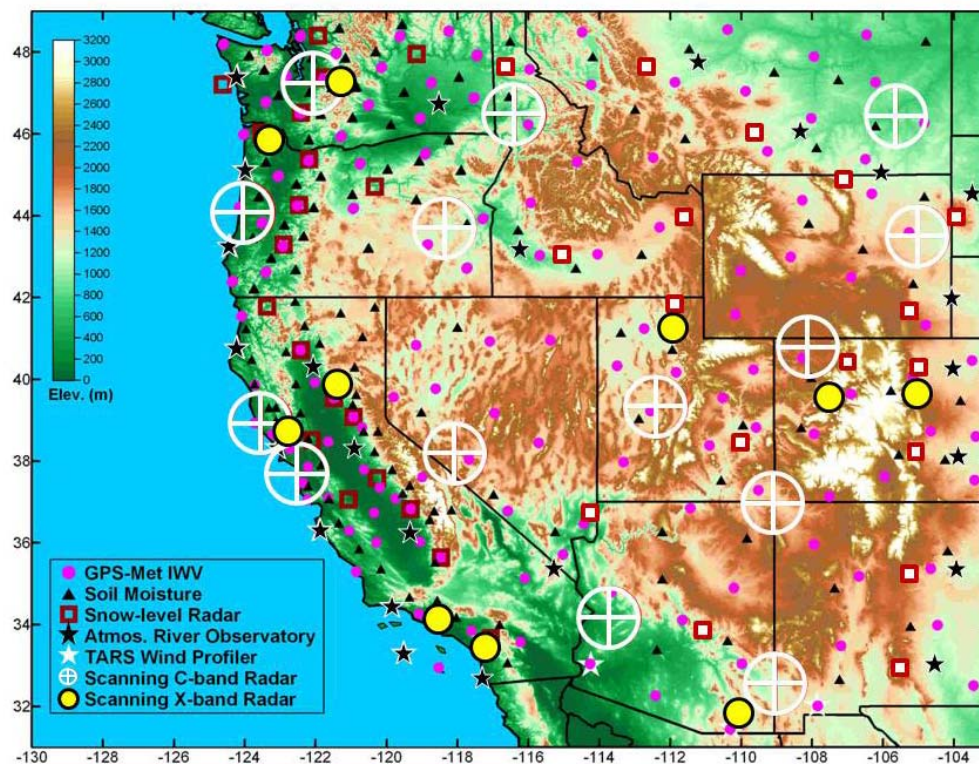


Figure 2. Schematic network of new sensors (land-based) to improve monitoring, prediction and climate trend detection for hydrometeorological conditions that create extreme precipitation and flooding.

Implementing the vision westwide will require research and development of instrumentation and methods for improving real-time tracking of hydrometeorological conditions, forecast lead times, and quantitative precipitation estimates focused on major storms in the West. The new network in California, however, is already demonstrating that these new technologies are feasible and valuable in actual operations. New instrumentation elements for the Westwide networks include new radars to monitor winds aloft and precipitation, streamgages, Snotel enhancements, and more, as well as entirely new and only recently-possible observational tools. Fundamental gaps are filled in monitoring water vapor transport in the boundary layer (a key factor in atmospheric rivers and monsoons, for example), in snowpack density and albedo, and in precursor storm conditions offshore. Atmospheric rivers hitting the west coast and penetrating inland, summer monsoon precipitation in the Southwest, spring upslope storms on the Rocky Mountain Front Range and summer thunderstorms over the Western Great Plains are addressed. The WSWC has endorsed the plan more than once since the vision document was completed, e.g., by WSWC Position Statement #332, <http://www.westgov.org/wswc/-332%20wswc%20position%20on%20extreme%20meteorological%20events%202011july29.pdf> and in a recent MOU with NOAA.

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NorWeST: A Regional Stream Temperature Database and Model for Climate Vulnerability Assessments and Improving Monitoring Efficiency

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Temperature in aquatic ecosystems is a fundamentally important property that dozens of resource agencies routinely monitor. Significant amounts of stream temperature data have been collected across the Northwest during the last two decades, but strategic coordination of these collection efforts within and among agencies has been lacking and many redundancies exist. Moreover, legislative mandates to maintain temperatures below certain thresholds, concern over climate change, and decreasing costs of data acquisition are only accelerating the amount of stream temperature data now being collected. A collaborative project by the USFS, NOAA, CSIRO, Trouts Unlimited, and USGS funded by the Great Northern Landscape Conservation Cooperative is addressing the issues associated with temperature monitoring and the effects of climate change on several fronts. First, the project is developing a comprehensive, interagency stream temperature database across a five state area in the Northwest (Fig.1). Within this area, hundreds of aquatic professionals from more than 60 federal, state, tribal, and private resource organizations have contributed data to the new NorWeST (NorthWest Stream Temperature) database, which contains > 45,000,000 million

hourly temperature recordings at > 15,000 unique stream sites (Fig. 2). The NorWeST database may be the largest in the world and would require an investment of approximately \$10,000,000 to replicate.



Figure 1. Map showing NorWeST project area.

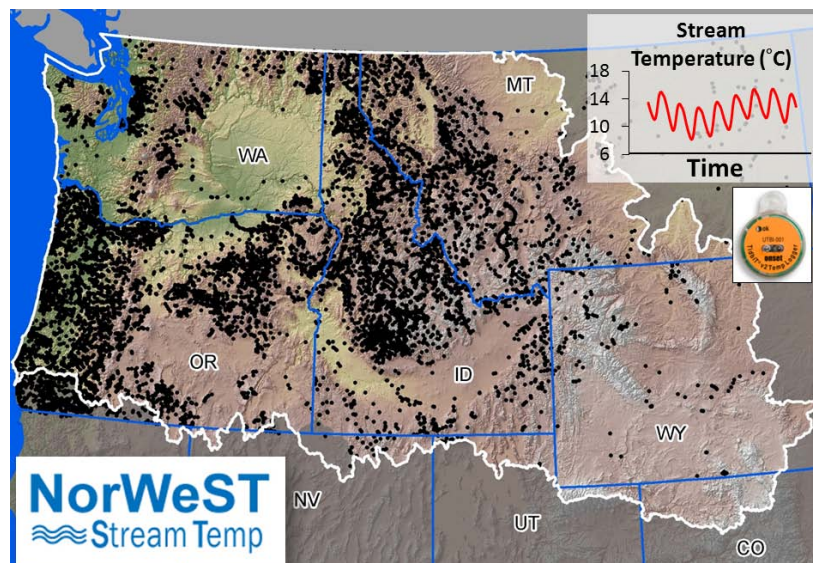
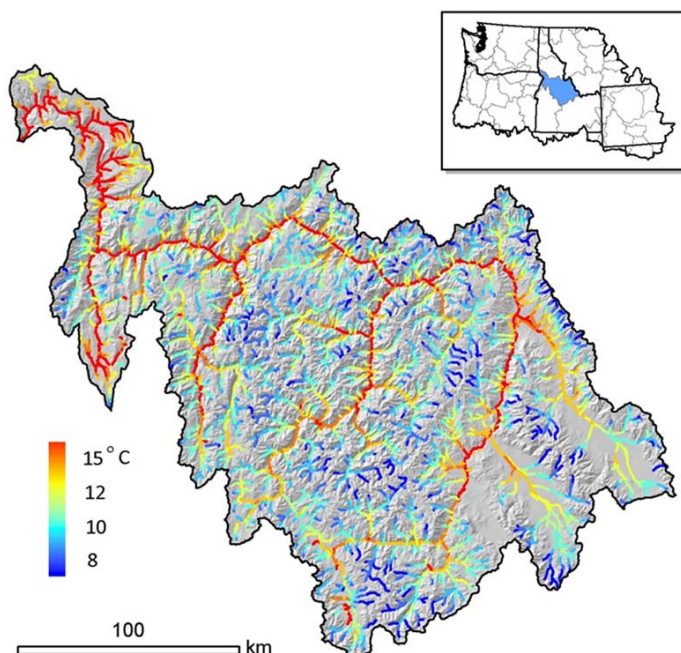


Figure 2. Map showing locations of stream temperature data in NorWeST contributed by hundreds of biologists from more than 60 resource agencies. Data represent >45,000,000 hourly temperature records at >15,000 unique stream sites.

Stream Climate Information from Data

The second project goal is to use NorWeST data to develop accurate stream temperature models, which will then be used to develop a consistent set of historic and future temperature scenarios for all 350,000 stream kilometers across the project area. Using a new type of spatial statistical model for stream networks (<http://www.fs.fed.us/rm/boise/AWAE/projects/SpatialStreamNetworks.shtml>), the first temperature models and climate scenarios have been developed for streams in north Idaho and northwest Montana that encompass more than 90,000 stream kilometers (Fig. 3 shows results for one river basin). The variables predicting stream temperatures in the models are derived from nationally available geospatial data layers to provide flexibility that could enable future expansion of the model to other parts of the U.S. The air temperature data used to represent climate scenarios with the stream temperature models are derived from the RegCM3 regional climate model predictions developed by USGS (archived online at: <http://regclim.coas.oregonstate.edu/>). Additional details regarding the stream temperature models are documented at the NorWeST website. Stream temperature data organization and climate scenario development are ongoing for the remainder of Idaho and Montana, with anticipated completion dates in summer of 2013. Stream temperature information for Oregon, Washington, and Wyoming will be addressed in the latter half of 2013 and 2014.



Disseminating Information

The third project goal is to openly distribute NorWeST stream temperature information so that it can be used to enable more efficient decision making, monitoring and planning efforts. A NorWeST website has been launched (<http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html>) that hosts a variety of geospatial stream temperature data products, all of which can be displayed in ArcMap and used for spatial database queries. These products include: 1) summaries of stream temperature data and georeferenced locations of monitoring sites, 2) GIS shapefiles of temperature model predictions for historic climate scenarios, and 3) GIS shapefiles of temperature model prediction precision, which are useful for designing efficient monitoring strategies. As temperature data products are developed and finalized within river basin, they are posted to the website and notification sent to the data contributors. Initial responses to these data products have been very positive and download activity from the NorWeST website shows significant utilization by resource professionals within river basins where results are currently available.

The Value of Better Information

Although the raw data assembled in NorWeST have significant monetary value, a much greater value will accrue over time from the improved efficiencies and decision making that accurate geospatial temperature data provide. A series of complementary projects that use NorWeST model outputs are being developed in parallel, including: 1) regional temperature and biological monitoring protocols, 2) vulnerability assessments for sensitive species, 3) decision support tools, 4) consistent thermal niche descriptions for aquatic species, and 5) improved bioclimatic models and projections. As the NorWeST project progresses, it is developing considerable interest and support across the region, stimulating collaborations and coordination among dozens of resource agencies, and serving as a model for initiatives in other parts of the country through the Landscape Conservation Cooperative system.

Figure 3. NorWeST stream temperature climate scenario map of August temperatures across 21,300 stream kilometers in the Salmon River basin of central Idaho.

The Kings River Experimental Watersheds: New Findings about Headwater Streams of the Southern Sierra Nevada

Carolyn Hunsaker

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The Kings River Experimental Watersheds (KREW) study was designed to (1) characterize the variability in watershed attributes considered important to understanding processes and health of headwater streams and forest watersheds and (2) evaluate forest restoration treatments—mechanical thinning and understory prescribed fire. Prior to KREW being established, no long-term watershed research experiment was functioning in the mountain source waters despite the importance of water to California. KREW also is ideally suited to address climate change because of its location; rain-dominated lower elevation watersheds, that also receive snow, provide a surrogate for how snow-dominated, higher elevation watersheds, could function with climate change.

The KREW is a paired watershed experiment located in the headwaters of the Kings River Basin (Fig. 1) which started collecting data in 2002. Two sites are instrumented with four watersheds each: the Providence Site between 1,500 and 2,100 m eleva-

tion and the Bull Site between 2,000 and 2,500 m. At each site one watershed is a control (no treatment), one has been thinned, one will be burned, and one will be both thinned and burned. A unique aspect of the study is that the control watershed in the Teakettle Experimental Forest can be considered “undisturbed” since it has no roads or history of timber harvesting; thus, it provides a “natural range of variability” while the other watersheds provide the “current range of variability.” The forest at KREW is mixed conifer growing in soils derived from granite and sustained by a Mediterranean climate. The pre-treatment phase of nine years will end with tree thinning completed in 2012 and prescribed fire planned for 2013-2014. The experiment was designed to provide information for adaptive management by evaluating the integrated condition of the perennial streams and their associated watersheds before and after fuels reduction and restoration treatments. To accomplish this goal, a diverse set of measurements are made.

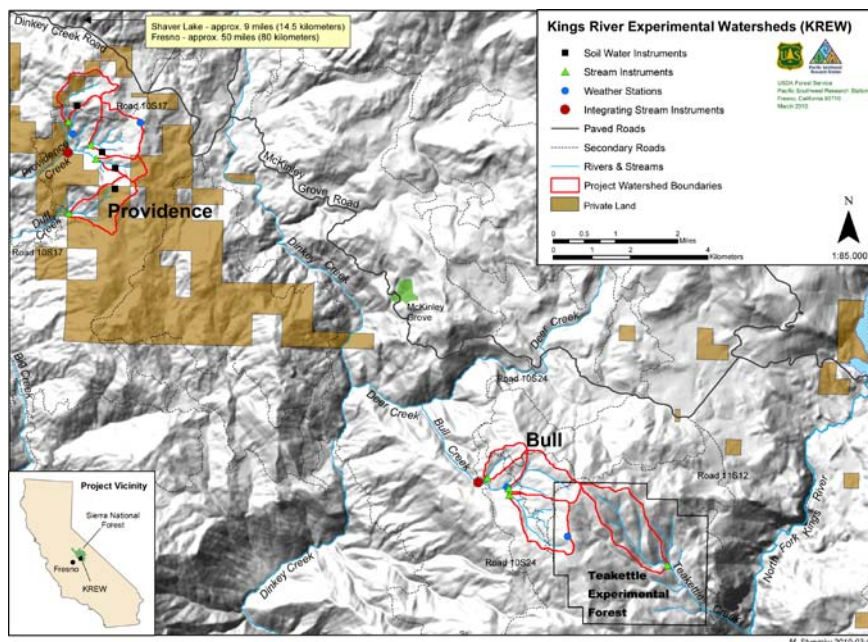


Figure 1. The Kings River Experimental Watersheds (KREW) research is located on headwater tributaries of the Kings River in the Sierra National Forest, east of Shaver Lake, CA. KREW consists of two sites approximately 15 km apart: Providence shown at the top of the figure, and Bull shown at the bottom of the figure.

- Physical measurements include upland erosion, turbidity (suspended sediment), stream temperature, streamflow, channel characteristics, and weather conditions.
- Chemical measurement for stream water, shallow soil water, precipitation, and snowmelt include nutrients (nitrate, ammonium, phosphate), chloride, sulfate, calcium, magnesium, potassium, sodium, pH, and electrical conductivity.
- Biological measurements include stream invertebrates, algae, and riparian and upland vegetation.

New information has been gained about Sierra headwater streams during the first nine years of the KREW study.

Water Budget: Stream Discharge, Precipitation, and Evapotranspiration

(Hunsaker et al. 2012, Bales et al. 2011)

The information learned on this topic is important for understanding how water yield may change with changing climate (Fig. 2).

- Precipitation amount and timing were very similar for all four KREW meteorology stations (75-200 cm) despite the nearly 700 m difference in elevation. This supports previous observations that precipitation on the west side of the Sierra Nevada reaches a maximum at about 1200 m.
- The annual runoff ratio (stream discharge divided by precipitation) increased about 0.1 per 300 m of mean catchment elevation over the range 1,800-2,400 m.
- The larger, snow-dominated watersheds (75-90% of precipitation is snow) have two to three times the stream discharge of the lower elevation watersheds.



Figure 2. One watershed in the Teakettle Experimental Forest is used as a control watershed; it has never been disturbed by roads or timber harvests. This photo shows the Teakettle stream at the Bull Site in winter; the weir and basin were constructed in the 1940s, and retrofitted with modern instruments for KREW measurements. Photo: S. Eagan

- Peak discharge lagged peak snow accumulation on the order of 60 days at the higher elevations and 20-30 days at the lower elevations.
- At the Providence Site, total annual evapotranspiration for water year 2009 was estimated to be approximately 76 cm. Trees at this elevation are growing and using water more than expected during the winter.

Flow Pathways

(Liu et al. 2012)

Processes controlling stream flow generation can be determined using water chemistry measurements.

- Streamflow in these headwaters was dominated by subsurface flow (about 60% of discharge), while snowmelt runoff contributed less than 40%, and fall storm runoff less than 7%.
- Subsurface flow is likely generated from the soil-bedrock interface through preferential pathways and is not very sensitive to snow-rain proportions.

Nitrogen Deposition and Movement through Ecosystem Compartments

(Hunsaker et al. 2007)

Nitrogen is an important indicator of the overall health of a forest, and knowing its concentration over time in atmospheric deposition, vegetation, soils, and water provides a useful assessment tool. Nitrogen is an essential nutrient, but if its concentrations become too high it can cause problems like acidification, excessive aquatic plant growth, and low oxygen concentrations in water (Fig. 3).

- Atmospheric nitrogen inputs to the research area are above known effects levels for sensitive lichens (3-5 kg/ha) and often exceed > 17 kg/ha, a level that is known to affect 26% of fine roots and could result in leaching to stream water.
- Despite the moderately high atmospheric inputs of nitrogen, soil water and stream water nitrogen concentrations seldom exceed 0.05 mg/L, an indication that the forest ecosystem is utilizing the incoming nitrogen.
- Interflow between the organic layer (e.g., needles, leaves, twigs) and mineral soil was measured and was enriched with nutrients. This could be an explanation for how soil nutrient “hotspots” are caused. Ammonium-nitrogen concentrations ranged from < 0.1 to 6.3 mg/L and nitrate-nitrogen ranged from < 0.1 to 8.7 mg/L, values that exceed those found in soil solutions and stream water.



Figure 3. Nitrogen deposition from the atmosphere to the ground and movement from the ground into the mineral soil is measured each year with resin lysimeters (shown in plastic bag in photo foreground) at hundreds of points across the watersheds. This photo shows a team of Sierra High School students installing resin lysimeters at a Providence watershed in 2012. Photo: C. Hunsaker

Soils

(Johnson et al. 2011)

Soil carbon and nutrient contents were characterized during the pre-treatment years to be able to understand how tree thinning and prescribed fire change these important attributes.

- The Bull Site watersheds had significantly greater carbon and nitrogen, likely because of slower decomposition rates at colder, higher elevations. Calcium, magnesium, and pH were lower at the higher elevation site because of higher leaching rates with more snow.
- These data showed that carbon and nutrient contents in soil would have been overestimated by 16% and 43% if quantitative pits were not dug and large rocks accounted for in calculations.
- Although soil ammonium nitrogen was high, the carbon to nitrogen ratio (a measure of soil condition) was normal (20-22).

Sediment

(Hunsaker and Neary 2012)

- The current range of variability in sediment loads of headwater streams in managed (roads and previous timber harvest) watersheds ranged between 2 and 17 kg/ha with standard deviations of similar magnitude (Fig 4).
- The natural range of variability for sediment loads in an undisturbed watershed was the same order of magnitude as for managed watersheds (16 ± 21 kg/ha).

- Fine and coarse particulate organic matter makes up 30-50% of the material collected in the sediment basins; this high proportion of organic matter is logical for headwater streams where organic matter provides the energy/food source for stream organisms like invertebrates (heterotrophic).

The publications that document these findings are available at www.treesearch.fs.fed.us; search for “Hunsaker” as an author. For more information about KREW visit the Pacific Southwest Research Station’s web site www.fs.fed.us/psw/topics/water.



Figure 4. Fiberglass flumes provide a uniform stream cross-section for accurate stream discharge measurements. This photo shows high flow at a Providence Site stream during a rain-on-snow event that created stream turbidity (suspended sediment) which is measured at KREW. Photo: T. Whitaker

The University of Nevada at Reno, the University of California at Santa Barbara, and the U.S. Geological Survey, Sacramento have collaborated on KREW since the start. KREW has hosted the National Science Foundation’s Southern Sierra Critical Zone Observatory (<http://criticalzone.org/sierra>) since 2007 and will be part of their Domain 17 of the National Ecological Observatory Network (www.neoninc.org).

From 2005 through 2010 KREW received funding from the CalFed Bay Delta Program under Proposition 50 (State Water Resources Control Board Grant Agreement 04-186-555-0). The KREW provided much needed information on headwater ecosystems in the southern Sierra Nevada to assist with CALFED’s actions “to reduce or eliminate parameters that degrade water quality at its source” and to understand “watershed processes and their relationships with one another.” Because of the limited watershed research in the southern Sierra Nevada, KREW findings are important for the Integrated Regional Water Management Plan process and the work of the State Water Quality Control Board.

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Castilleja applegatei. Photo: J. Blanchard

Landscape Genomics: An Emerging Discipline That Can Aid Forest Land Managers with Planting Stock Decisions

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The Issue

Forest land managers must frequently contend with identifying appropriate planting stock for many needs, from reforestation following harvest or disturbance, to habitat restoration and conservation plantings. Difficult enough in the best of times, such decisions are complicated today by anticipated global climate change and decades of fire protection that have altered, in some cases, our understanding of what constitutes historical species assemblages. Indeed, much thought is now being given to the concept of assisted migration, or the deliberate movement of planting stock of forest tree species far from their location of origin, to ensure species survival in the event conditions in the native range become intolerable. Regardless of the specific need, the goal of a land manager is to ensure that planting stock used for reforestation is adapted and grows well. Deciding what to plant requires an intimate knowledge of the environments intended for planting and the genetic makeup of the planting stock. The emerging field of landscape genomics may soon provide tools to aid the land manager in making those decisions.

Landscape genomics is a newly emerging discipline that combines the fields of population genetics and landscape ecology to study patterns of demographic and adaptive genetic variation across highly diverse landscapes. The science of landscape genomics is driven by the merger of rapidly developing technologies in both genomics and GIS (Geographic Information Systems). Landscape ecology has been described as the science of studying and improving relationships between ecological processes and particular ecosystems. (http://en.wikipedia.org/wiki/Ecological_geography). Genomics is the simultaneous study of an organism's complete genetic complement. With the ability to characterize genetic diversity and map environmental variation better than ever before, the science of landscape genomics promises to bring an entirely new set of precise, diagnostic tools to the land manager (Fig.1).

Before we proceed much further with the introduction of landscape genomics, it is worth taking a bit of time to reflect on the more traditional methods used to identify adapted planting stock, where tree improvement programs do not exist. While the science

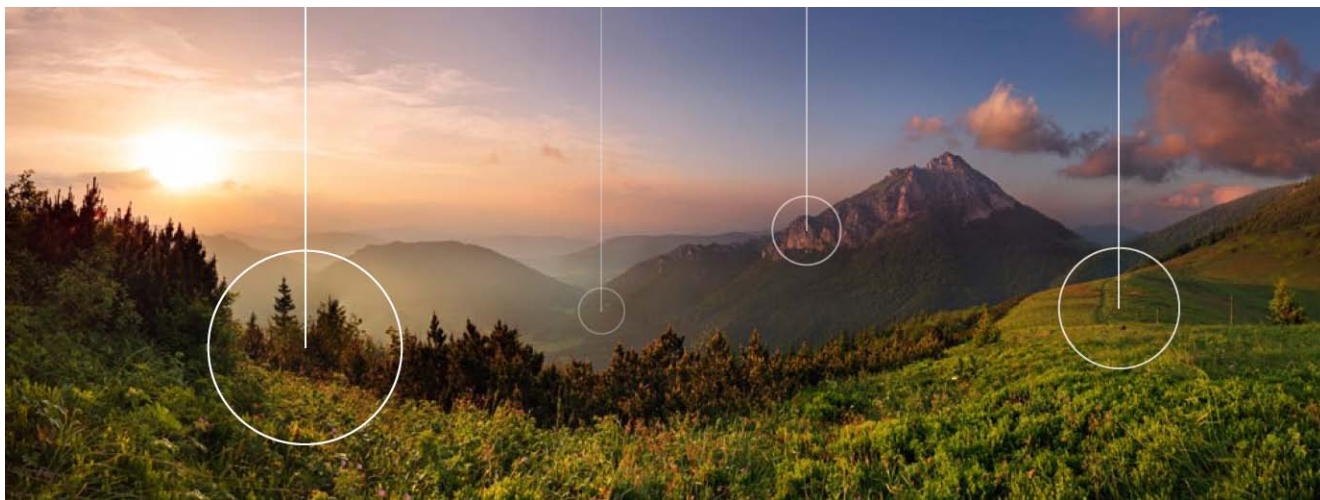


Figure 1. Species assemblages develop across the landscape as a function of demographic, environmental and genetic factors. Landscape genomics seeks to identify which environmental and genetic factors most influence adaptation (Wheeler and Neale, 2013).

of landscape genomics is just developing, land managers have long sought to match planting stock to environment to ensure their forests are thrifty. These techniques found favor because of rather bad experiences with maladapted planting stock in early reforestation efforts. Today, foresters rely principally on seed zones for guiding their decisions on reforestation needs (Fig.2). Simply stated, stock used to replant a site in a given seed zone should have originated from that zone. Zones are roughly identified by geography, elevation, drainage, climate, and so forth. This approach is sure to provide planting stock with a generally accepted level of adaptation and performance, though it does not address issues that could arise due to rapidly changing environments. For that matter, trees growing across the landscape today may not even be optimally adapted to current conditions.



Figure 2. Forest tree seed zones of California.

The provenance, or common garden trial, provides a more empirical means of identifying seed sources that perform well and are adapted to various environments. Though provenance trials first appeared several hundred years ago in Europe, they were only widely adopted in America by forest geneticists in the middle of the last century and remained popular for a relatively short period of time, from about 1960 to 1980. A typical provenance trial may include seed collections from a few trees from each of many populations (e.g., 50 to 100 or more) across the species natural range. Seedlings are raised in a common nursery, and

out-planted to replicated plantations established on many field test sites, again, distributed across the species range. In some cases, such trials are exported beyond the species natural range, or even overseas. Species such as Sitka spruce, Douglas-fir and lodgepole pine, for instance, are now widely planted in the UK, Europe, New Zealand and Scandinavia as a result of such trials having identified the best sources for the new environments.

While provenance trials can be very informative they have a number of limitations. They require a great deal of time and money to plan, establish, and maintain for long periods of time. Administering these long-term projects requires a dedicated and committed staff with constant funding. Plantations need to be replicated across the landscape, reaching to extremes of the natural range, and perhaps beyond. For such reasons, provenance trials have been established for relatively few, generally highly valued, species.

The most informed decisions regarding seed source movement across the landscape are provided by intensive tree improvement programs. Extensive and expensive genetic field trials provide excellent empirical evidence of adaptability and phenotypic plasticity in varying environments. With the rapidly developing genomic resources for a few species, tree breeders are now developing a growing understanding of which genes are contributing to performance and adaptation traits. Landscape genomics seeks to extend this intimate knowledge of genetics to the full range of tree species for which breeding programs do not exist.

The Science of Landscape Genomics

Simply stated, landscape genomics attempts to explain which genetic and environmental factors play a role in how organisms adapt to their surroundings. Environmental factors like precipitation, temperature, soil chemistry, water holding capacity, insects and disease, etc., determine which tree species, and individuals within species, survive and thrive in a given environment. They do so by acting on the natural genetic variation within the species. Trees with the best combination of genes will succeed and adapt; those with less favorable combinations will eventually perish.

Consider the scenario shown in Figure 3, representing a timeline of 200 years. In this progression, a recently deforested landscape, scarred by fire, is naturally regenerated with a genetically diverse group of seedlings from one or more species of forest trees. Colors represent trees with various combinations of genes that confer more or less cold tolerance. In the beginning, they are relatively evenly distributed, as one might expect from seed

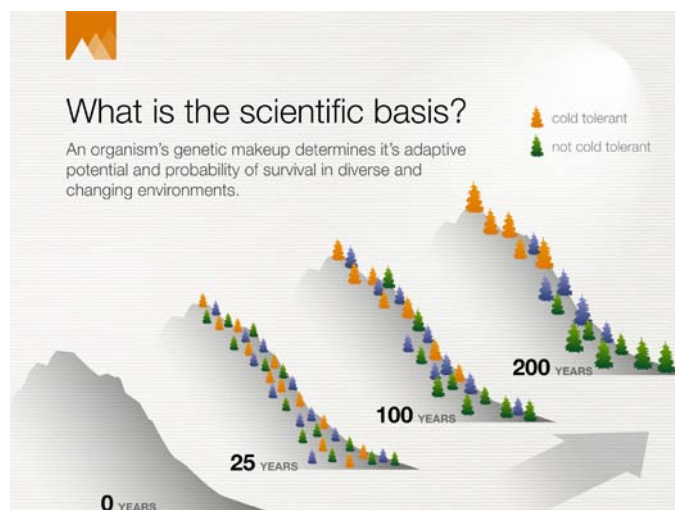


Figure 3. Hypothetical development of tree populations following disturbance (Wheeler and Neale, 2013).

that flies into the valley on strong winds from nearby populations. Orange trees, with gene combinations that confer cold tolerance, eventually become dominant at higher elevations while green trees, lacking cold tolerance, become dominant at lower elevations. Landscape genomic approaches can identify those suites of genes that confer adaptedness and the environmental factors driving selection.

Another way of illustrating the fundamental basis of landscape genomics is to contrast approaches to identifying adapted planting stock, with respect to the classic equation used by forest geneticists to describe the relationships between phenotype, genotype, and environment (Fig.4). The phenotype of a tree is what we can see or easily measure. It is determined by the individual tree's genotype at literally thousands of genes, and the environment in which the tree grows. Typically, phenotype has been the unit of selection. With provenance trials one seeks to identify associations between phenotypes and environments. For instance, it might tell you that trees from higher elevation, or more northern latitudes, in general, have later bud flush and are more cold hardy than those from lower elevations. By contrast, tree breeders seek to understand the association between genotype and phenotype. For traditional programs genotype is defined by pedigreed families. For intensive tree improvement programs with genomic resources such as genetic markers, breeders seek to reveal associations between specific genes, and their alleles, with specific phenotypes like cold hardiness. Landscape genomics differs from these approaches by seeking to identify associations between environments and genotypes, where genotypes are defined by knowledge of specific genes and their alleles. The premise of landscape genomics is that phenotypic traits are

distributed according to environmental variation because those traits affect fitness. All approaches have utility, and may be used in complementary fashion, but come with different costs and constraints. In contrast to genetic tests and provenance trials, costs for landscape genomics are largely front-loaded, without the burden of long-term trials. Furthermore, landscape genomics can provide basic information that would be valuable across time and space, and study of one species may lend itself to application in other species.

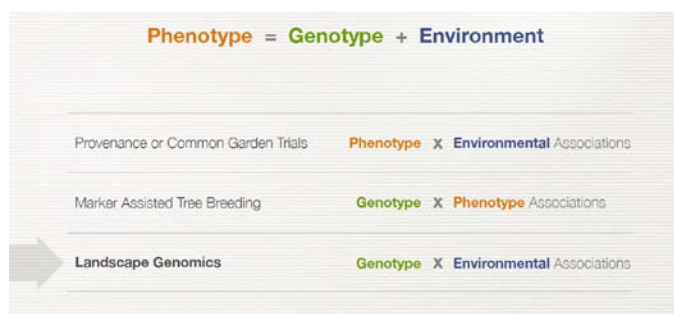


Figure 4. Contrasting approaches to identifying stock adapted to planting site (Wheeler and Neale, 2013).

The scientific goals of a landscape genomics project can be generally described by noting major steps in the experimental process. The first step in the process is to characterize the genome of the species of interest. That is, identify all the genes, their putative function, and their genic or allelic diversity. This process, though seemingly impossible only a few years ago, is becoming increasingly tractable, both technically and financially. Analysis of these data will allow one to identify those genes under natural selection from environmental factors, both biotic and abiotic in nature. The next step is to characterize the spatial distribution of allelic diversity across the landscape and lastly, test for associations between tree genotypes and environmental traits tree genotypes and phenotypes. The results of these analyses may be used to predict or model which trees or populations are best suited for placement in areas requiring reforestation or restoration.

An Example

The science and application of landscape genomics may best be illustrated by example. In 2010, Eckert et al. published a paper that described how their team identified an array of genes that appeared to be strongly associated with bioclimatic variables. The team gathered climate data from the WORLDCLIM 2.5-min geographical information system (GIS) layer and overlaid this on distribution maps of over 900 loblolly pine trees with known genotypes for over 3000 genes. Monthly minimum and maxi-

imum temperatures, monthly precipitation, and 19 other bioclimatic variables were evaluated. The temperature and precipitation data were used to estimate potential evapotranspiration (PET) and an aridity index was defined as the ratio of precipitation to PET. This was done on a quarterly basis. The pattern of aridity observed across the Southeastern United States is illustrated (Fig. 5) for the second quarter of the calendar year.

Environmental association analysis identified five genes associated with aridity gradients. The primary functions of gene products encoded by these loci were abiotic and biotic stress responses, as determined in previous studies. The relationships between genotypes and aridity are shown (Fig. 5) for four of the genes. The genotype is defined here by letters on the x-axis of the graphs, while the Y axis is a measure of aridity. The letters designate the combination of alleles that an individual tree possesses at a given gene. Take for example the left-most graph, showing the gene identified as a photosystem II protein. Of the 900+ trees in the study, some proportion of them had two C alleles (CC), some, one A and one C allele (AC) and some two A alleles. Collectively those groups occurred more or less frequently in areas of differing aridity, implying they contributed to the adaptation of those trees to those sites. While no single gene contributed dramatically to adaptation to arid conditions, the cumulative effect of all genes detected can approximate the total genetic variability (additive genetic variation) in a species. The results of this study could be easily used as a basis for Marker Assisted Selection for trees best suited for more arid landscapes. Furthermore, knowledge of which genes are associated with aridity in this species can likely inform which genes should be evaluated in other species for the same trait.

Summary

Landscape genomics offers the potential for land managers to fine-tune their decision making process with regards to reforestation, habitat restoration, and conservation. The knowledge gained from the study of forest tree genomes, coupled with enhanced understanding of our changing environments and landscapes, will guide decision making for seedling deployment in a flexible, sustainable manner for broad geographic regions. Common garden trials can, and probably should be employed to validate landscape genomic prescriptions, though their drawbacks must be weighed carefully. Common garden trials are expensive and time-consuming to establish and must be maintained for many years. In situations where planting materials are drawn exclusively from seed lots obtained from local seed zones, landscape genomic tools could significantly improve survival and productivity in a changing landscape.

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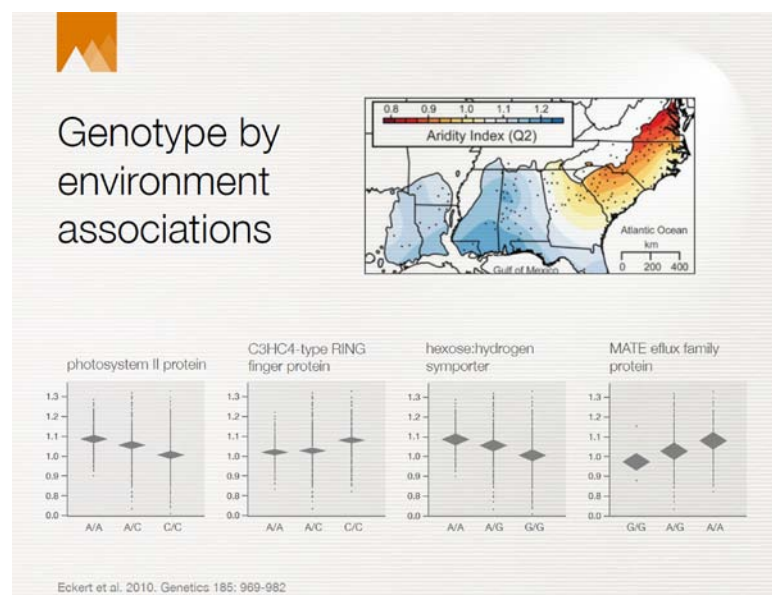


Figure 5. An example of genotype by environment associations discovered in loblolly pine (Wheeler and Neale, 2013).

BREVIA

Increases in Atmospheric Dust over Regions of the Western U.S. and its Effect on Precipitation, pH, and Alkalinity

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Brahney, J., Ballantyne, A.P., Sievers, C., and Neff, J.C. 2013. Increasing Ca^{2+} deposition in the Western US: The role of mineral aerosols. Aeolian Research, [In press.]

Changes in atmospheric dust concentrations can have a variety of environmental implications through effects on climate (Slingo et al. 2006), biogeochemical cycles (Okin et al. 2004), ecosystem and human health (Shinn 2000, Griffin et al. 2001), and atmospheric chemistry (Andreae and Crutzen 1997). Some of the major constituents of dust are calcium bearing minerals, such as calcite (CaCO_3). Because these minerals have acid-neutralizing properties, they have the potential to affect the chemistry of precipitation as well as the chemistry of the regions where they are deposited. In the Western U.S., anecdotal reports suggest increasing dust storm activity, while current aerosol monitoring networks (IMPROVE) indicate otherwise (Hand 2011). This discrepancy suggests that monitoring networks may not be effective in capturing dust events, likely because these networks exclude particles greater than $10\ \mu\text{m}$ that tend to dominate soil aerosol emissions (Lawrence and Neff 2009, Neff et al. in review). Brahney et al. 2013 addressed this knowledge gap by using dissolved Ca^{2+} concentrations in wet deposition as a proxy for mineral aerosol deposition. Trend analysis revealed increases in

dust sourced Ca^{2+} deposition over large areas of the Western U.S. These changes appear to be due to a combination of increased wind storm activity and drier climates, with a large unquantified component that may be related to ongoing land-use change. This analysis has revealed that a large disturbance in regional biogeochemical cycles is occurring, of which we have been largely unaware. Increases in dust emissions in these regions appear to have significantly increased the alkalinity of precipitation and may have important implications for ecosystem and human health.

To evaluate recent changes in precipitation chemistry in the U.S., Brahney et al. 2013 conducted a trend analysis of alkalinity, pH, and the ionic composition of wet deposition from 175 sites in the National Atmospheric Deposition Program (NADP) from 1994 to 2010. To obtain regional statistics, sites were subsequently regionalized using the U.S. Environmental Protection Agency (EPA) level III Ecoregion boundaries. Composite Ca^{2+} trends were then constructed by compiling all sites within a region. Annual observations at each site (O) were normalized to their respective variance ($O - \mu/\sigma$) before being averaged by year for a regional trend. All sites and regional trends were analyzed with the non-parametric Mann-Kendall statistic. See Brahney et al. 2013 for more details.

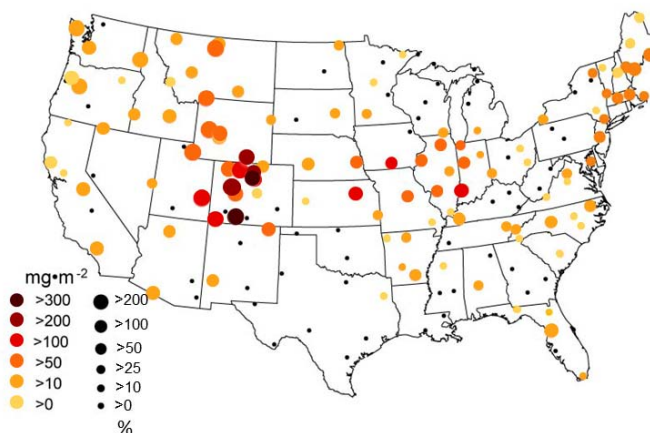


Figure 1. Changes in Ca^{2+} deposition across the U.S. plotted by the magnitude of the increase in mg m^{-2} , and by percent increase from 1994 values. Black dots represent sites where Ca^{2+} deposition decreased.

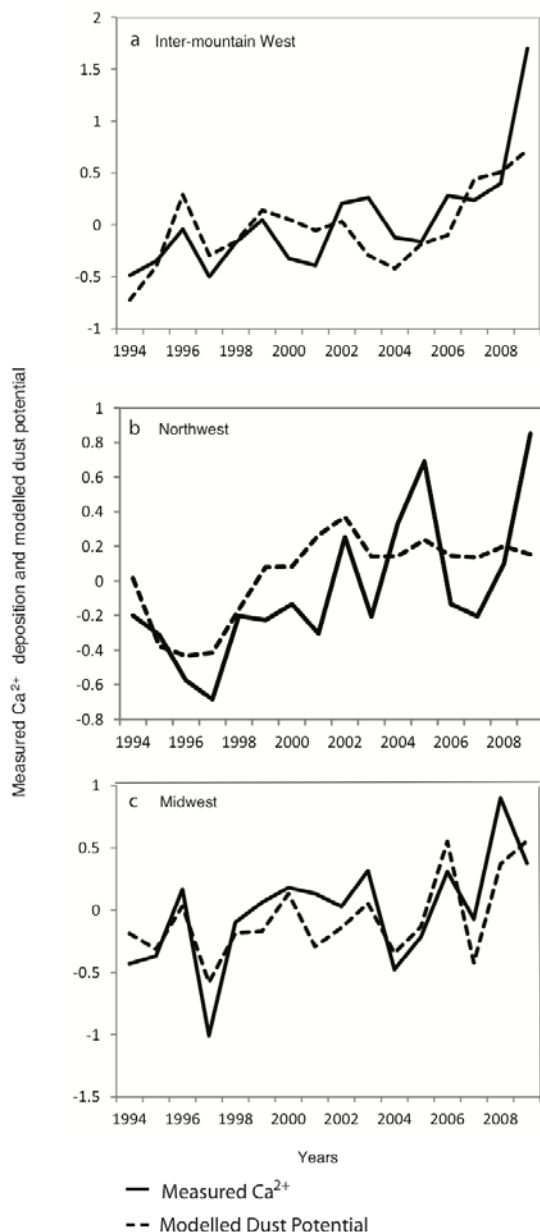


Figure 2. Composite Ca²⁺ deposition trends compared to modelled dust generation potential. (a) Inter-mountain West region, $r^2=0.55$, (b) Northwestern region, $r^2=0.41$, c) Midwestern region, $r^2=0.62$. Units in the Y-axis have been normalized.

Increases in Ca²⁺ Deposition across Three Main Regions of the Western U.S.

Increases in calcium deposition are seen across much of the nation, with three prominent hot spots in the Western U.S. (Fig. 1). Regionally, trends of Ca²⁺ deposition in the Inter-mountain West, Northwest, and Midwestern regions were significant at $p < 0.05$ (Fig. 2). On a site-by-site basis, trend analysis indicated that 116 of 175 (26 significant) sites across the U.S. have received increases in Ca²⁺ deposition over the last 17 years. Seven of eight EPA Ecoregion groups showed increases in Ca²⁺ concentration. Western states, particularly Colorado, Utah, and Wyoming, have seen the greatest increases in calcium deposition, with roughly double the Ca²⁺ deposition rate (average 230 mg m⁻² yr⁻¹ in the last 5 years) than that found in the eastern states. On average, these Western states have seen ~168% increase in calcium deposition over the last 17 years. The Northwestern region has seen 54 % increase and the Midwestern region ~24% increase in Ca²⁺ deposition.

Brahney et al. 2013 evaluated potential industrial and natural sources of calcium to the atmosphere, and found that the most congruent explanation was a rise in soil mineral aerosol emissions. In fact, the highest rates of Ca²⁺ deposition in this study are found near the Southwestern Deserts, specifically the Mojave Desert and the arid regions in the Four-Corners area that regularly produce dust storms that travel east and northeast (Fig. 1).

Causes of Dust Ca²⁺ Increase

Mineral aerosols are produced by a combination of factors that include the erosive forces of wind, and the surface properties that act to resist these forces. Wind speeds control the erosion potential of surface materials and subsequent transport, while soil properties and the presence of surface protectors (e.g. rocks, vegetation) determine the erodibility of the soil (Goudie 2006). Climate, and specifically drought, can increase soil erodibility by reducing the amount of soil moisture and decreasing the amount of surface-stabilizing vegetation (Field 2009). Human land uses can also increase the erodibility of soils by diminishing soil stability and decreasing or removing vegetative cover (Neff et al. 2005). Thus, the potential for dust generation can be conceptualized as a function of soil erodibility, aridity, land-use, and transportability (wind). To examine the contribution of climate factors on dust generation, statistical regression models for each region were created that determine the climatic potential for dust generation using the Palmer Drought Severity Index (PDSI), as a measurement of soil aridity, and regional wind statistics, specifically days of winds speeds greater than 25.7 m s⁻¹, as a measure of transportability.

Transportability, days of winds greater than 25.7 m s^{-1} , increased in all three regions. However, the PDSI as a measure of aridity only increased in two areas, the Midwest and Northwest. Despite some years of drought (2002-2003), the PDSI in the Inter-mountain West region did not exhibit systematic drying over the last 17 years, suggesting that drought cannot explain recent increases in soil susceptibility to erosion in this area. In the Inter-mountain West, including the PDSI only marginally improved the correlation and decreased the significance. The PDSI and wind least-squares regressions (dashed line in Fig. 2) indicated that these climate factors explained 62% of the variation in the Midwest, 41% of the variation in the Northwest, and 55% of the variation in the Inter-mountain West.

Although much of the increase in Ca^{2+} deposition can be explained by the climatic factors of transport and aridity, a large proportion of the variance remains unexplained. An unaccounted for variable in the analysis is the disturbance due to human land-use change, which can significantly increase soil mobility (Field 2009). It is very difficult to quantify the impact of human land-use change, though independent studies in all three regions have shown that modern dust emissions are strongly tied to human modifications of the landscape. Dust emissions in Western U.S. deserts have been closely linked to anthropogenic factors in site level studies (Belnap and Gillette 1998, Munson et al. 2011). These areas are sensitive to human disturbance because soil crusts are destabilized through foot, vehicle, and livestock traffic, as well as through industrial and agricultural activities (Belnap and Gillette 1998). In the last 17 years, the population in the Mojave Desert has increased by 22% and on the Colorado Plateau by 29%, and recreational use of off-road vehicles has increased three to four fold (Cordell 2008). In addition, the number of wells drilled for natural gas extraction quadrupled from 2000 to 2009 in the Colorado Plateau (COGCC 2011, Utah.gov 2011).

Two of the three regions with significant increases are upwind of large agricultural areas. Agricultural practices and extensive loess deposits in both the Midwest and Northwest are known to contribute to windblown dust (Claiborn 1998, Lee et al. 2012). Crop type affects erosion potential through soil exposure and the modification of soil properties, as well as through the duration of fallow periods (Lee et al. 2012). Active farm operations, such as plowing, also contribute to mineral-dust formation (Carroll 1997). Collectively, these changes provide an illustration of regions that are undergoing rapid and widespread changes that have the potential to cause changes in wind erosion of soil. The relative importance of each of these factors to dust generation remains uncertain and is an important area for future work.

Effects of Increased Atmospheric Dust on Precipitation, Alkalinity, Downwind Ecology, and Human Health

Considerable research has focused on the role of industrial emissions in controlling the acidity of precipitation, and over the past two decades, legislation in the U.S. and elsewhere has focused on reducing emissions of the acid precursor gases SO_2 and NO_x . However, precipitation acidity is not exclusively controlled by acid precursor emissions, but through the relative proportion of acids and bases in solution. Therefore, soil aerosols also have the potential to affect precipitation acidity. To illustrate, in areas of the Inter-mountain West, industrial development and population increase has led to increases in acid emissions and concerns over deposition impacts (Wolfe et al. 2001), however, Brahney et al. 2013 have shown that observed acidity has decreased across the continental U.S., even in regions where acid precursor emissions have increased.

To evaluate the direct effect of dust emission on precipitation chemistry, Brahney et al. 2013 used charge-balance equations to calculate alkalinity. These same equations were used to determine the fraction of alkalinity changes attributable to increase in Ca^{2+} concentration, or to decreases in acid anions, specifically NO_3^- and SO_4^{2-} , over the last 17 years. All 175 sites analyzed showed increases in alkalinity (Fig. 3) and pH. Ca^{2+} increases contributed a large fraction of the overall change in alkalinity in the Inter-mountain West, the Midwest, and the Northwest (Fig. 4). Particularly in the Inter-mountain West region a $\sim 168\%$ increase in wet calcium deposition over the last 17 years provided an additional $442 \mu\text{eq m}^{-2} \text{ yr}^{-1}$ acid-neutralizing capacity. Increase in Ca^{2+} accounted for 52% of the regional alkalinity change and as much as

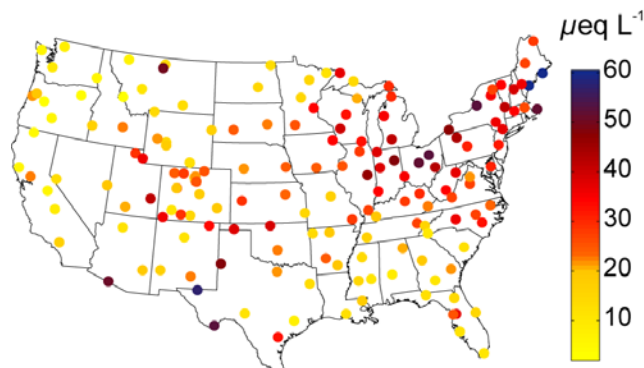


Figure 3. Change in alkalinity of precipitation from 1994-2010 reported as $\mu\text{eq.L}^{-1}$

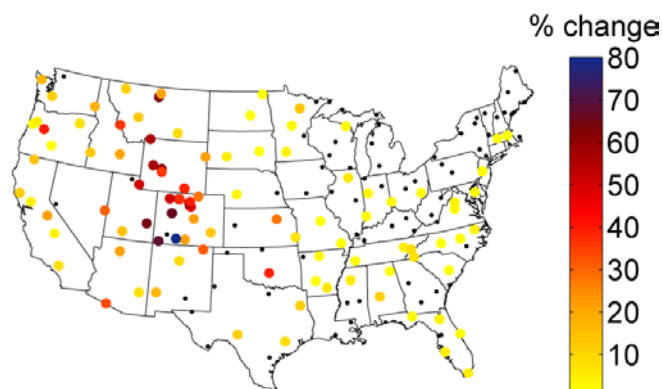


Figure 4. Change in alkalinity from 1994-2010 due to increases in Ca^{2+} concentration. Black dots represent areas where Ca^{2+} decreased over the time period.

~70% of the alkalinity increase at individual sites. It is worth noting that the NADP was not set up to capture dust chemistry signals. The network measures wet-only deposition and there are no sites in some prominent dust emission and deposition regions, e.g, southern Nevada. Thus, this analysis likely represents a conservative estimate on the contribution of base-cations in many regions, especially areas where dry deposition is high.

In addition to neutralizing airborne acids, the emission and subsequent deposition of dust has the potential to affect regional biogeochemistry. Dust associated base-cations can add buffer capacity, increase surface-water pH, and contribute nutrients to downwind ecosystems. The potential benefits listed above are counterbalanced by the negative implications of soil erosion and deposition. Wind erosion preferentially removes the fine fraction of the soil, which contains most of the soil's nutrients, cation-exchange capacity, and water holding capacity (Field 2009). Dust may also contain a variety of undesirable contaminants e.g. pesticides, fertilizers, heavy metals, and industrial compounds and nutrients that can have negative effects in sensitive ecosystems. Dust can also act as vector for the transport of pathogens that can affect human and ecosystem health. For example, there have been large increases in the incidence of Valley Fever (*Coccidioidomycosis*) in Southwestern states (CDC 2013) from the mid-1990s to present. This disease is caused by the inhalation of a soil born fungus known as *Coccidioides*.

Long-term increases in dust generation are possible in response to projected changes in climate and land-use. The analysis by Brahney et al. 2013 has demonstrated that dust emissions are increasing across regions of the Western U.S., and that the causes

are due to a combination of drought, frequency of high speed wind-events, and an undefined component of land-use change. Most model predictions suggest that continued warming will result in an increase in drought frequency over much of the Southwestern U.S. (Seager 2007). This condition would lead to drier soils related to the enhanced evapotranspiration that accompanies warmer temperatures (Seager 2007, Cayan et al. 2010). Increased drought frequency and greater soil aridity have the potential to increase dust emissions in the future.

In summary, dust emissions have increased over the last 17 years over large regions of the Western U.S. due to an interaction between wind speeds, drought cycles, and potentially changes in human land uses. This pattern suggests that dust may be an underappreciated contributor to the atmospheric particulate load in some U.S. regions near deserts or large agricultural areas. Changes in dust deposition have a clear impact on ecological systems and may also have broad implications for air quality, climate processes, ecology, and human health. These results highlight the need to expand the measurements and locations of the atmospheric deposition network while focusing on the factors that influence dust emission, transport, and deposition.

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Penstemon davidsonii and 3 Sisters. Photo: J. Blanchard

BREVIA

Alpine Wetlands as Sentinels of Climate Change

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Drexler, J.Z., D. Knifong, J.L. Tuil, L.E. Flint, and A.L. Flint. 2013. Fens as whole-ecosystem gauges of groundwater recharge under climate change. Journal of Hydrology 481: 22–34.

Currently, little is known about the impact of climate change on groundwater recharge in the Sierra Nevada of California or other mountainous regions of the world (Goderniaux et al. 2009, Earman and Dettinger 2011, Viviroli et al. 2011). There is concern that in mountain ranges with dwindling snowpacks, such as the Sierra Nevada, groundwater recharge is declining (Earman and Dettinger 2008, Manning et al. 2012). At this time, there is no monitoring network for groundwater recharge in the mountainous western United States (Earman and Dettinger 2008), in large part because of the difficulties and uncertainties related to monitoring recharge through time.

Fens are peatlands that receive consistent groundwater flows. Because of this, they have a diverse and distinct flora dominated by mosses, grasses, and sedges (Bedford and Godwin 2003, Cooper and Wolf 2006). In the Sierra Nevada of California, fens

can occur alone or as part of meadow complexes that contain other wetland types including dry meadows, which remain wet for only several weeks following snowmelt, and wet meadows, which stay wet for approximately 1-2 months during the growing season (Benedict 1983, Bartolome et al. 1990, Cooper and Wolf 2006). When the amount of groundwater flow to a fen is reduced, the elevation of the water table drops. This typically leads to desiccation, compaction, and increased microbial oxidation of the organic soil, ultimately resulting in subsidence of the fen surface (Schothorst 1977, Price and Schlotzhauer 1999, Whittington and Price 2006). In cases where groundwater flow is reduced over an extended period of time, major changes in flora can occur, resulting in the loss of the moss carpet and eventual conversion of fen into wet or dry meadow or even pine forest (Bartolome et al. 1990).

In this project we tested a new approach using fens as whole-ecosystem gauges of groundwater recharge under climate change. Seven fens in the Sierra Nevada and southern Cascade Range were studied over a 50-80 year period using historic aerial photography (Fig. 1). In each aerial photograph, fen areas were identified as open lawn and partially treed areas that exhibited (1) dark brownish-green coloring or various shades of gray and



Figure 1. Left: Location map of fen study sites in California, USA; Below: The largest fen in the study, Cooper Swamp.



black in black and white imagery and (2) mottling of colors and clustering of vegetation, which signified a distinct moss canopy with overlying clumped sedge vegetation. In order to examine potential causes for the areal changes we found, we carried out a climate analysis for the period from 1951-2010 using measured climate data from the U.S. Department of Agriculture Natural Resources Conservation Service SNOpack TELemtry System (SNOTEL) as well as modeled data using a distributed parameter water-balance model called the Basin Characterization Model (BCM; Flint et al. 2004, Flint and Flint 2007). The BCM is a downscaled version of the Parameter-elevation Regressions on Independent Slopes Model (PRISM; Daly et al. 2004).

Over a period from approximately the 1950s to present, the five fens in the Sierra Nevada were found to be decreasing between 10-16% in delineated area. The BCM climate analysis revealed significant increases through time in annual mean minimum temperature (T_{min}) between 1951-1980 and 1981-2010 in the grids containing the Sierra Nevada fens (Fig. 2). In addition, April 1 snow water equivalent and snowpack longevity estimated by the BCM also decreased between 1951-1980 and 1981-2010. For the fens in the southern Cascade Range, there were no discernible changes in delineated area. At these sites, increases in T_{min} occurred only within the past 20-25 years and decreases in snowpack longevity were more subtle.

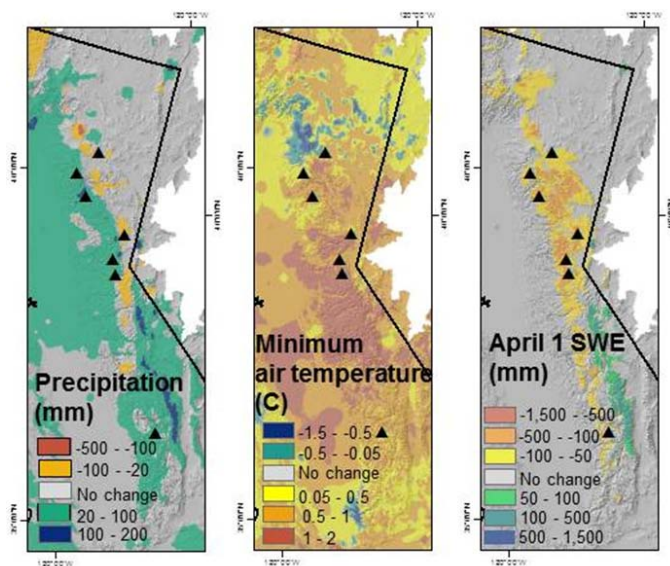


Figure 2. Change in annual total precipitation, mean annual T_{min} , and mean April 1st snow water equivalent (SWE) between two 30-year periods: 1951-1980 and 1981-2010. Fens are depicted by filled triangles.

There are major hydrogeological differences between the bedrock in the southern Cascade Range vs. the Sierra Nevada that are likely the underlying causes for the different responses of the fens through time. The granitic bedrock of the Sierra Nevada, on the whole, has lower porosity, lower hydraulic conductivity, and smaller groundwater reservoirs than the basaltic bedrock of the Cascade Range. Therefore, the fens in the Sierra Nevada are much more vulnerable to changes in groundwater flow than fens in the Cascade Range (see conceptual model, Fig. 3). Because of this, Sierra fens are better whole-ecosystem gauges for determining long-term changes in groundwater recharge under climate change. Due to either more moderate climate change and/or hydrogeological differences, fens in the southern Cascade Range currently do not yet appear to have the same utility.

Using fens as gauges for climate change holds great promise for a better understanding of local as well as regional changes in groundwater recharge in the Sierra Nevada. We look forward to applying this technique to a greater number of sites in the future. In addition, we hope to integrate fen monitoring with groundwater dating studies, which could potentially quantify changes in groundwater recharge identified using the fens.

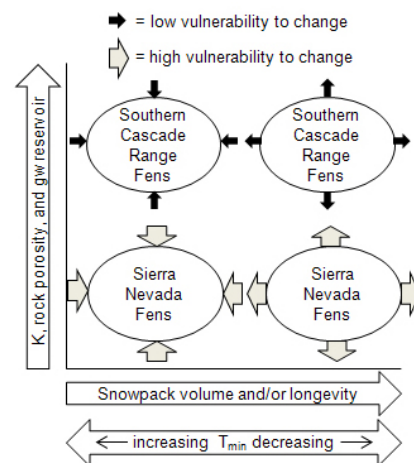


Figure 3. A conceptual model illustrating the vulnerability of fens to changes in delineated area and what likely controls such changes. Long-term changes in T_{min} and snowpack volume and/or longevity, which are major determinants of groundwater recharge, are strongly associated with changes in delineated areas. However, underlying hydrogeology, particularly hydraulic conductivity (K), rock porosity, and size of the groundwater reservoir of the watershed as well as the fen itself, may be important as buffers to sudden changes.

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BREVIA

Where Did All That Snow Go? Compensating Vapor Losses Following Forest Disturbance in the Rocky Mountains

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Biederman, J., P.D. Brooks, A.A. Harpold, D. Gochis, E. Gutman, D. Reed, E. Pendall, and B. Ewers. 2013. Multi-scale observations of snow accumulation and peak snowpack following widespread, insect-induced lodgepole pine mortality. *Ecohydrology*. Available online: <http://onlinelibrary.wiley.com/doi/10.1002/eco.1342/abstract>.

Harpold, A.A., J. Biederman, K. Condon, M. Merino, Y. Korgankar, T. Nan, L.L. Sloat, M. Ross, and P.D. Brooks. 2013. Changes in winter season snowpack accumulation and ablation following the Las Conchas Forest Fire. *Ecohydrology*. Available online: <http://onlinelibrary.wiley.com/doi/10.1002/eco.1363/abstract>.

The Rocky Mountain region is reliant on the melt of seasonal snowpacks from montane forests for critical water resources and ecological services. The effects of widespread changes in climate (Mote 2006, Harpold et al. 2012) and more frequent forest disturbance (Westerling et al. 2006, Bentz et al. 2010) on water availability are largely unknown. The structure of forest canopy (e.g. leaf area index and stem density) at the tree and stand scale strongly controls net snow accumulation (precipitation minus losses from sublimation and evaporation) and the rate and timing of melt by intercepting snow, shading the ground surface from shortwave radiation, re-emitting longwave (thermal) radiation, and reducing wind speeds and latent and sensible heat fluxes. It is unclear how the loss of forest canopy, due to disturbance from insects, fire, and other vectors, will modulate the coupled water and energy budgets of seasonally snow covered forest ecosystems.

The removal of the forest canopy by disturbance should alter two competing sets of ecohydrological processes that control water availability: 1. Additional snow accumulation leading to a larger melt rate and 2. Increased energy inputs to the snowpack surface causing winter-season vaporization (e.g. evaporation or sublimation prior to melt) leading to smaller snowpacks and less melt. The loss of forest canopy will reduce the amount of snow that is intercepted and, thus, increase the amount of snow that accumulates on the ground (Pugh and Small 2011, Burles and Boon

2011). Limited evidence from Canada has shown faster melt following disturbance from increased radiation and latent and sensible heat inputs relative to healthy forests (Burles and Boon 2011). Increased energy inputs after canopy removal could also vaporize the snowpack by evaporation or sublimation and reduce peak snow water equivalent (SWE), yet few studies have investigated these winter-season snowpack processes.

We present empirical evidence that net snowpack accumulation did not increase following the Las Conchas forest fire in New Mexico (Harpold et al. 2013) or following large-scale Mountain Pine Beetle (MPB) induced tree mortality in Wyoming (Biederman et al. 2013; Fig. 1). Our results suggest that winter-season vapor losses due to sublimation from the snowpack surface were likely compensating for reduced interception after the forest canopy was removed. Although initially surprising, these findings are consistent with a growing body of research that suggests that sublimation is minimized and net snow water input maximized in moderately dense forested sites (Musselman et al. 2008, Rinehart et al., 2008, Veatch et al. 2009, Gustafson et al. 2011). This illustrates the important role that intact forest canopy plays in decoupling mass and energy transfers between the snow surface and the atmosphere. The presence of “dry” atmospheric conditions (e.g. high vapor pressure deficit) and “high energy” inputs (e.g. sunny days) in the central and southern Rocky Mountains are the likely cause for the observed winter season vapor losses. Unfortunately many of these montane forests are already water-limited, and natural resource managers should consider the implications of these competing ecohydrologic processes on negative feedbacks for water availability after severe forest disturbance.

No Increase in Peak Snowpacks Following Forest Disturbance

We observed substantial differences in spatial distribution of snowpacks following disturbance indicating reduced influence of forest canopy. By applying Light Detection and Ranging (LiDAR) datasets from before a crown-removing fire in New Mexico, we demonstrated significant changes in the spatial dis-

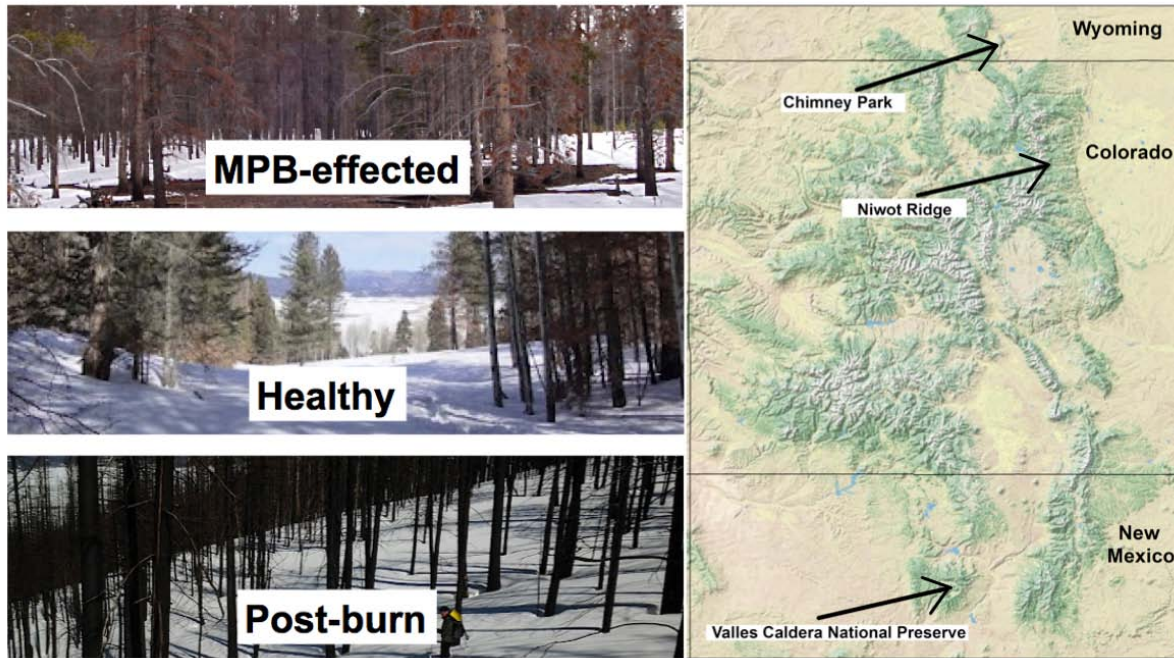
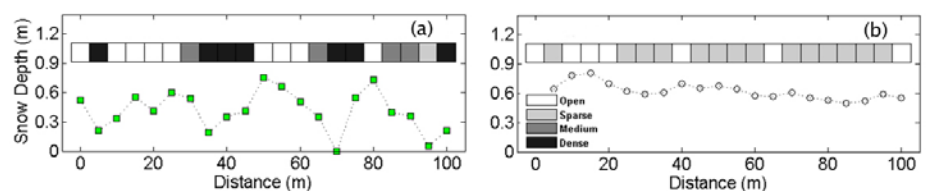


Figure 1. Map showing the central and southern Rocky Mountain States where the two studies were conducted. The Biederman et al. (2013) study investigated impacts of Mountain Pine Beetle (MPB) induced tree mortality at Chimney Park in southeast Wyoming and used Niwot Ridge in Colorado as an unimpacted control site. The Harpold et al. (2013) study investigated impacts of the Las Conchas forest fire at the Valles Caldera National Preserve in northern New Mexico.

tribution of snow after disturbance (Harpold et al. 2013). Before the fire, snow depths reflected variable interception losses that were a function of canopy structure (Fig. 2); after fire, the snow depth distribution was more influenced by topographic position (slope and aspect) (Fig. 2). Similar to previous observations from mixed-conifer forests, Harpold et al. 2013 observed interception measurements for a single storm of 25% to 45% in healthy stands and less than 10% in the Post-burn area (Fig. 3). In addition, snow depths had longer spatial correlation lengths (e.g. less small-scale variability seen in Fig. 2) at the Post-burn area in New Mexico compared to the nearby healthy forests (Harpold et al. 2013). Similar changes were observed at the beetle-killed lodgepole forest in Wyoming, with seasonal interception reduced from 20% to a negligible amount and spatial patterns indicating reduced influence of forest canopy (Biederman et al. 2013).

Despite reductions in intercepted snow following disturbance, we found equal or less peak snow accumulation in post-disturbance areas. The ratio of snow water equivalent (SWE) to winter precipitation (SWE:P ratio) is an estimate of how much snowfall remains as snowpack just prior to melt. At the burned site in New Mexico, we found significantly smaller ($p < 0.05$) SWE:P ratios of 0.55 following disturbance as compared to 0.65 for a nearby unburned stand, despite these same stands having similar SWE:P prior to disturbance (Fig. 4) (Harpold et al. 2013). At the beetle-killed forest in Wyoming, the snowpack water content just prior to melt was unaffected as compared to a healthy stand, with SWE:P of 0.62 for both stands (Fig. 5) (Biederman et al. 2013). Collectively, these SWE:P ratios demonstrate that winter sublimation can remove a third or more of winter snowfall prior to melt regardless of forest disturbance.

Figure 2. Observations of snow depths along two 100-m long transects in the 2012 Unburned site (a) and 2012 Post-burn site (b) in New Mexico. The vegetation density is shown as a shaded bar above the snow depth values. Snow distributions change from canopy density before fire to topographic controls after fire (adapted from Harpold et al. 2013).



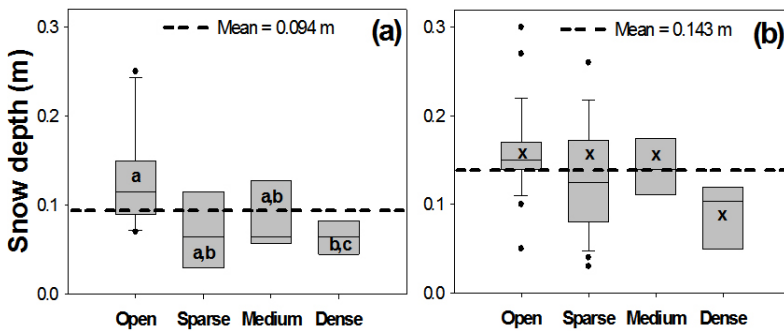


Figure 3. Box plots of new snow depth from a single storm event in March 2012 based on the four canopy categories from the Unburned site (a) and the Post-burn site (b) in New Mexico. The mean of all data from each site is shown as a thick dotted line and differs significantly ($p < 0.01$) between the burned and unburned areas. The letters with the boxes refer to differences between the categories based on one-way ANOVA tests ($p < 0.05$). The Post-burn site received significantly more new snow than the Unburned site. (From Harpold et al. 2013)

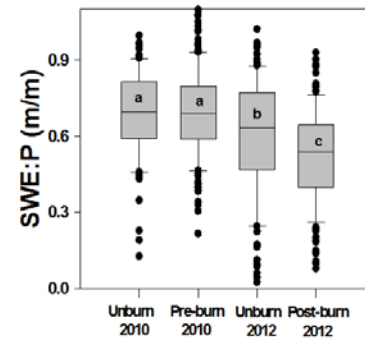


Figure 4. Box plots for snow water equivalent to winter precipitation ratio (SWE:P) at peak snow accumulation in 2010 (before the fire) and 2012 (after fire). The letters refer to differences between the categories based on one-way ANOVA tests ($p < 0.05$). The SWE:P declined in 2012 following smaller winter snowpacks, but the Post-burn area was significantly less than all other groups. (adapted from Harpold et al. 2013).

Several lines of evidence suggested that reductions in the SWE:P values in post-disturbance forests were due primarily to increased sublimation from the snowpack surface. Snowpack temperature and crystal structure during the snow surveys indicated that melt did not occur prior to peak snowpack. The presence of deep layers of faceted snow crystals in the Post-burn area corresponded to a stronger pressure and temperature gradient than in nearby healthy forests (Harpold et al. 2013). In the MPB-affected stands we found higher near-surface wind velocities and evidence of isotopic enrichment of snow water, consistent with sublimation, that was not observed in the healthy forest stands (Biederman et al. 2013). The loss of the forest canopy at these Rocky Mountain sites could act to increase sublimation in several ways: 1. Increase direct shortwave radiation inputs during the day, 2. Increase longwave emissions from the snowpack during clear, cold nights cooling the snowpack, delaying melt, and increasing the opportunity for sublimation, and 3. Increase turbulent kinetic energy near the snow surface resulting in greater transport of water vapor and/or greater turbulent heat inputs. Measurements of sublimation are rare, and relatively little is known about the role of sublimation in snowpack energy balance across the regional hydroclimate of the interior Western U.S. (Harpold et al. 2012).

Implications of Increased Snowpack Sublimation Following Disturbance

It is unclear how feedbacks between a warming climate and increasing forest disturbance are likely to affect the partitioning of snow water to runoff and vegetation, which exposes water and forest managers to substantial future risks. Most future climate scenarios suggest more variable, and often smaller, snowpacks in

the southern Rocky Mountains (Seager and Vecchi 2010), which could cause more water limitations and reduce carbon uptake by forests (Hu et al. 2010). Changes in the structure of forest canopy will have complex impacts on exchanges of water and energy between the land surface and the atmosphere that depend on the local conditions of a particular site (e.g., windy or not windy locations) as well as the stand-scale topography and tree species (e.g., north or south facing hillslopes). Quantifying changes in the water and energy balance will therefore require improvements in distributed models and measurement techniques for representing the snowpack energy budget under the forest canopy.

There is a potential for negative feedbacks on water availability in “higher energy” locations after the removal of the forest canopy. Following the Las Conchas fire in New Mexico, we observed a 10% increase in winter snowpack sublimation loss relative to a healthy forest at primarily north-facing areas. We speculate that “higher energy” locations (e.g. steeper and more south-facing) could have even greater sublimation losses relative to similar healthy forests because shortwave radiation inputs would be more sensitive to loss of shading by the disturbed canopy. These “high-energy” environments will also have greater potential for soil evaporation and, therefore, potentially less water available for vegetation regeneration after disturbance. The potential for negative feedbacks on water availability following forest disturbance requires greater scientific understanding, but early indications suggest that resource managers should consider these processes as they evaluate the response of seasonally snow covered forests to unprecedented levels of disturbance.

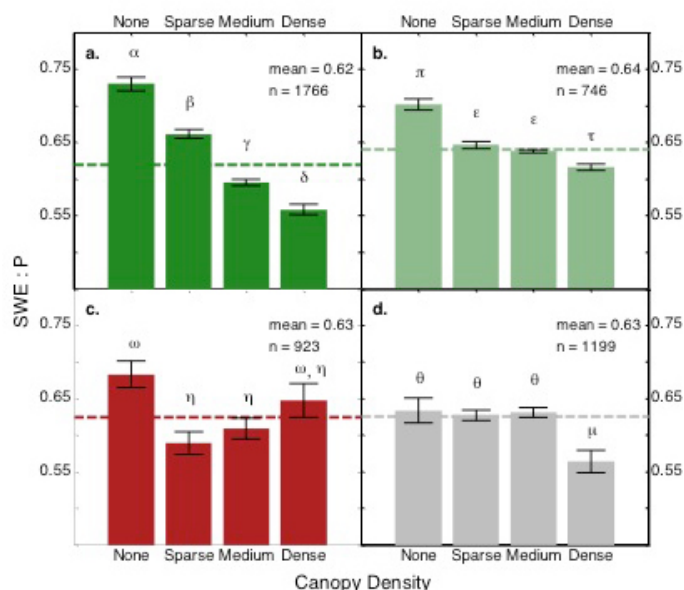


Figure 5. Snow water equivalent to winter precipitation ratio (SWE:P) at peak snow accumulation the 2010 and 2011 surveys in Unimpacted (a), MPB-2009 (b), MPB-2008 (c), and MPB-2007 (d) stand types. All points were in mature lodgepole stands, and canopy density was recorded using the categories None, Sparse, Medium and Dense. Dashed lines are means of each forest cover type, bars are means of each canopy type, and error bars are standard error of the mean. The means were equal for Unimpacted, MPB-2008 and MPB-2007 stand types but slightly higher ($p < 0.05$) for the MPB-2009 stand type. (From Biederman et al. 2013)

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BREVIA

Remotely-Sensed Climate Response to Forest Disturbance

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Maness, H., Kushner, P. J., and Fung, I. 2013. Summertime climate response to mountain pine beetle disturbance in British Columbia. *Nature Geoscience* DOI:10.1038/ngeo1642

The current mountain pine beetle (MPB) infestation in British Columbian forests ranks among the largest ecological disturbances recorded to date and may foreshadow similar scale outbreaks in North American forests over the coming decades. The associated dieback may result in substantial shifts in evapotranspiration and albedo, which alter the local surface energy balance, thereby affecting regional temperature and climate. Historically, the influence on regional scale climate of disturbances like this has been difficult to quantify through traditional *in situ* observations of surface fluxes, temperature and humidity. It is typically infeasible to monitor more than a handful of sites, and the disturbance signal is small relative to the local signature of large-scale climate variability, rendering few-year monitoring campaigns of limited utility for establishing statistically robust results. In Maness, Kushner & Fung (2013), we demonstrate the capability of remotely sensed observations to help overcome some of these difficulties, adopting as a test case the ongoing MPB disturbance in British Columbia.

Volumetric Forest Kill (%): 1999-2010

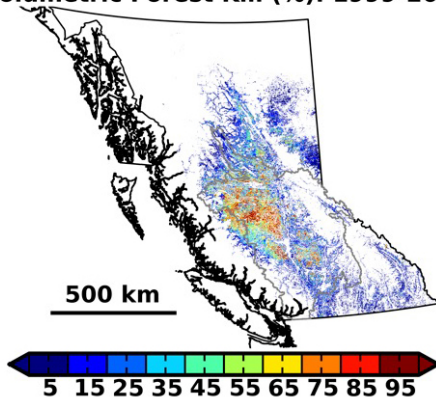


Figure 1 illustrates the utility of remotely sensed observations for quantifying the effects of disturbance on the regional scale. The map on the left shows cumulative volumetric forest mortality, $\Delta\Sigma$, taken from British Columbia forest survey data (Walton 2011). The plots on the right show time series of observed mortality (panel a) compared to those for remotely-sensed summertime evapotranspiration (panel b) and mid-day relative to night-time surface temperature (panel c). The time series average over the many locations shown in the map and over multiple years of disturbance; thus, the remotely sensed data enable an estimate of disturbance typical to the region and largely independent of interannual fluctuations. The latter is especially crucial because at each location interannual variability dominates over disturbance. To obtain the robust disturbance signal in Fig. 1, local time series are composited separately for different degrees of disturbance (percent mortality), are shifted in time according to the year of onset of the disturbance, and are averaged over multiple locations.

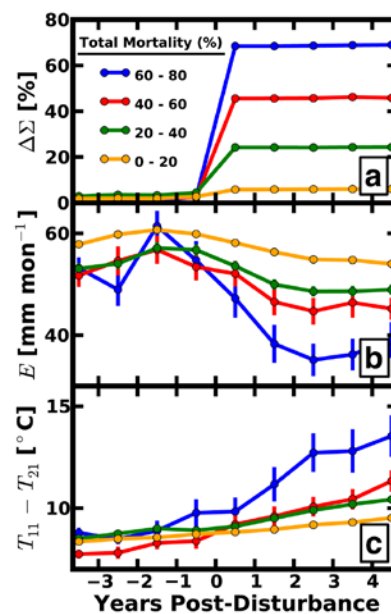


Figure 1. Left: Cumulative volumetric forest mortality, $\Delta\Sigma$, from forest survey data (Walton 2011). The Fraser River basin is outlined in grey. Right: Time series at the 1-km scale, averaged over multiple pixels and years and segregated by the degree of mortality. The time series match qualitative expectations: Increases in forest mortality (panel a) are accompanied by decreases in remotely-sensed evapotranspiration (panel b) and increases in daytime (11:00 LST) relative to nighttime (21:00 LST) surface temperature (panel c). The magnitude of the observed change depends on the level of mortality.

Figure 1 shows that, as expected, summer evapotranspiration declines in the years following forest mortality. Solar energy previously spent evaporating water heats the surface post-disturbance; a corresponding increase in the day-night temperature difference is therefore observed. These conclusions are also segregated by the degree of disturbance: the greater the mortality, the lower the evapotranspiration post-disturbance, and the greater the warming.

There are good reasons to be skeptical of any quantitative conclusions drawn from Fig. 1 alone. Remotely sensed observations require ground-truthing. Evapotranspiration in particular has a large uncertainty (~200-300%; Vinukolu et al. 2011), as it is estimated indirectly from characteristics of the land surface rather than through direct observation. The quantitative results in our study therefore rely significantly on the large quantity and variety of data available to test these results. For example, using remotely-sensed GRACE gravity measurements, gauge precipitation data, and gauge runoff data we verify that remotely-sensed evapotranspiration satisfies a closed water balance at the regional scale (Fig. 2). Published stand-level estimates of soil evaporation and forest transpiration in this region further give us confidence in the post-disturbance decreases observed in the evapotranspiration product. Finally, observations of remotely sensed albedo show that post-disturbance changes in summertime shortwave radiation are negligible in comparison to decreases in evapotranspiration. This finding, together with published flux tower observations, leads to the expectation of a known linear relationship relating the post-disturbance temperature change and the post-disturbance evaporative change. The MODIS remotely sensed data confirm this expectation (Fig. 3).

Altogether, our study derives a closed energy balance describing the summertime surface response to mountain pine beetle disturbance. The median fractional loss in forest volume post-disturbance is $\Delta f_{\text{live}} = 30\%$ (Fig. 1); this level of mortality corresponds to a 19% reduction in evapotranspiration, accompanied by a 1°C increase in summertime surface temperature (Fig. 3). Larger changes are observed in tree stands with higher mortality.

We expect this type of analysis will not be easily portable to other examples of disturbance in many locations. Our results indicate that in well-instrumented, well-studied regions such as the forests of British Columbia, it is becoming increasingly possible to empirically quantify the effect of the biosphere on regional climate. While our study relies heavily on globally available satellite observations (e.g., surface temperature, vegetation indices, albedo, gravimetric water storage), this work would not have been feasible without significant ongoing investment in *in situ* observations (e.g., routine forest inventory measurements, river and weather station monitoring, water-balance research at the stand-level, etc.). The varying degree of disturbance and the decade worth of extensive damage were of course unplanned but also important to our results.

In the future, it is our hope that analyses such as this will prove useful in evaluating and improving the representation of the biosphere in regional and global climate models. A concerted effort in this direction would demonstrate concretely the utility of long-term, diverse, and widespread observation networks. Such a demonstration could help make the argument to governments for a more comprehensive, coordinated, and standardized approach to biosphere monitoring.

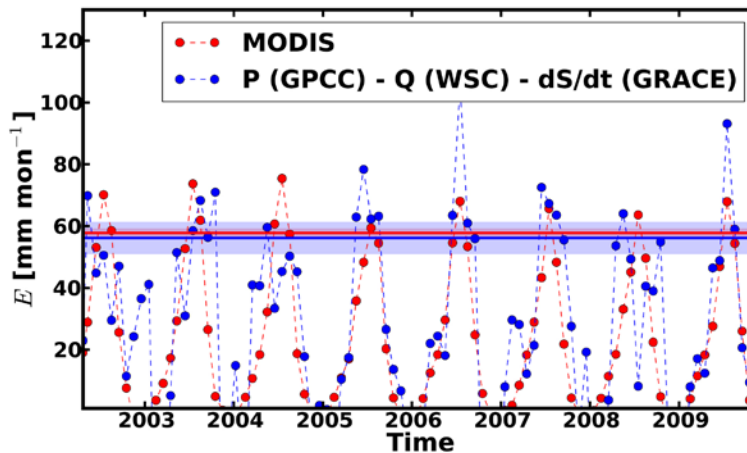


Figure 2. MODIS remotely-sensed evapotranspiration over the Fraser river basin (Fig. 1) compared to that expected from water balance, adopting precipitation (P) and streamflow (Q) gauge data and GRACE satellite storage data (dS/dt). The red and blue horizontal lines indicate the average summertime evapotranspiration calculated from the two time series, with translucent bars (corresponding colors) indicating the error in these climatologies. This comparison shows the MODIS evapotranspiration satisfies a closed water balance at the regional scale.

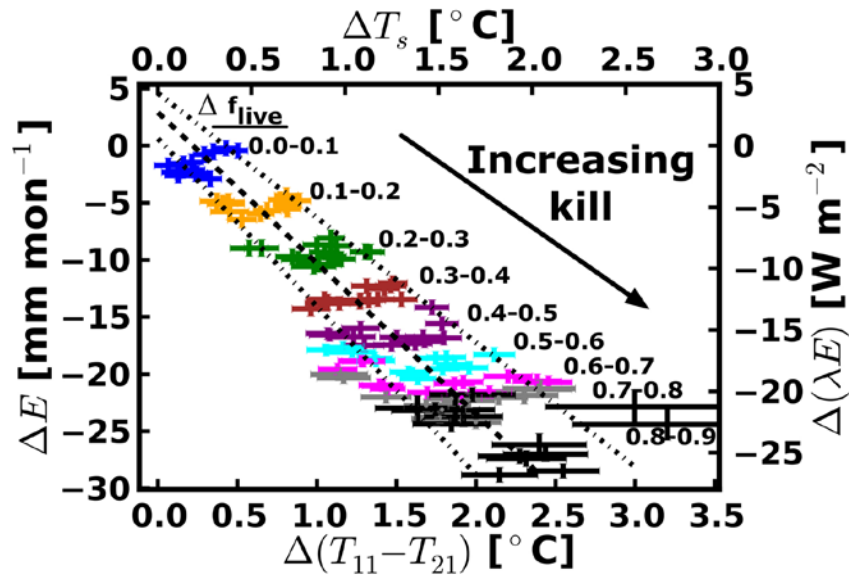


Figure 3. Post-disturbance change in remotely-sensed summertime evapotranspiration against changes in day (11:00 LST) relative to night (21:00 LST) surface temperature. Conversions to the average daily temperature change and latent heat flux change are indicated at the top and right, respectively. The fractional change in forest volume is denoted by Δf_{live} . The data confirm the linear relationship expected from analysis of the surface energy balance. Moreover, the slope of the best-fit line (thick dashed line) is in agreement with that expected from previously published flux tower results reported for evergreen forests. The remotely-sensed data therefore satisfy a closed surface energy balance.

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Lupinus sp. Photo: J. Blanchard

Rephotographing Glaciers on the Volcanoes of the Pacific Northwest

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Perched high on a cliff overlooking South Tahoma Glacier in Mount Rainier National Park with my tripod precariously standing near the edge, I saw something through my camera viewfinder that puzzled me. My goal was to recreate the vantage of a historical photograph taken over a century ago for the Glacier Rephoto Project. The cramped conditions on the small ledge were made worse by tree branches that were not present in the photograph taken over a hundred years ago. I glanced back and forth between the printed photograph and the scene before me. I expected the glacier to have retreated, but the magnitude of retreat gave me pause. The South Tahoma Glacier had retreated two miles up the slopes of Mount Rainier. Witnessing the glacier retreat from the ground can be a profound experience which can be difficult to convey in words. An excellent alternative to being in the actual location is the pairing of historical and modern photographs, known as repeat photography (Fig. 1).

Glacier change is the most visible sign of climate change in alpine regions. Glaciers are sensitive to long-term changes in snowfall and air temperature, and respond by shrinking or expanding. Over the past century, temperate glaciers have been shrinking in response to a changing climate (Dyurgerov and Meier 2000, McCabe and Fountain 2013). Knowledge of historical glacier fluctuations can provide important information about past cli-

mates in remote regions. Historic glacier photographs provide insights into past climates by capturing the glacier's extent and physical character. Repeat photography is particularly helpful to determine how glaciers have changed. Some camera locations, or photo stations, have been visited multiple times over the past century providing a useful time series of glacier change. The results provide a virtual time machine, allowing past and present conditions to be compared. The photographs can assist scientists in quantifying glacier change (Hoffman et al. 2007, Basagic and Fountain 2011).

Repeat photographs of glaciers have been collected intermittently by various individuals and organizations over the past century. However, because no comprehensive compilation of repeat photography exists for the American West, the photographs remain scattered in various photo collections, archives, and reports, resulting in a fragmented view of the glacier change story. This fragmentation makes unclear which glaciers have a history of repeated photographs and when they were taken.

The Glacier Rephoto Project is compiling existing photographic records in the American West and updating the record by rephotographing some of the glaciers. The resulting database centralizes the photographs and will include information on trail access and



Figure 1. The South Tahoma Glacier terminus was covered by rock debris and surrounded by forest in 1906. The glacier has retreated two miles up the side of Mount Rainier over the past century. (1906 by unknown photographer, Library of Congress; Sept. 19, 2012 rephotograph by H. Basagic)

photo station coordinates that will make future rephotography easier. The database will be available on the world-wide-web so that scientists and the general public can download the images and initiate their own record of glacier change. This past year was spent working on compiling photographs and developing the database for glaciers of the Pacific Northwest between Mount Shasta, CA and Mount Baker, WA.

Methods

Glacier repeat photographs and associated metadata (photographer, date, and location) were inventoried from archives, photo collections, and reports, and then compiled into a database. The location of any photograph without coordinates was initially estimated using Google Earth and aerial photography. These coordinates assisted in planning how to access the photo stations in the field.

In September and early October of 2012, I visited Mount Shasta, Three Sisters, Mount Hood, Mount Adams, Mount Rainier and Mount Baker. Each volcano had a unique glacier photo record. On Mount Shasta, I set out to reoccupy photo stations established by Philip Rhodes in the 1970s. I was fortunate to meet up with Rhodes for the first day of photographic surveys on Hotlum Glacier. Rhodes was invaluable in describing routes to stations and sharing his observations. At Mount Hood, I retraced the steps of H.F. Reid who first established the photo record in 1901 (Reid 1906). Smoke from a forest fire on Mount Adams made good photography impossible at Mount Adams, and reminded me that random events including weather can get in the way. Numerous photo stations were discovered at Mount Rainier, a product of

monitoring efforts by the National Park Service and U.S. Geological Society (Veatch 1969). Few photo stations were established at Mount Baker, but several new repeat photos were established from historical photographs.

Few stations had known coordinates, and, because of this, relocating them in the field was exciting and at times frustrating. The search was initially guided by the coordinates estimated from Google Earth. Once at the approximate location, the exact location was determined by aligning landscape features in the historical photograph and matching them in the field view (Harrison 1974). Access to the photo stations varied greatly from short walks on paved trails to overnight cross-country trips.

Results

I reoccupied 40 photo stations on the volcanoes of the Pacific Northwest and established 15 new photo stations based on historical photographs. When combined with my previous work in the Sierra Nevada of California, the database now contains 100 photo stations. Twelve stations were not able to be photographed as the stations were either destroyed by erosion or overgrown with vegetation. The 2012 rephotographs were added to the database, which now contains a total of 975 images.

Overall, the repeat photographs reveal the change (loss) in glacier area and volume, changes in tree-line, and, to some degree, erosion, over the twentieth century. All glaciers photographed are smaller now than a century ago. Many glaciers did advance somewhat during the 1960s and 1970s. Most of this advance appears to have been erased over the past several decades, with the

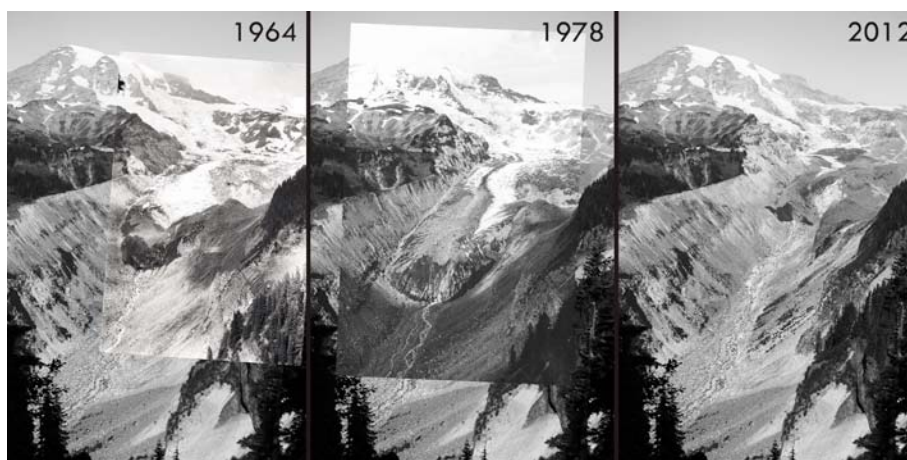


Figure 2. A three frame sample from the database illustrates the advance of the Nisqually Glacier on Mount Rainier in the 1960s and 1970s, followed by glacier retreat in the 1990s and 2000s. (Sep 9, 1964 by F. M. Veatch, National Snow and Ice Data Center; 1978 by D.R. Crandell, U.S. Geological Survey; Sep. 20, 2012 rephotograph by H. Basagic)

exception of a few glaciers, including Whitney Glacier on Mount Shasta. One of the benefits of the photo database is comparing multiple photos taken over the past century to determine when changes have occurred. A time lapse view can be produced for photo stations with numerous repeat photos at a frame rate interval of years to decades (Fig. 2).

Pioneer vegetation has begun to occupy higher elevations including the area vacated by glacier retreat, especially at the higher latitude volcanoes of Mount Rainier and Mount Baker. Some photos show erosion of moraines, particularly at Eliot Glacier on Mount Hood, and this is to be expected due to the oversteepened walls on the glacier-side of the moraine and the frequency of human traffic over these features (Fig. 3).

Glacier repeat photography can be an important tool for communicating climate change in a direct visual manner and assists scientists in quantifying glacier change. The photos relay information that the climate is not only changing in distant faraway places but also within the western US. Immediate plans for the Glacier RePhoto Project are to document other glacier regions in the American West. The database would make a great platform for other regions in the world as well.

This project is conducted in collaboration with Andrew Fountain and the Glaciers of the American West project at Portland State University ([//glaciers.us](http://glaciers.us)), and received funding from the Mazamas, a climbing organization in Portland, Oregon, in a 2012 Mazama Research Grant, and from an American Alpine Club Nikwax Alpine Bellwether Grant.

Check out more photos and maps on the web: <https://rephoto.glaciers.us>

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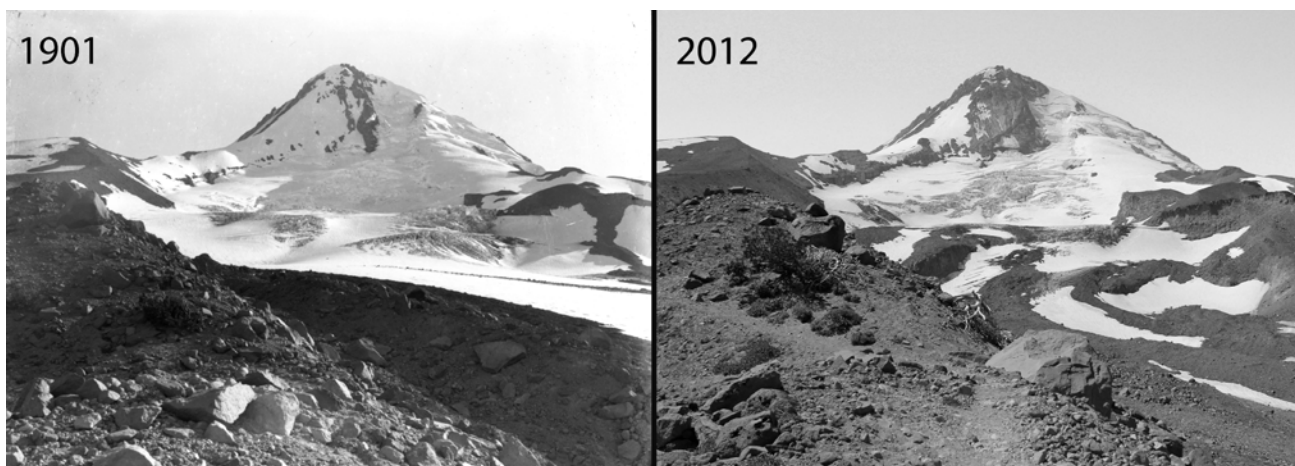


Figure 3. The Eliot Glacier on Mount Hood. In addition to the loss of ice, the lateral moraine has eroded and a hikers trail now crosses through the frame. (1901 photograph by H.F. Reid, National Snow and Ice Data Center; Sep 16, 2012 rephotograph by H. Basagic)

A 350-Year Record of Glacier Change in the North Cascades Region, Washington State, USA

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Glaciers exist on nearly every continent, and the World Glacier Monitoring Service (WGMS), which collects glacier data from all over the world, has observed worldwide trends in glacial ice loss in recent decades (WGMS 2008). In North America, glaciers are found in Alaska, the Canadian and U.S. Rockies, Pacific Coast ranges, and even in Mexico. Many of these glaciers are in the Pacific Northwest (PNW) region of North America and have been rapidly receding since the mid-1970s. The North Cascades region in Washington State (USA) contains more than half of the glaciers in the continental U.S., but since 1900, glacial area in the mountain range has decreased by 46% (McCabe and Fountain 2013). South Cascade Glacier (SCG; Fig. 1) is an alpine glacier in the North Cascades that is used as a benchmark glacier by the U.S. Geological Survey (USGS) and has retreated 0.7 km and lost around 1 km² in area since measurements began in 1959 (Bidlake et al. 2010; Fig. 2).



Figure 1. South Cascade Glacier, North Cascade Range, Washington

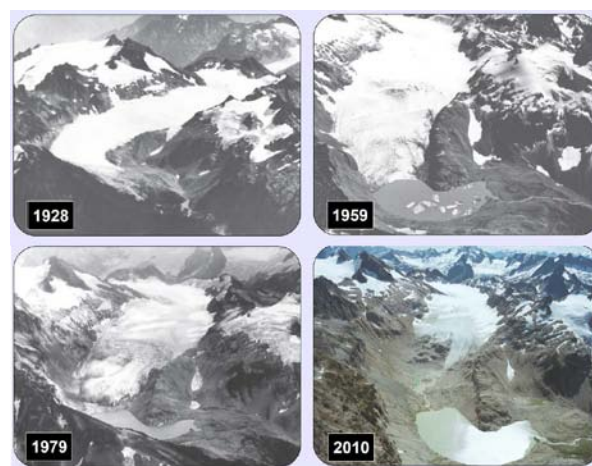


Figure 2. Changes in South Cascade Glacier over time. Photos taken in 1928, 1959, 1979, and 2010. Photo from USGS, http://ak.water.usgs.gov/glaciology/south_cascade/comparison.html.

In order to investigate recent ice loss trends in the PNW in the context of a longer record, we reconstructed SCG net, winter, and summer mass balance from mountain hemlock growth chronologies in the North Cascades (Marcinkowski and Peterson, in review; Fig. 3). Glacial ice dynamics are typically assessed through mass balance measurements, which react seasonally to changes in temperature and precipitation. Summer temperature and winter precipitation drive mass balance changes, but atmospheric circulation anomalies and sea surface temperatures and pressures also influence glacier mass balance (Hodge et al. 1998, Bitz and Battisti 1999). Tree growth responds to similar climatic variables as glacier mass balance and can be used as a proxy to reconstruct mass balance (e.g. Lewis and Smith 2004, Larocque and Smith 2005). Mountain hemlock (*Tsuga mertensiana*) grows at high elevations, experiences similar climate as glaciers, and can live for several hundred years, making it an ideal candidate for glacier reconstructions.

Standard dendrochronological procedures were followed when creating the mountain hemlock growth chronologies (Stokes and Smiley 1968), and principal components analysis (PCA) was conducted on the four chronologies to identify a commonality

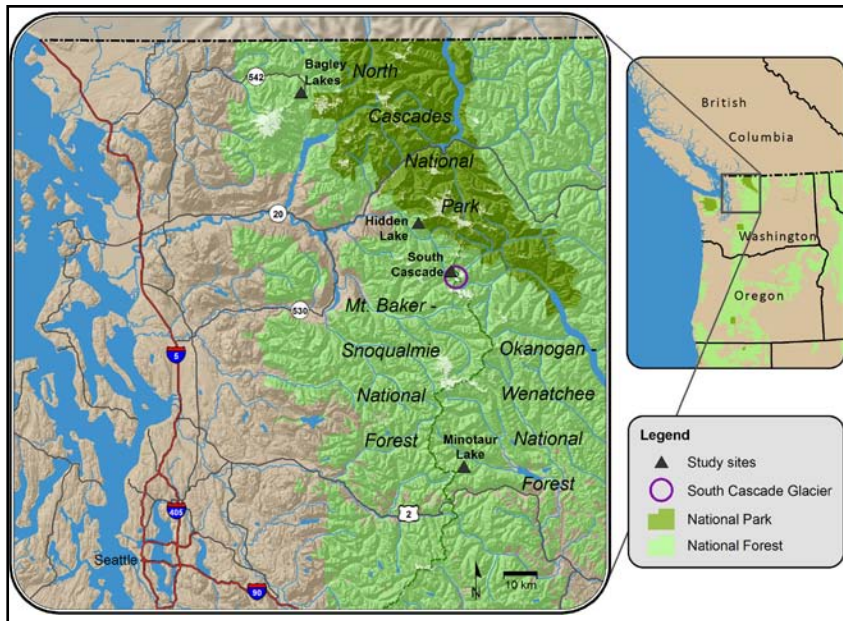


Figure 3. (above) Map of sampling sites. Triangles represent sampling locations. Purple circle represents the location of South Cascade Glacier. Shaded light green areas represent National Forests, and shaded dark green areas are National Parks. Map Credit: Rob Norheim. (upper right) South Cascade Glacier was a sampling location, and mountain hemlock trees were cored on the hillside across from South Cascade Lake. (lower right) Field crew coring mountain hemlocks at the Thornton Lakes site.

between the sites that might better represent changes in SCG mass balance. The chronologies and the net, winter, and summer SCG mass balance measurements were compared with monthly climatic variables using Pearson product-moment correlations. Correlations between tree growth and climate and mass balance and climate were examined in order to better understand the climatic variables that drive both growth and mass balance. Pearson product-moment correlations were also calculated between the chronologies and the mass balance measurements to determine if statistically significant ($p < 0.05$) relationships existed. Linear regressions were performed for each of the chronologies (including PC1) with net, winter, and summer mass balance measurements. Coefficients of determination (R^2) were the criteria for choosing the regression model for net, winter, and summer mass balance, and models were tested for autocorrelation with the Durbin-Watson (D-W) test and for skill in prediction with the Reduction of Error (RE) statistic.

The net balance reconstruction, created from the PC1 chronology, spans 350 years, from 1659 to 2009, the summer balance was reconstructed for 1346–2009 from the Hidden Lake chronology, and the Minotaur Lake chronology reconstructed the winter mass balance reconstruction for 1615–2009 (Fig. 4). These series are the longest and most up-to-date mass balance reconstructions for SCG.

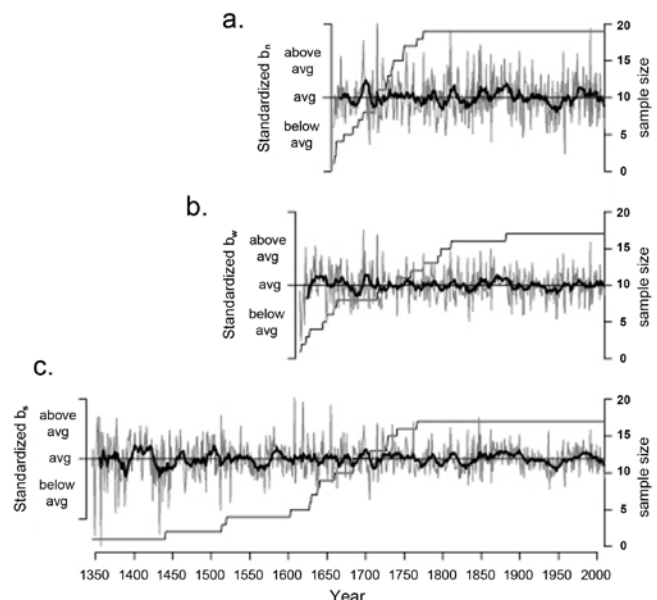


Figure 4. Time series plots of reconstructed net (b_n), winter (b_w), and summer (b_s) mass balance. Net balance (a) is reconstructed from PC1 for 1659–2009, winter balance (b) is reconstructed from the Minotaur Lake residual chronology for the span 1615–2009, and summer balance (c) is reconstructed from the Hidden Lake residual chronology, 1346–2009. The thick black line represents a 10-year moving average. Sample depth is indicated by the thin black line and the right side y-axis, where sample depth for (a) indicates the shortest chronology entered into the PCA.

Above- and below-average reconstructed balance for net, summer, and winter occurred during roughly the same time periods (Table 1). Comparison of SCG mass balance with other glacier balance reconstruction in the PNW revealed that above- and below-average periods at SCG were concurrent with similar periods at other glaciers (e.g. Larocque and Smith 2005, Malcomb and Wiles 2013). An emphasis is placed on the similarities in patterns between the reconstructions, because differing tree species, sampling locations, glaciers, and methods were used. Common above- and below-average patterns suggest that glaciers in the PNW are responding similarly to regional external forcings. As a USGS benchmark glacier, SCG is intended to be regionally representative of glaciers, and agreement among the reconstructions indicates that SCG mass balance changes are reflective of regional balance fluctuations and can be used to make broader inferences for the PNW.

Correlations between mass balance and winter precipitation, temperature, the Pacific Decadal Oscillation index, and the El Niño Southern Oscillation index indicate that these influence glacier balance at various temporal scales. Tree growth showed similar relationships with winter precipitation variables and circulation indices. Warm phases of PDO and ENSO correspond to lower mass balance and higher tree growth, and increased balance and decreased growth occur during cool phases. The reconstructed net balance matches the negative relationship found between the observed and index values (Fig. 5).

Rate of change was calculated for several time periods in which mass balance switched from above-average to below-average in the 10-year moving average of the reconstruction. The current rate of decline, from 2000 to 2009, in the reconstructed balance

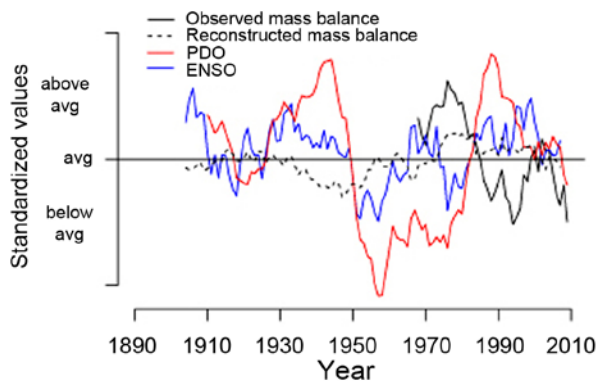


Figure 5. Time series plot of reconstructed net mass balance, observed net mass balance, average winter Pacific Decadal Oscillation (PDO) index values, and average winter Niño 3.4 (ENSO) index. The series are displayed as a 10-year moving average.

Above-average time periods	Below-average time periods
1690-1710, 1810-1820, 1845-1860, 1865-1890, 1970-1985	1680-1690, 1790, 1810, 1825-1840, 1925-1955

Table 1. Approximate common above- and below-average periods between net, summer, and winter reconstructed South Cascade Glacier mass balance.

record has been faster than any decline in a century. With temperatures in the PNW projected to increase, on average, 0.3°C per decade in the 21st century (Mote and Salathé 2010), this decreasing trend is expected to continue.

Increasing temperatures and decreasing mass balance will affect glacier-influenced water resources in the PNW. Glaciers in the North Cascades Range yield around 800 million m³ of runoff annually (Post et al. 1971), and many PNW streams and lakes are fed by this meltwater. Glaciers influence on low-flow periods like summertime, and glacier-fed streams in the PNW have experienced a decline in late summer flow during the last few decades that is predicted to intensify with continued glacial retreat (Stahl and Moore 2006, Moore et al. 2009, Nolin et al. 2010, Pelto 2011). Glacier retreat is also expected to cause increases in stream temperature, changes in sediment flow, and decreased water quality (Moore et al. 2009), affecting the habitat, reproduction, and food supply of aquatic organisms. The negative effects of glacier decline on water resources will complicate water-use planning, and municipalities, hydroelectric power plants, agricultural irrigation, and wildlife managers will be challenged to mitigate these changes.

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Sun cups, N. Sister icefields, Oregon. Photo: J. Blanchard

Climate Change Vulnerabilities and Adaptation in North Cascadia

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Addressing the effects of climate change is a priority for the U.S. Forest Service (USFS) and National Park Service (NPS), and both agencies are increasing organizational capacity to develop science-management partnerships, educate employees, assess vulnerability, and implement adaptation options. The USFS and NPS initiated the North Cascadia Adaptation Partnership (NCAP) (<http://northcascadia.org>) in 2010 to (1) increase climate change awareness among agency staff and partners, (2) assess vulnerability of natural and cultural resources and infrastructure, and (3) develop science-based adaptation options to reduce adverse effects of climate change and ease the transition to new climate states and conditions. The partnership brings together scientists and resource managers in the region, expanding previous adaptation case studies on federal lands to a larger, more ecologically and geographically complex landscape (Raymond et al. 2013, Raymond et al. in press).

Vulnerability assessment and adaptation planning focus on two national forests (Mount Baker-Snoqualmie and Okanogan-Wenatchee) and two national parks (Mount Rainier and North Cascades) in and adjacent to the North Cascade Range, Washington (USA), which comprises a land area of 2.4 million ha, making it the largest science-management partnership of its kind. The partnership includes other local, state, and federal agencies, academic institutions, non-governmental organizations, and tribes.

Biogeographic Setting and Climate

On the west side of the Cascade Range, a temperate, maritime climate dominates, and annual precipitation ranges from 100 to over 250 cm. On the east side of the Cascades, the climate is more continental, and annual precipitation is as high as 130 cm near the crest and as low as 25 cm east of the crest. Regionally, most precipitation falls in winter (about 70% or more of the annual total) and relatively little falls in summer (less than 30%). West of the Cascade Range, the Pacific Ocean and Puget Sound moderate the climate, keeping winters relatively warm and summers relatively cool compared to the east side. Elevation gradients and variable temperature and moisture regimes create

many different ecosystems in the North Cascades, including dry coniferous forests, temperate coniferous rainforests (Fig. 1), subalpine forests, riparian forests, subalpine meadows, and alpine tundra.



Figure 1. Temperate coniferous rainforest typical of westslope mid-elevation ecosystems of the North Cascadia region.

The region contains a complex system of streams, rivers, lakes, and wetlands fed by extensive glaciated areas, permanent snowfields, and high winter precipitation (Figs. 2, 3). Waterways in the region provide water and hydroelectric power for downstream communities, including the Seattle-Tacoma metropolitan area. They also provide habitat for salmon and other cold-water fish species. The region includes an extensive network of roads and trails that intersect waterways in numerous locations with bridges and culverts that must be managed to maintain access and reduce impacts on aquatic habitat.

Global climate model simulations for the A1B emissions scenario indicate that temperature in the region is expected to increase on average by 2.1°C by the 2040s, and 3.8°C by the 2080s, with the largest increases projected for summer (Mote and Salathé 2010). Seasonality of changes in temperature is important for understanding effects on hydrology, snowpack, and ecological processes. Small increases in precipitation are projected for all seasons except summer. Changes in seasonal precipitation

would have significant effects on hydrological processes such as streamflow, snowpack, and soil moisture.

In the North Cascades, one of the most significant changes will be a shift to more winter precipitation falling as rain rather than snow, leading to reduced snowpack, earlier snowmelt, and shifts in the timing of peak streamflow from late spring or early summer snowmelt events to late autumn and early winter (Elsner et al. 2010). These effects will be most pronounced in mid-elevation river basins where winter precipitation currently falls as a mix of rain and snow. Extreme flood events associated with peak flows are projected to increase throughout much of the North Cascades.



Figure 2. Rainy Pass in the high North Cascadia is typical of the headwaters cirques that provide water and other downstream ecosystem services.



Figure 3. Watersheds and their main stem river courses supply water to the large lowland Puget Sound metropolitan region, as well as supporting diverse mountain mesic ecosystems. Photo: R. Minear.

Developing the Science-Management Partnership

The North Cascades has a complex history of land use and ownership, and although much of the area is managed by the USFS and NPS, a regional response to climate change is important because of the diversity of adjoining land ownerships (Fig. 4). The NCAP focused on a two-way dialogue in which scientists shared the latest scientific information on climate change, and managers shared expert knowledge on their local systems and management practices (Littell et al. 2011). Through this dialogue, participants identified climate change vulnerabilities and adaptation options to reduce these vulnerabilities. One-day educational workshops on climate change, one for each national forest and national park, initiated the NCAP process. Scientists presented the latest scientific information on projected changes in climate and effects on natural resources, providing an opportunity for resource managers to interact with climate change scientists, voice current and future management challenges, and develop a common understanding of local climate change effects on natural resources.

Building on the educational component of NCAP and projected changes in climate, we assessed the vulnerability of natural resources, infrastructure, and current management objectives through a series of four 2-day workshops focused on (1) hydrology, roads, and access; (2) vegetation and ecological disturbances; (3) wildlife and wildlife habitat; and (4) fish and fish habitat. USFS and NPS managers emphasized concerns about changes in ecological disturbances (fire and insects) and challenges associated with maintaining road and trail access for the large numbers of recreational users that visit the area.

We used a review of the scientific literature and expert knowledge to assess vulnerability, focusing on effects and projections specific to the NCAP region. To assess adaptive capacity, we reviewed current USFS and NPS management objectives and practices to determine opportunities and barriers for adapting to climate change and information needs for building agency capacity to respond to climate change. After identifying key vulnerabilities, we used facilitated discussions to identify potential adaptation options. We went beyond general concepts to identify specific actions that could be implemented into projects and plans.

For each resource sector workshop, participants identified strategies (general approaches) and tactics (on-the-ground actions) for adapting management practices. Adaptation strategies included actions to create resistance, promote resilience of resources and ecosystems, and enable natural and built

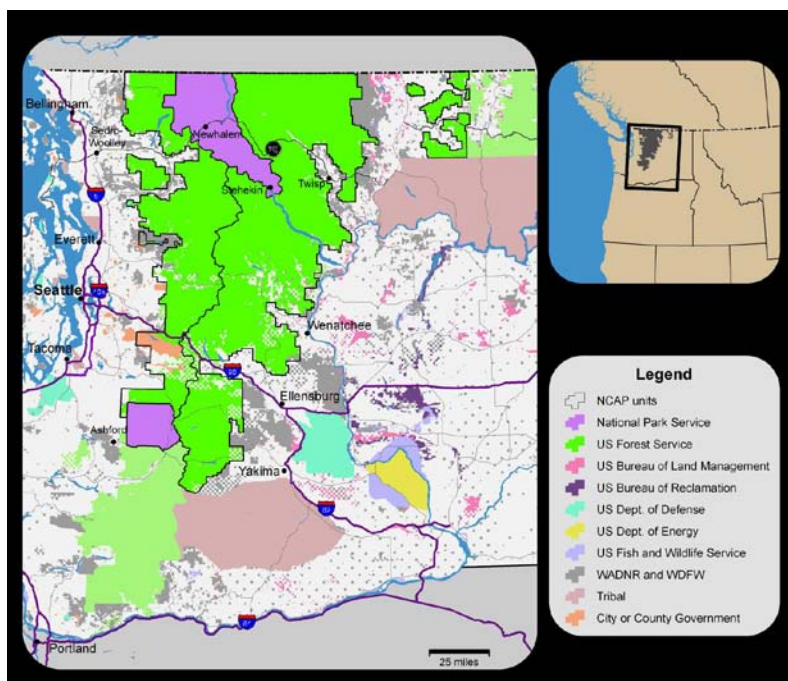


Figure 4. U.S. Forest Service and National Park Service lands compose the focal area of the NCAP, but these lands are surrounded by other municipal, state, federal, private, and tribal ownerships. The NCAP includes many of these stakeholders in an effort to use an “all lands” approach to adapting to climate change. Map by Robert Norheim.

systems to respond to changes in climate (Millar et al. 2007). Participants generally focused on adaptation options that could be implemented given current scientific understanding of climate change effects, but they also identified research and monitoring that would benefit future efforts to assess vulnerability and adapt management practices.

Vulnerabilities and Adaptation to Climate Change

Over 300 USFS and NPS employees from all sectors of the workforce and stakeholders attended the workshops. The two-day workshops for each of the four resource sectors further built organizational capacity by providing detailed information on climate change science and effects on specific resources. These workshops were attended by a smaller group of resource specialists, specifically tasked with considering climate change in management actions. During the workshops, resource specialists were also introduced to principles, tools, and processes for assessing vulnerability and adaptation planning.

We focused as much on partnership and process as on products because of the importance of partnerships in successful agency responses to climate change. The NCAP built capacity to respond to climate change challenges that cross jurisdictional boundaries

by increasing interaction among managers from different agencies who are working on similar challenges, thus strengthening collaboration between agencies and developing a coordinated regional response to climate change.

Vulnerabilities and Adaptation Options for Roads, Trails, and Sustainable Access

The transportation system in the North Cascades is inherently sensitive to climate change. Many forest roads were not built with the intention that they would be permanent and were not constructed to design standards promoting longevity. For example, many culverts were designed to withstand only a 25-year flood. Roads and trails were also built in valley bottoms and along waterways to avoid steep, rugged terrain. Managers are already coping with a backlog of flood-related damage from extreme flood events and large landslides in the last decade.

Higher peak flows in autumn and winter (Hamlet and Lettenmaier 2007, Tohver and Hamlet 2010) will increase flood risk to roads, trails, stream crossing structures, and infrastructure. Increased soil moisture in winter is likely to reduce slope stability and increase the likelihood that landslides and slope failures will damage roads and trails. Reduced snowpack and earlier snowmelt will increase the length of the snow-free season (Elsner et al. 2010), potentially increasing visitation early and late in the season. Lower low flows in summer will reduce water availability. Adaptation strategies and tactics to reduce these vulnerabilities include actions to resist the effects of flooding, increase the resilience of the transportation system, and facilitate the transition to systems that can be sustained under new climatic conditions (Table 1).

Vulnerabilities and Adaptation Options for Vegetation and Ecological Disturbances

Workshop participants identified several changes in climate that will have implications for vegetation and ecological disturbances. Warmer temperatures and decreased snowpack, without increases in summer precipitation, will cause a longer duration of low soil moisture throughout most of the North Cascades (Elsner et al. 2010). Warmer temperatures will also increase potential evapotranspiration, the amount of water that can be evaporated from land and transpired from plant tissues. When potential evapotranspiration exceeds actual evapotranspiration, water balance deficit exists. Water balance deficit is projected to

Table 1. Adaptation strategies and tactics for transportation and access in the North Cascades. Adaption tactics are examples only; for comprehensive list, see Raymond et al. (2013, and in press).

Adaptation strategy	Adaptation tactics
Increase resistance to higher peak flows where waterways cross roads.	• Install hardened stream crossings. • Continue to use grade control structures, humps, and water bars to reduce velocity and redirect flow.
Increase resilience of stream crossings, culverts, and bridges to higher peaks flows	• Continue to replace culverts with higher capacity culverts. • Prioritize structure replacement in high risk (mid-elevation) basins. • Continue to upgrade trail bridges with stronger rot resistant materials.
Facilitate response to higher peak flows by reducing the road and trail system.	• Reroute roads and trails and move infrastructure out of floodplains. • Continue to decommission roads and trails with high risk and low access. • Change user expectations of access with public outreach and education.
Increase resistance to landslides by protecting roads and infrastructure.	• Increase road and trail maintenance frequency. • Stabilize slopes mechanically or with vegetation. • Improve drainage.
Facilitate response to higher landslide risk by relocating infrastructure out of high risk areas.	• Decommission roads and trails with low access and high landslide risk. • Locate new construction away from areas of high landslide risk.
Maintain safe access at beginning and end of the summer.	• Increase public education on the risks of early and late season access. • Limit access when public safety is a concern.
Maintain sufficient water supply to meet demand during low flows.	• Investigate alternative water sources (e.g. groundwater). • Consider constructing new wells, cisterns, and reservoirs.
Increase resilience to low dry-season flows with water conservation.	• Educate the public about water shortages and conservation and reduce user expectations of water availability. • Reduce campground capacity and close facilities to decrease water demand

increase in the eastern part of the region and locally increase or decrease in the western part.

Most low-elevation forests that currently experience water limitations will likely experience more severe or longer duration water limitation in the future. The short-term effects on water-limited forests will likely be decreased seedling regeneration and tree growth and increased mortality (especially for seedlings). Moisture stress will likely increase tree vulnerability to insects and some pathogens. Warmer, drier summers in the North Cascades will almost certainly increase the area burned by fire (Littell et al. 2010), and may also increase the frequency, size, and severity of fires (Fig. 5).

In contrast, current energy-limited forests in the North Cascades will likely become less energy limited, and the effects of climate change will depend on the degree of seasonal water limitation. Increased length of the growing season, warmer temperatures, and increased soil moisture will lower environmental barriers to tree establishment in subalpine and alpine ecosystems. Loss of tundra, expansion of tree islands in the subalpine ecosystems, and

rising treelines may be the most visible changes in high-elevation forests (Rogers et al. 2011).

In response to these vulnerabilities, workshop participants identified adaptation strategies and tactics to increase the resilience of forest and subalpine ecosystems (Table 2). The sensitivity of forest ecosystems to water limitations and fire and insect disturbances is exacerbated by current stressors, so adaptation tactics focused on reducing these stressors. In historically fire-adapted forests, the effects of climate change will depend on the degree to which past harvesting and fire exclusion have affected stand density and species composition (Hessburg et al. 2005). Climate-driven increases in insect outbreaks and fire will likely be more evident in forests where tree density and fuels are sufficiently developed and fire intolerant species have increased in abundance.

Vulnerabilities and Adaptation Options for Wildlife and Wildlife Habitat

Many animal species in the North Cascades are adapted to cold wet winters and warm dry summers. Some animal species will be less vulnerable to a warmer climate because they are generalists, are less physiologically sensitive to changes in temperature and moisture, can more easily disperse to new locations, or occupy habitats that are likely to be more resilient to climate change. Specialist species that have limited dispersal, narrow climatic niches, or rare habitats are likely to be



Figure 5. Wildfires such as the 2006 Tripod Fire in the North Cascades demonstrate the type of burn patterns likely in a warmer climate. Photo: R. Harrond.

Table 2. Adaptation strategies and tactics for vegetation and disturbances in the North Cascades. Adaptation tactics are examples only; for comprehensive list, see Raymond et al. (2013, and in press).

Adaptation strategy	Adaptation tactics
Increase resilience of forests to disturbances by increasing tree vigor.	• Thin to decrease stand density and increase tree vigor. • Plant resistant species or genotypes. • Increase stand-scale biodiversity and minimize monocultures.
Increase resilience to large and extensive fires and insect and pathogen outbreaks.	• Design forest gaps that create establishment opportunities. • Increase diversity of patch sizes.
Plan and prepare for more frequent and severe fire and greater area burned.	• Consider climate change in fire management plans. • Anticipate more opportunities to use wildfire for resource benefits. • Manage for future range of variability in structure and species.
Increase ecosystem resilience through post-fire management.	• Consider climate change in post-fire rehabilitation. • Anticipate greater need for seed sources and propagated plants.
Prevent invasive species establishment after disturbances.	• Include invasive species prevention strategies in all projects. • Increase regular inventory to detect new populations and species.
Increase resilience by promoting native species and adapted genotypes of native species.	• Consider assisted migration. • Emphasize use of species in restoration projects that will be robust to changes in climate.
Increase understanding of changes in plant species function and distributions in alpine and subalpine ecosystems.	• Monitor and attribute changes in tree distribution and establishment patterns at treeline. • Expand long-term subalpine and alpine monitoring programs.

by snowpack in the winter and short growing seasons in summer, will likely decrease as lower snowpack and longer growing seasons facilitate tree establishment. Drier meadows may also experience tree encroachment; however, these meadows may be maintained by more fire. Loss of meadows would reduce habitat for species such as American pika, hoary marmot, and Cascade red fox.

Vulnerabilities and Adaptation Options for Fish and Fish Habitat

Fish populations and habitats will be affected by changes in timing and increased magnitude of peak flows, lower low flows in summer, and warmer water temperatures. Peak flows in winter are projected to increase for many watersheds in the North Cascades, particularly in mid-elevation basins that receive winter precipitation as both rain and snow (Elsner et al. 2010, Mantua et al. 2010). Increases in the magnitude of winter flooding will likely reduce egg-to-fry survival rates for pink, chum, sockeye, chinook, and coho salmon due to increased intensity

more vulnerable. In both wet maritime forests and dry fire-adapted forests in the North Cascades, altered disturbance regimes will be an important vulnerability. More area burned by wildfire will indirectly affect wildlife by altering food resources, thus decreasing area and connectivity of late-successional forest habitat and increasing early-successional habitat. These changes will benefit species that are well adapted to fire-prone habitat, but reduce habitat for the endangered northern spotted owl and marbled murrelet which require late-successional forests. Many adaptation options for management of wildlife habitat are complementary to adaptation options for managing vegetation (Table 3).

The combined effects of warmer summer temperatures, changes in seasonality of precipitation, and reduced snowpack may cause earlier drying of ephemeral streams and ponds and receding shorelines (Corn 2005). Amphibian species that depend on wetland habitats are expected to be some the most sensitive species to changes in climate because of their permeable skins and moisture requirements, as well as their bi-phasic life histories requiring water for breeding and upland habitats for other activities. Tactics to facilitate adaptation for wetland species include reducing non-climatic threats and increasing the resilience of wetland habitats to changes in temperature and moisture regimes (Table 3). Wet montane meadows, maintained

Table 3. Adaptation strategies and tactics for wildlife and wildlife habitat in the North Cascades. Adaptation tactics are examples only; for comprehensive list, see Raymond et al. (2013, and in press).

Adaptation strategy	Adaptation tactics
Increase resilience of late-successional habitat in wet maritime forests.	• Increase diversity of age-classes and restore patch mosaic. • Thin to accelerate development of additional late-successional habitat in matrix land outside of reserves.
Increase resilience of late-successional forests and surrounding habitat in dry fire-adapted forests.	• Increase resilience of forests with thinning and prescribed burning. • Increase fuel reduction treatments in urban growth boundaries. • Increased use of wildfire for ecological benefits.
Increase resistance of late-successional habitat in fire-adapted forests strategically across a large region.	• Protect remnant habitat from fire and insect outbreaks. • Manage and plan for growth in the wildland-urban interface
Increase habitat connectivity and permeability in fire-adapted forests.	• Increase use of conservation easements. • Increase road closures and restrictions on access in critical habitats. • Accept loss of some ecosystem components to protect others.
Increase amphibian resilience by reducing non-climatic stressors.	• Remove exotic fish. • Maintain hydrology of critical habitats. • Increase habitat connectivity and heterogeneity.
Increase amphibian resilience to pathogens.	• Manage for decreased snowpack. • Limit recreation and other use through restrictions or closures
Increase resilience of wetland habitat to altered temperature and hydroperiod by enhancing breeding sites.	• Use vegetation to increase shading of wetlands and microhabitats. • Increase microhabitat structures (e.g. woody debris) for microclimate refugia, nesting habitat, and egg deposition structures.
Protect montane habitat for American pika, hoary marmot, and Cascade red fox.	• Monitor tree establishment in montane meadows. • Remove trees from meadows using fire and mechanical treatments. • Restrict visitors around montane meadow habitats
Increase population resilience of subalpine-dependent species.	• Increase education and regulatory enforcement to prevent adverse human-wildlife interactions. • Augment currently stressed populations of mountain goats from populations that are larger and more robust.

Table 4. Adaptation strategies and tactics for fish and fish habitat in the North Cascades.

Adaptation strategy	Adaptation tactics
Increase spawning habitat resilience to higher peak flows by restoring stream and floodplain structure and processes.	• Restore stream and floodplain complexity. • Increase protection of alternative spawning habitat. • Protect habitat by increased use of engineered log jams where feasible.
Increase habitat resilience to higher peak flows by reducing threats from roads and infrastructure in the floodplain.	• Designate and restore natural floodplains and associated habitat. • Reduce road density near streams. • Increase culvert capacity.
Increase aquatic habitat resilience to low summer flows.	• Increase off-channel habitat in side channels and channels fed by wetlands. • Protect wetland-fed streams that maintain higher summer flows.
Manage vegetation to retain water and snow, slowing spring runoff.	• Increase forest cover to retain snow and decrease snow melt. • Restore wetlands that have been altered by past management.
Increase habitat resilience for cold-water fish by restoring structure and function of streams.	• Protect wetland-fed streams that maintain higher summer flows. • Remove dikes and levees. • Restore and protect riparian vegetation.
Increase understanding of thermal heterogeneity in streams and cold-water refugia.	• Inventory cold water refugia, springs, and groundwater input to streams. • Identify seasonal refugia (winter and summer). • Study how fish use thermal refugia.
Increase resilience of native fish by reducing barriers to migration and removing nonnative species.	• Remove or control nonnative fish species. • Assess migration barriers and potential new habitat for native species. • Remove barriers to fish passage where this will not increase threats from nonnative species.

and frequency of redd and egg scouring, although the effects of higher peak flows in winter will differ across species and populations. Higher peak flows can also reduce availability of slow-water habitats, which can flush rearing juveniles downstream from preferred habitats and reduce freshwater survival rates. Adaptation tactics to increase habitat resilience to higher peak flows include restoring spawning habitat and removing migration barriers, thereby increasing access to more spawning habitat (Table 4).

In combination with higher summer water temperatures, reduced summer flow will limit rearing habitat for salmon with stream-type life histories (in which juveniles rear in freshwater for one or more years) and increase mortality during spawning migrations for summer-run adults. Adaptation tactics to increase resilience of aquatic habitat to low summer flows include restoring structure and function of stream channels and managing upland vegetation to retain snow and water, thereby slowing spring runoff (Table 4). Future air and water temperatures in August on the west slopes of the North Cascades are likely to be high enough to move streams from favorable to stressful categories of thermal rearing habitats for salmonids, but a few sites remain favorable (Mantua et al. 2010). Climate change is also projected to increase the frequency and persistence of thermal migration barriers. It is likely that

a warmer climate will reduce the availability of cold-water refugia in some North Cascades basins, making it imperative to reduce thermal stress on fish populations and protect cold-water refugia (Table 4).

Accomplishments and Next Steps

The NCAP made significant progress in responding to climate change on public lands in the North Cascades region, enabling national forests and national parks to accomplish several elements of their agency climate change response strategies. Based on identified vulnerabilities to climate change, a “menu” of adaptation options was developed that can be incorporated into existing programs and plans for each resource sector. The science-management dialogue identified management practices that, in their current form or with slight modifications, are useful actions for increasing resilience, as well as new management practices for adaptation. Not all of these options are equally viable or useful, but resource managers can draw from this menu of options as needed and when resources permit.

The scientific information synthesized through the NCAP process is relevant for other land management agencies and stakeholders in the region. Many of the adaptation options are likely applicable throughout the Pacific Northwest and can provide a starting point for adaptation planning in other locations. In addition, the NCAP science-management partnership has since led to five additional projects focused on climate change effects in this region. However, more work is needed to truly achieve an “all lands” approach to adaptation. The agencies involved had different mandates and objectives and were at different stages in the process of responding to climate change, and although these differences allowed agencies to share approaches and learn from the experiences of others, they present challenges for the development of collaborative adaptation plans.

The most important and potentially most challenging next step is to implement adaptation strategies and tactics in resource management plans and programs. We anticipate that implementation will occur gradually over time, with major advances occurring as specific needs arise or in response to disturbances, extreme events, plan and program revisions, and changes in policies and regulations. As with the initial planning process, implementation will require collaboration among multiple land owners and management agencies in the region. The USFS and NPS are in transition from viewing climate as unchanging to viewing climate as dynamic and mediating

changes in the environment (Halofsky et al. 2011, Peterson et al. 2011, Swanston and Janowiak 2012). Evolving science and climate policy, combined with near-term changes in ecosystems will necessitate iterative evaluation of adaptation options for land management.



Photo: A. Snover

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Collaborative Climate Adaptation in Utah: Beaver Restoration Projects Reinforce Ecosystem Functionality

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For the Grand Canyon Trust, It All Comes Down to Water

Roughly centered within the Four Corners region of the southwestern United States, the Colorado Plateau is largely made up of high desert and a scattering of forests. Nicknamed "Red Rock Country" due to its brightly colored rock left bare by dryness and erosion, it's geologically noteworthy with relatively little rock deformation within the last 600 million years. Many of the ecosystems on the Colorado Plateau, however, are facing serious threats due to climate change. Earlier snowmelt, higher temperatures, longer droughts and more extreme precipitation events have already begun.

Preparing habitats to effectively deal with the litany of uncertainties that lie ahead is fast becoming a priority for conservationists working on the Colorado Plateau. Many are turning their attention to locally appropriate, practical tools to help ecosystems adapt to changing conditions.

Native to North America, beavers are described as inhabiting all regions of Utah except the desert environments of the Great Basin (Durrant 1952), and early Utah explorers and fur trappers considered beaver abundant prior to 1825 (Rawley 1985). This large rodent constructs dams, ponds and canals to access food resources and lodges and bank dens for shelter and protection from predators. As human development has encroached into formerly wild areas, the natural beaver activities often result in widespread flooding of woodlands and agricultural lands and plugging culverts, flooding roads, railroad tracks and causing property damage. This human-wildlife collision earned the beaver its reputation as a nuisance.

These same "bad" behaviors have been found to be tremendously valuable to riparian areas, which are hosts to a wide variety of biodiversity, and aquatic systems, which are among the most imperiled in the West. Beaver dams expand riparian areas, creating ponds and wetlands. They slow water runoff, allowing the groundwater to recharge, reducing the erosive power of floods, especially if the dams occur in series. Dams also trap sediment that repairs damaged, incised creek channels, creating

habitat for frogs, salamanders, fish, ducks, and cavity-nesting birds. Seen in this light, natural beaver behavior is far from deleterious, but in fact increasingly important since it improves habitat for a majority of species that rely on riparian areas (Fig. 1).



Figure 1. A beaver chews willow as part of an engineering agreement with Grand Canyon Trust. Photo: Grand Canyon Trust

Encouraged by the research on the use of beavers as a riparian restoration tool, Mary O'Brien, Utah Forests Program Director with the Grand Canyon Trust (GCT) based in Flagstaff, Arizona, made the logical leap to using beaver as an ally in climate-change adaptation efforts. Since beaver are native to Utah and a proven value to riparian habitats in this increasingly dry area, enhancing populations is a practical and prudent adaptation action to take.

To help them start taking these actions, in 2011 the Grand Canyon Trust received support from the Climate Adaptation Fund (<http://www.wcsnorthamerica.org/ClimateAdaptationFund/tabid/4813/Default.aspx>). With funding provided by the Doris Duke Charitable Foundation and managed by the Wildlife Conservation Society, the Climate Adaptation Fund is partnering with non-profit conservation organizations poised to take on-the-ground adaptation actions. Armed with strong climate science and planning, GCT was well positioned to begin using beavers as a climate adaptation tool.

The Grand Canyon Trust's plan includes live-trapping and translocating beaver from nuisance situations to one of 87 creeks and water bodies. These were identified as priority areas within three national forests in southern Utah (Dixie, Fishlake and Manti-La Sal) and, once restored, these habitats will assist in maintaining the long-term function of these ecosystems given the many uncertainties of climate change.

In order for these translocations to be successful, historic beaver habitat in these identified areas had to be surveyed for beaver population status and suitability of the habitat to support a population; a task that hadn't been conducted since the 1970s. With the help of volunteers, GCT quantitatively assessed beaver populations and availability of cottonwood, aspen, and willow while also mapping these areas. In addition, Utah, like much of the West, needed to re-evaluate cattle grazing allotments. GCT has worked with District Rangers and Range Specialists to negotiate grazing management and installing livestock exclosures to allow for the regeneration of vegetation thereby improving potential beaver habitat quality.

Bringing these elements together—translocation of invasive beaver to viable habitats in priority areas-- has resulted in successful outcomes thus far.

As an example of this, in April 2012 irrigators in Panguitch, Utah, a town located within the Dixie National Forest, turned on water in canals and ditches only to find beaver opportunistically taking advantage of newly abundant willow. As a result, culverts began damming up, preventing the free flow of water through the delivery system. Nine of these beavers were trapped and released (following a quarantine period to prevent the spread of aquatic invasive species) on two priority sites that the GCT data revealed had suitable beaver habitat and no current population. As of August 2012, the transplanted beaver had built new dams at both sites, adding stream complexity to the systems and expanding the riparian area (Fig. 2).

Given the beaver's ability to rapidly modify a physical environment and their influence in re-shaping riparian corridors following conversion into a beaver dam-pond complex, the GCT is carefully monitoring reintroduction sites. Photo-point monitoring and vegetation transects are being utilized at key sites to track dams' sequestration of sediment and significant renewal and expansion of willow species. Assessing that the structural and biogeochemical modifications necessary to buffer these systems against the intensified disturbances of climate change are in place is a top priority. But, so too is mitigating conflicts that could lead to a decreased tolerance of beaver, which often prompts lethal removal.

The Grand Canyon Trust recognizes that climate change adaptation is fundamentally a locally driven, but landscape-scale issue with global repercussions. The effectiveness of their project relies heavily on success of their collaborations and participation of local communities. Through this project, and those like it across the country, conservationists are learning that they must integrate strong ecological science with keen social understanding to achieve long-term success in their climate adaptation efforts.

To learn more about this project, and others supported by the Climate Adaptation Fund, go to: <http://vimeo.com/59008212>

A.



B.



Figure 2. Using photo points to monitor their work, the Grand Canyon Trust records how beavers are changing the ecosystems into which they are introduced. A) Before introduction, and B) After introduction. From July 2011 to July 2012, invasive plants were drowned out due to the creation of the beaver pond and the aquifer was replenished, providing habitat for a variety of plants and animals. Tracking their progress allows them to take an adaptive management approach to their work. Photos: Grand Canyon Trust

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Rocky Mountain Futures: Preserving, Utilizing, and Sustaining Rocky Mountain Ecosystems Symposium 9

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Symposium 9 was organized by Jill Baron and was held on Tuesday, 7 August 2012 at the Ecological Society of America Annual Meeting in Portland, Oregon.

In 2002 we published *Rocky Mountain Futures, An Ecological Perspective* (Island Press) to examine the cumulative ecological effects of human activity in the Rocky Mountains. We concluded that multiple local activities concerning land use, hydrologic manipulation, and resource extraction have altered ecosystems, although there were examples where the ‘tyranny of small decisions’ worked in a positive way toward more sustainable coupled human/environment interactions. Superimposed on local change was climate change, atmospheric deposition of nitrogen and other pollutants, regional population growth, and some national management policies such as fire suppression.

Ten years later we revisited this profoundly human-influenced landscape with an ESA 2012 Symposium to evaluate the 2002 predictions, and ask whether local decisions still drive ecological change and whether ecological conditions are improving or degrading. As illustrated in the summaries below, we were surprised by the pace with which climate change has restructured mountain ecosystems and by the dramatic increase in energy development due to technical innovation and national policies. Dan Fagre noted the pace of climate change has been more rapid than anticipated and ecosystems are responding in unanticipated ways in **The Indirect Effect of Human Influence on Western Mountain Environments: Vulnerabilities and Resiliencies**. Retreating glaciers and earlier snowmelt affect stream run-off patterns and stream temperature profiles. The distribution and abundance of thermally-sensitive stream macroinvertebrates, the foraging behavior of associated salmonids, such as bull trout, and their competitive interactions with invasive lake trout are all at risk. Retreating glaciers add additional nitrogen to high-elevation

aquatic systems as they expose new substrate, stimulating high elevation lakes. Research of the past decade has underscored the dependence of mountain organisms, ranging from wolverines to alpine poppies, on snow cover. The landscape is snow-dependent as well. Avalanches provide wildlife habitat through frequent disturbance. Earlier snowmelt has left some species such as snowshoe hares with white pelage in spring, exposing them to predation. Some organisms show resilience to accelerating climate change through behavioral adaptation. Protection of critical habitats, such as the US-Canadian North Fork of the Flathead River, can provide a buffer against change that may increase the resiliency of species.

Among the consequences of climate change are multiple pressures on Rocky Mountain forests. Diana Tomback, in her talk **Forest Health Challenges in the Rocky Mountain West**, found that during the past decade general forest health has declined precipitously in the Rocky Mountains, with major changes in forest structure and disturbance patterns. Reduced snowpack and changes in the timing of snowmelt altered local hydrology and water availability, leading to drought stress in many forest communities. Warming trends and drought have caused unprecedented outbreaks of mountain pine and other bark beetles as well as regionally-synchronized, high-intensity fires. Invasive plants, pests, and diseases have further altered forest community structure; and distributional shifts in response to climate warming are predicted for all forest trees. Tomback used whitebark pine to illustrate how factors interact to alter forest communities and ecosystem function. White pine blister rust, mountain pine beetle outbreaks, and fire suppression are reducing forest diversity and changing structure, altering stream flows and impacting animals that live in whitebark pine communities or feed on whitebark pine seeds, including Clark’s nutcrackers and grizzly bears.

Bark beetle outbreaks were mentioned only a few times in the 2002 book. In their talk **The Emerging Significance of Bark Beetle Outbreaks in the Rocky Mountains**, Jeffrey Hicke and Jesse Logan noted predictions made in 2001 that warming at the northern and high-elevation range limits of mountain pine beetle would facilitate northward expansion into the boreal forest and upward expansion to high-elevation whitebark pine forests. These predictions have come true. Warming has intensified outbreaks in areas that were once too cold to support large beetle populations. Beetle outbreaks have also occurred in unusual habitats. A warmer drought in the Southwest coupled with bark beetle activity caused pinyon pine mortality across millions of hectares. Large forested areas of the western US and British Columbia are being killed by bark beetles. Tree mortality affects ecological relationships, subsequent wildfire intensity, human uses of the forest, carbon sequestration, and water cycles.

Some options exist for managers to minimize influences of these disturbances but are not widely applied. By increasing species diversity and diversifying age structure, managers can limit mortality caused by bark beetles, which typically attack one or a few species of host trees. Thinning can promote tree defensive capability and alter the microclimate; both reduce the suitability for beetle outbreaks. Monitoring and rapid detection of outbreaking populations can prompt management activities. Pesticides and use of semiochemicals (a chemical emitted by a plant or animal that evokes a behavioral or physiological response in another organism) are options for high-value trees, but not suitable for widespread application. Ultimate management efforts could include reducing greenhouse gas emissions, thereby limiting future warming.

Elizabeth Garcia and Naomi Tague picked up on the effects of beetle-caused tree mortality on streamflow and vegetation in their presentation **A Comparison of Climate Change and Biotic Disturbance on Streamflow and Carbon Cycling in the Colorado Rocky Mountains**. They applied an ecohydrologic model to the Big Thompson River of Colorado to address how hydrologic changes associated with warming impact vegetation productivity. They further asked how changes in forest structure, such as caused by beetle kill, interact with climate driven changes to alter streamflow regimes. Warming increased annual streamflow due to increased runoff production during winter and snowmelt periods. Variable precipitation resulted in the large increases in total amount and variability in streamflow. However, the largest increases in total amount of streamflow occurred for bark beetle outbreak scenarios. Minimum flows under beetle scenarios were greater by 150%, whereas climate perturbations

had a negligible effect on minimum flows. Model results emphasize that while temperature and precipitation changes may alter streamflow directly, the greatest changes are likely to arise as a result of indirect effects associated with climate-related forest disturbances (Fig. 1).

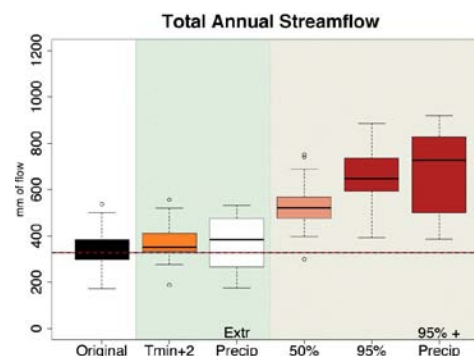


Figure 1. Average (1998-2008) annual streamflow for the Big Thompson River, CO, modeled over 20 years using a variety of disturbance scenarios. From left to right each bar represents: historical average without disturbance (black); 2°C increase of minimum temperatures (orange); high variability annual precipitation (white); 50% of subalpine fir converted to snags as representation of beetle disturbance (pink); 95% of subalpine fir converted to snags (red); 95% of subalpine fir converted to snags modeled with the high variability precipitation climate.

In 2002 the major, ongoing threat to remaining Rocky Mountain grasslands was physical conversion to urban, suburban, exurban, or row agriculture along with the suppression of fire. Fire suppression increased the abundance of shrublands and forests at the expense of grasslands. Exurbanization, fire suppression, and conversion to shrublands have continued since 2002. However, and somewhat ironically, the Rocky Mountain region now is believed to have more grasslands and meadows than in 2002. In his presentation, **Grassland Transformations in the Rocky Mountain West**, Timothy Seastedt suggested there will be more grasslands in our future. The widespread die-off of pines from bark beetles is opening the canopy. Repeated fires are projected to remove woody species seed and seedling sources, perpetuating grasslands. Fragmentation from energy development, carbon dioxide fertilization effects, and nitrogen deposition alter plant competitive interactions, which, combined with the presence of non-native species, continue to transform plant species composition of grasslands. Warmer and drier conditions and increases in October to March precipitation are selecting for certain plant species over others.

The emergence of hydraulic fracturing (fracking) as an economically feasible way to extract oil and gas found under many regions in the Rockies was not on our radar screen in 2002

but has expanded rapidly during the last decade. Similar rapid growth in wind energy production is attributable predominantly to renewable energy standards for states and federal incentives for production of renewable energy (Fig. 2). In their talk **Trends and Issues Associated with Energy Development in the West**, Zack Bowen, Tanya Gallegos, Christopher Potter, and David Mott addressed the development of unconventional oil and gas resources and wind power as important drivers of landscape change in the Rocky Mountain Region. Domestic energy production is a national priority and the Rocky Mountain region is rich in energy resources including coal, oil, natural gas, geothermal, and uranium and has great potential for solar and wind energy. Development of these resources is driven by a combination of technological innovation, incentives, markets, and energy production standards. The pace of change is rapid. Understanding of environmental consequences lags implementation of these new technologies, and incorporation of research results into policy and management decisions takes additional time.

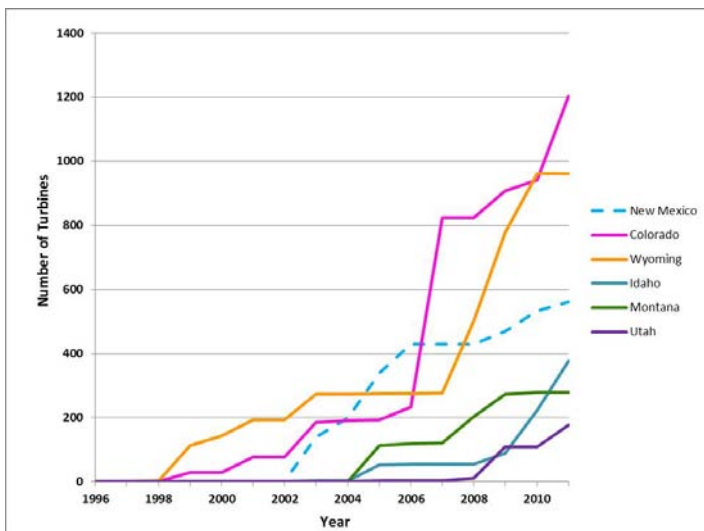


Figure 2. Number of wind turbines producing electricity in US Rocky Mountain states (although not necessarily in mountains) from 1996 – 2011. Wind energy development in the Rocky Mountain region has grown rapidly in the last decade and presents new challenges for land managers responsible for balancing renewable energy development with potential effects on wildlife and wildlife habitat. Data are from the American Wind Energy Association.

In the final presentation of the symposium, **Only Fools and Newcomers Predict the Future: the Hubris of Forecasting**, Jill Baron addressed the elements of surprise that may be inevitable to environmental predictions. Rapid climate change has brought about dramatic changes in the hydrologic cycle, including seasonal snow, avalanche, and ice dynamics. Rocky Mountain Futures failed to appreciate how quickly climate change would increase extreme events in restructuring some Rocky Mountain ecosystems. Forests, overwhelmed by drought, beetles, disease, and fire, have been dramatically altered; cascading effects of climate change to food webs and ecosystem processes are only now becoming apparent. National and global energy policies, coupled with innovative technologies, have unleashed unprecedented development of both fossil fuel and renewable energy development. And a stagnant global economy has dramatically slowed immigration, suburban, and exurban development. In response primarily to climate change projections, broad coalitions of stakeholders and resource managers are beginning to consider future scenarios of change as they develop plans for adapting to climate change. Adaptation options range from increased resource use efficiencies to multijurisdictional collaborations for forest, wildlife, and water conservation while facilitating resource development. While some decisions about Rocky Mountain resources are still made locally, they are increasingly influenced by regional, national, and global forces.

This summary is a product of The Western Mountain Initiative.

The Long Path Toward Restoration of Sierra Nevada Bighorn Sheep; An Interview with John Wehausen

The Spring 2012 issue of *Mountain Views Newsletter* included updates from a recent 10-year accomplishment report of the Sierra Nevada Bighorn Sheep Recovery Program (Stephenson et al. 2012). Given the critical role that research has played in the successes of this effort, I thought to include an interview with Dr. John Wehausen, recently retired research ecologist from the University of California's White Mountain Research Center, Bishop, California, as a model example of science-based restoration. John has been a pioneering scientist and leading conservation biologist working for the recovery of Sierra Nevada Bighorn Sheep for four decades.

– Editor

Back Story

(Adapted from the Sierra Nevada Bighorn Sheep Foundation website) Sierra Nevada bighorn sheep are descendants of wild sheep that crossed the Bering land bridge from Siberia slightly more than one million years ago. There are three distinct subspecies of bighorn sheep in North America: Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*), desert bighorn sheep (*Ovis canadensis nelsoni*), and Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*). Sierra Nevada bighorn sheep are found only in their namesake mountains. Historically they were scattered along the crest and eastern slopes of the Sierra Nevada from the central Sierra near Sonora Pass to peaks south of Mount Whitney, also occupying a region near Mineral King and the Kaweah Peaks, in what is now southern Sequoia National Park. At least 1,000 bighorn probably inhabited the region prior to 1850, after which, a number of factors initiated a decline that brought the population to barely more than 100 animals by 1995. It is difficult to pinpoint the exact chain of events that led the species to the brink of extinction. Unregulated hunting, spread of diseases contracted from domestic sheep, and mountain lion predation all appear to have played a role in this long history of decline. Intensive restoration efforts began in the late 1970s and were initially successful, but legal constraints hindered the initial full recovery of the sheep. In 1999, the Sierra Nevada Bighorn Sheep Foundation and four other environmental organizations successfully petitioned the state of California and the U.S. Fish and Wildlife Service to grant the sheep endangered species status. At the federal level emergency endangered status was obtained within a few months, and full endangered species protection in less than a year (in early 2000).

In an unprecedented and unexpected action, subsequent to endangered species listing, the California Legislature requested the California Department of Fish and Wildlife to administer a state-funded Recovery Program for these sheep. The first task completed by the Recovery Program was the creation of a small interagency team of scientists and stakeholders that drafted the *Recovery Plan for Sierra Nevada Bighorn Sheep* (USFWS 2007).

This plan identifies key issues, sets recovery goals, and lists recommended recovery actions.

Based on historical evidence of occupation and known patterns of habitat use, the *Recovery Plan for the Sierra Nevada Bighorn Sheep* designated sixteen areas as potential herd units. These areas extend from Olancha Peak in the south to the Twin Lakes region in the north (Fig. 1). Twelve must be occupied for the subspecies to be downlisted to “threatened” status, of which nine are currently occupied, as well as the non-required Bubbs Creek herd unit.

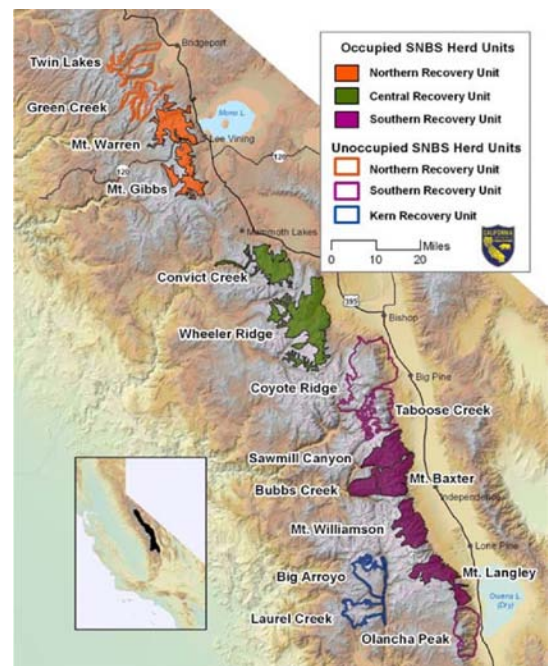


Figure 1. Sixteen herd units in four recovery units. All units are required for recovery except Bubbs Creek. From Stephenson et al. 2012.

In John's Words

Connie: When did you start working with Sierra Nevada Bighorn Sheep (SNBS) and what drew you to their study and conservation?



John Wehausen. Photo: J. Pleyte

John: In the summer of 1973, I took a trip to look at the summer habitat and saw my first SNBS, but I really started in the summer of 1974; that was a summer feasibility study. After another academic year at the University of Michigan, I then worked continuously in the Sierra Nevada from summer 1975 until late 1979 when I returned to UM for 9 months to write my dissertation.

What drew me to the SNBS were (1) an animal clearly in need of adequate data and data-based conservation, both of which were largely lacking; (2) an excuse to spend a lot of time in the Sierra Nevada; (3) something really challenging; and (4) a topic for a dissertation (I always viewed the PhD as a vehicle to do something needed, useful, and interesting, as opposed to the degree itself as the goal).

Connie: What was the status of Sierra Nevada Bighorn Sheep when you started working with them?

John: The only clearly known status was that SNBS still existed south of Independence on Mt. Williamson and north of Independence in what was called the Mt. Baxter herd, which I eventually figured out to be two separate female populations: Mt Baxter and Sawmill Canyon herds. The rest about "status" amounted mostly to guesses, rather than data. Even the distribution in winter, when these sheep come low along the base of the escarpment and are very accessible, was not well known. I pretty much had to start from scratch and figure it all out, from seasonal distribution to demography, food habits, nutritional patterns, etc. by wearing out a lot of pairs of boots.

In my early years I slept about 100 nights a year on the ground, and during the winter months put in about 25 days a month in the field. When I started working with SNBS there was a prevailing hypothesis that "human disturbance" was responsible for their limited and shrinking distribution. The question was even asked whether I should be allowed to study these sheep because of the disturbance I would cause – a rather frightening attitude given that the human disturbance hypothesis was just that, a hypothesis with a lack of any data to back it. It was one of the issues I had to deal with early on through a scientific approach. I could tell

you more about status after I started working on them, i.e. what I found, but that is really a different question.

Connie: OK, then what is the current status and prognosis for recovery and sustainability of the Sierra Nevada Bighorn Sheep populations?

John: In 2012 the total population of SNBS crossed 500 for the first time in many decades. This is a huge milestone; but on careful inspection these sheep are exactly 2/3 of the way to distribution and population size goals we set in the USFWS Recovery Plan (Stephenson et al. 2012). That is huge progress since the population low ebb of about 115 total animals in 1995. However, completing the final third of Recovery Plan goals will take a lot of funds and enormous dedication. In other words, it will take an unknown amount of funding from outside of the state government, which has borne most of the cost of the program to date. With current political attitudes it is not clear how much funding will become available. Sierra Nevada Bighorn Sheep are now more available than ever for moving to re-introduce herds into vacant historic habitat and augment existing herds, but if we bring in genetic considerations there are effectively a lot fewer sheep available to move because of the high variation in heterozygosity levels among individuals.



Figure 2. Ewes and lambs on Wheeler Crest, Sierra Nevada. Photo: Courtesy of California Department of Fish & Wildlife.

Unlike most endangered species, habitat for SNBS is secure in public ownership, but that does not guarantee that the ecosystem has not changed or will not change (e.g. climate change) in a way that makes it less suitable for this species to persist. My molecular dating indicates that Sierra bighorn have survived in the Sierra Nevada through three glacial cycles, which means they have endured extreme climatic variation. In colonizing such a high mountain range, these sheep seem to have found a chunk of real estate that has been able to provide an adequate amount of suitable habitat regardless of climatic conditions, which in part

accounts for their becoming a separate subspecies in just one mountain range. Current climate change needs to be put in the context of the large climatic variation these sheep have survived in the past.

With adequate funding and full implementation of the recovery effort I believe that in less than a decade we can reach downlisting goals.

Connie: These are amazing achievements and an optimistic prognosis. What key science elements guided effective recovery efforts to date? (e.g., your genetic work, studies of sheep reproduction, SNBS collaring and movement studies, lion monitoring)?

John: That's a complex question, because it could be separated into data development vs. data analysis. I make that distinction because good data can be mis-interpreted through biased or otherwise incorrect analyses. Your question suggests an adaptive management consideration, for which in many cases it is the basic data that matter; so I will primarily address the question of data development.

a) Mountain Lions. Detailed collection of data on mountain lion numbers, distribution, and prey selection of individual lions has been very important. It is well documented that it is frequently one or a few lions that make inroads into bighorn sheep populations. The information developed by Wildlife Services personnel have been particularly important to this program because those data have been the basis for selective removal of lions killing SNBS, and those removals have done more to assist in recovery of these sheep than any other actions since endangered listing. Capturing and radio-collaring lions have been essential to this part of data development, especially when GPS collars have been used. Investigation of past GPS data clusters from collars to determine the prey being eaten has allowed an estimate of the proportion of SNBS kills that were otherwise missed.

b) Demographic data on SNBS. Development of the best possible data on sizes of the reproductive bases of different herd units and their reproductive output and success has been essential. This has been greatly enhanced by the addition of radio collars in some key populations. Those radio collars in turn have allowed measurements of survivorship rates in different herds, and to increase data on cause-specific mortality. Adult survivorship is a particularly important variable that is otherwise very difficult to measure.

c) Distribution. Radio collars, especially GPS collars, have also provided considerable data on SNBS movement patterns. Much or most of this has yielded patterns expected or known already, but there have been some other situations in which it has taught us important lessons on habitat use patterns not known. Detailed knowledge of habitat use patterns at different times of year has been an essential foundation for deciding when and where the best herd counts can be made.

d) Genetics. Development of data on genetic diversity in different SNBS herds, comparison with data from many desert bighorn sheep herds, and the findings of low genetic diversity, high variation among SNBS in heterozygosity levels, a strong signature of a recent major bottleneck, and a significant heterozygosity-fitness correlation are all important relative to how recovery of this taxon is approached. Continued development of genetic data can be used in a planning and adaptive management context to incorporate genetics in considerations of which sheep get moved and where for re-introductions and augmentations so as to upwardly bias genetic diversity of some populations, especially re-introduced ones. My development of a highly reliable method of DNA extraction from bighorn fecal pellets allows the monitoring of heterozygosity levels of lambs born in populations of interest, and to use that information in an adaptive management context. I expanded my research into molecular genetics in the late 1990s in part to allow actual data, rather than assumptions, to be used as the basis of conservation planning and actions relative to genetics. My recent development of a simple genetic method to separate bighorn sheep and deer fecal pellets has been and will continue to be very useful in tracking range expansions.

Connie: With this base of knowledge to build on, what do you see as the greatest challenges facing recovery of population and species stability to the levels specified by the Recovery Plan?



Figure 3. Collared ram in Sawmill Canyon, Sierra Nevada. Photo: Courtesy of Todd Calfee and California Department of Fish & Wildlife.

John: Here's my list:

- Getting sheep established in vacant herd units.
- Getting more subpopulations established in some occupied herd units.
- Increasing gene flow among some of the more isolated herds.
- Reducing mountain lion predation in some herd units.

Connie: How do you think changing climate will affect SNBHS recovery and sustainability?

John: I touched on this above. Climate change can take a lot of forms and involves multiple variables. There are questions of seasonal temperatures and precipitation, and variances. We will not know how it manifests until we have sufficient actual data that show the changes. Future temperatures will likely increase, which may initiate growing seasons earlier, but only if there is adequate soil moisture. Earlier growing seasons result in earlier rises in diet quality for sheep in both winter and summer ranges, but this is not necessarily better for sheep if it trades off diet quality at the tail end of the summer growing season, which would be detrimental to lamb growth. Drier conditions may be detrimental, but this is also complex. In most years, diet quality on winter ranges is determined by the timing of the first soaking storm, not by the amount of winter precipitation. Summer diet quality is positively influenced by increasing winter and summer precipitation independently. This opens the possibility that there may be little to no change if one of these decreases but the other increases.

Connie: With your decades of science-based work toward SNBS conservation, can you offer any lessons to mountain scientists who are working with other species at risk from multiple stressors such as SNHS?

John: Here's my short list of lessons:

- Treat theory as a human abstraction that has a high probability of being incorrect; instead, give primacy to data, work to develop the best possible data, and let the data lead you to hypotheses about cause and effect relationships. The devil is almost always in the details and better data can make a huge difference. Recognize that ecology is multivariate with a lot of noise, thus quite messy statistically, and unlikely to yield simple clean answers. Be prepared to devote a long time if you want an adequate understanding at a system level; e.g., think at time scales of decades, not years. It may take climatically extreme years to expose system dynamics adequately.
- Be open to the possibility that variables you never considered may be very important, relegating a lot of previous research to little more than a preliminary study. Finally, there is no substitute for spending a great deal of time in the field. That is where you are likely to do some of your best thinking, especially about what variables might be important.
- Work from a carefully-thought-out and detailed problem analysis and revisit and question it as often as possible so as to revise it when some aspect is inadequate. There is usually little value in continuing research that is based on an inadequate problem analysis. Unfortunately, most research I see begins with an inadequate problem analysis.



Artist Jane Kim drafting the mural for the Mt. Williamson Motel. Photo: Courtesy of INK-DWELL. See article next page.

The Sierra Nevada Bighorn Sheep Migrating Mural

(Adapted from the Sierra Nevada Bighorn Sheep Foundation and INK-DWELL websites)

The Migrating Mural is a series of murals painted along migration corridors shared by both people and endangered animals. Animal migrations are remarkable behaviors of the natural world, yet they often go unnoticed by the general public, even when they take place near centers of human civilization. The purpose of the Migrating Mural is to expose the public to endangered, elusive, and transient animals that otherwise go unseen. It highlights animal migration routes while beautifying human migration routes, and thereby aspires to catalyze both wildlife conservation and public art. The Migrating Mural is an opportunity to show, through paintings, moments in the life of a migrating animal in the places through which it actually travels.

The first Migrating Mural focuses on the Sierra Nevada bighorn sheep (see Interview with John Wehausen, pg XX). This year-long project entails a series of four murals showcasing the life of Sierra Nevada bighorn sheep and painted along a 150-mile stretch of California's Highway 395, which runs in the shadow of the Eastern Sierra. The four mural sites are Lee Vining, Bishop, Independence, and Lone Pine, California.



Mural on Mt. Williamson Motel, Independence, California. This scene depicts the life stages of Sierra Nevada Bighorn Sheep, showing “Willie” from a lamb through yearling to an 8-yr-old adult ram. The Mt Williamson Herd Unit was the original remaining group of Sierra Nevada Bighorn Sheep and remains critical to restoration. Photo: Courtesy of INK-DWELL.

Each handpainted mural is unique and reveals the habits and behaviors of hard-to-see wildlife. The Migrating Mural will not only promote public art and beautify the surrounding area, it will also educate travelers and engender public support for this endangered species—a critical step toward restoration and conservation.

The project is created and painted by Jane Kim, artist, science illustrator and founder of INK-DWELL (<http://ink-dwell.com/>), a studio which creates art that inspires people to love, appreciate, and protect the Earth. INK-DWELL has partnered with the Sierra Nevada Bighorn Sheep Foundation and the California Department of Fish and Wildlife's Sierra Nevada Bighorn Sheep Recovery Program to coordinate and implement this project.

See more of Jane Kim's Sierra Nevada bighorn sheep paintings throughout this issue.



Willie as an 8-yr-old ram depicted on the Mt. Williamson Motel. Photo: Courtesy of INK-DWELL.

Voices in the Wind

In this section of Mountain Views, we query members of the CIRMOUNT community for their perspective on a question of current interest. An initiative is underway to develop the North American Treeline Network (NATN; see MVN, 2012, vol 6), and so we asked mountain scientists from different backgrounds and experiences the following question, with the intent that their replies would inform the nascent network. — *Editor*

The Question we posed:

In that alpine and arctic treeline ecotones are climatically, hydrologically, and ecologically important, what do you consider critical research (problems or questions) in regard to these ecotones for the near future?

Adelia Barber, Department of Ecology & Evolutionary Biology, University of California, Santa Cruz, CA

One of the most persistent, thorniest questions affecting ecological research across the treeline ecotone is how to decouple historical land use changes (such as grazing and fire regimes) from climatic changes. I would like to see more creative research solutions to this problem, especially focused on more complex aspects of treeline-ecotone change, such as large-scale demographic changes in treeline forests or shifts in community-level species diversity.



Andy Bunn, Huxley Tree-Ring Laboratory, Western Washington University, Bellingham, WA



I think the most critical issue regarding mountain ecotones that the research community needs to address is the role of forcings vs. feedbacks in driving change in ecotones. The arctic research communities have done fantastic work describing the importance of feedbacks at multiple scales both in terms of conceptual models and getting on-

the-ground measurements to fit those models. The mountain community can learn a lot from those efforts.

Jessica Lundquist, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA

The key question is "At what rate are the trees moving (marching up the hill, or invading the meadows), and what controls this process?" I'm envisioning Ents (from Lord of the Rings) as I write this, but in reality I think the heart of the question relates to seedling dispersion and survival. Changes in forest-covered area in the future will have huge feed-backs in terms of albedo and snow accumulation and melt, so we need to know how rapidly (or slowly) that area is expanding or contracting.



Georg Grabherr, Department of Conservation Biology, Vegetation Ecology, and Landscape Ecology, University of Vienna, Vienna, Austria

Treeline ecotones in the Alps have been impacted by pasturing since prehistoric times. Nowadays alpine farming has declined in many parts, having been geared to more intensive uses in Switzerland and western Austria. To maintain dairy farming in particular, environmental subsidies are paid in relation to the area that is feasible for pasturing. For about 10 years some bureaucrats have recognized that parts of those pasturelands might be stony, wet, or have already lost size due to progressing forests. The subsidies are now modified for these areas so as to encourage farmers to cut back young emerging forest or bulldozing dwarf shrub heath that is covered, for example, by alpine rose. I am not so much afraid of the effects of climate change (note that fire does not play such devastating roles as in North American mountains), but more by the stupidity of an agricultural policy that neglects ecological basics.



George Malanson, Department of Geography, University of Iowa, Iowa City, IA

I am interested in how changes in alpine treeline will affect biodiversity. Will increasing tree cover lead to the extinction of herbaceous alpine species? For monitoring treeline, this question leads to a focus on conifer seedling establishment. This focus would lead to work on rare events, and time spent observing nothing. But this work is important and rates of seedling establishment may (or may not) be changing. Given these caveats, study of the conditions in which seedlings established in the past is also worthwhile; we know a lot more now than a decade ago, but not enough. In addition to observing change, we need to understand when and where we do not see it. Given the direction of my interest, interaction with alpine plants (role of subshrubs, anyone?) seems a useful research topic wherein multiple approaches can be fruitful. Other interactions are also important in a changing climate: pathogens, pests, other fauna, fire, and geomorphic processes have their own responses to climate as well as to climate-affected plants. Given the complexity of the problem, I am confident that this ecotone can be the setting for fundamental work in ecology and geography.



Lisa Graumlich, College of the Environment, University of Washington, Seattle, WA



Treelines captured my scientific imagination over 30 years ago. At that time, I never imagined that over the course of my career the scientific study of treeline would change from a somewhat obscure topic for people interested with physiological limits to growth to a global bellwether of climate change impacts.

What is the most critical problem to tackle as a NATN? For the arctic, my concerns are understanding the ecosystem level feedbacks that occur as tundra gives way to woody plant growth. What factors accelerate change? Where are the tipping points? And, how might this affect subsistence of those who make their living from the high arctic landscape? For alpine treelines, I am intrigued (or, more honestly, freaked out) by contemplating the ability of alpine species to adapt to climate change through migration, given the double whammy of rising temperatures and land-use changes that make high altitude natural areas increasingly isolated.

Jeremy Littell, Alaska Climate Science Center, USGS, Anchorage, AK

The literature that justifies our scientific fascination with treeline is inconsistent in its mechanisms. Few treeline ecotones are "textbook", much as few glaciers are. We don't even have a typology of treeline change that explains our varied observations of mountain treeline dynamics. The real explanation must be that they are complicated in different ways EVERYWHERE, so the next 50 years should be very interesting for treeline research ANYWHERE. But we need, collectively, to be measuring for the long haul.



Melanie Harsch, Department of Biology, University of Washington, Seattle, WA

Research at the treeline ecotone over the past few decades has brought significant advances across many research disciplines. Further advances, however, will require coordinated efforts across disciplines and treeline sites. For example, rather than disregarding unexpected results, we are likely to find these unexpected results will provide new insights when analyzed across multiple sites.



Janneke Hille Ris Lambers, Department of Biology, University of Washington, Seattle, WA



Will upward or poleward shifts in treeline proceed faster or slower than rates of climate change? Limited seed dispersal and long generation times of trees may cause lagged responses, while positive feedbacks driven by facilitative interactions may cause unexpectedly rapid shifts in treeline. I think we need a better understanding of both the

climatic and biotic factors that currently limit population growth at treeline, as well as the rates at which trees can invade meadows or tundra as those limiting factors are altered by climate change.

Martha Apple, Department of Biological Sciences, Montana Tech, Butte, MT

How are plants on either side of abrupt treeline ecotones influenced by differences in temperature, light, and water? For example, how do epiphytes of southern beech (*Nothofagus*) trees of New Zealand respond to changes in temperature, light, and water across the abrupt treeline of these forests?



How do plants affect the hydrology of the treeline ecotone and vice-versa? Aspects of hydrology to be considered in exploring this question are the accumulation and retention of snow, timing of snowmelt, and erosion from melt-water, while aspects of plants include growth forms (krummholz trees, shrubs, tussocks, cushion plants), evergreen vs. deciduous leaves, and root structure.

How would a climate change-induced increase in rock and snow avalanches change treeline ecotones? Would re-establishment of trees on avalanche chutes be delayed with climate change? In a related question, what would treeline ecotones be like in areas where glaciers and/or permanent snowfields retreat and moraines (or previous sites of snowfields) eventually become inhabited by trees?

Matt Germino, Forest and Rangeland Ecosystem Science Center, USGS, Boise, ID

Alpine treeline ecotones (ATEs) are perceived to be valuable as bellwethers for larger, incipient climate impacts on ecosystems, specifically major shifts in landcover boundaries.



At the landscape level, the literature now suggests that changes in tree or tree seedling abundances are occurring with recent climate shifts in some ATEs, yet others have exhibited little change. We need to identify the factors that poise ATEs for change (or resistance to change) in order to utilize whatever bellwether value ATEs confer to us.

At the community level, we have some idea of how tree species differ in their ecology in ATEs, but the information is based largely on what can be learned from established plants. Interactions among tree species, and with neighboring herbs and other taxa, are not well known except for the few cases which demonstrate that these biotic interactions are very important to

treeline dynamics. For example, it appears that whitebark pine or herb canopies can facilitate subalpine fir beyond its normal limits within an ATE, but are these relationships also occurring in other mountains and species?

At the population level, climate-responses are known best for a few demographic stages of trees. Changes in tree abundance in ATEs is foremostly a problem in population ecology, and the treeline change can be most concisely framed as a tendency for tree population growth to increase, remain stable, or decrease (i.e., $\lambda > 1$, $= 1$, or < 1). However, population modeling is scarce or absent for ATEs.

Physiological limitation is likely a key aspect of ATEs, and population models are needed in order to relate factors considered limiting for a particular demographic stage to the tree population. Most information in the literature is for trees, seedlings, and seeds (in this decreasing order). But, as an example, how important is tree growth to tree populations in ATEs, given all the other aspects of tree populations? We can only make assumptions at this point.

At the organismal level, there are ideas and supporting data for how low-temperature, desiccation, harsh radiation, or wind affects trees at treeline. However, there appears to be an unquenched need to better understand the precise way that alpine climates limit tree establishment. Chronic growth problems related to carbon uptake or use factor prominently in studies aimed at revealing the nature of physiological limitation to trees or seedlings at treeline. The research is revealing a need for a more robust way for assessing how changes in tree carbon and growth can be attributed to suppression or adaptive strategy. In other words, how much of the change in trees along gradients to treeline is due to active regulation of plant form or function, versus merely the passive responses to climate that are typically assumed? This issue is a core problem in detecting and characterizing limitation and thus explaining ATE formation and stability.

In summary, ATEs should present a relatively tractable framework for linking climate to vegetation boundaries and change. Other landcover boundaries have intense land use, invasives, and disturbance-succession patterns that complicate the climate "signal" in vegetation change, although this is not to say biotic interactions are not important. Still, considerable work lies ahead for understanding climate drivers and responses in ATEs. The work includes assessing physiological limitation and how it plays into demographic bottlenecks for tree population and community change, and knowing where and which treelines are more or less poised to exhibit these changes.

A Global Campaign on Accelerated Warming at High Elevations

Greg Greenwood

Mountain Research Initiative, University of Bern, Bern, Switzerland

The Mountain Research Initiative is developing a global campaign to assess if, where, to what extent and why mountains and other high elevation regions of the world are warming more rapidly and experiencing changing precipitation patterns as compared to other portions of the planet.

The idea was first broached in a side event on 3 December 2012 at the Fall Meeting of the AGU, and featured contributions by Ray Bradley (U Mass), Tandong Yao (ITP/CAS), Michel Baraer (ETS), Nick Pepin (U Portsmouth), Jim Miller (Rutgers), Wolfgang Schöner (ZAMG), and in absentia from René Garreaud (U Chile) and David Hik (U Alberta).

Since then a small group chaired by Ray Bradley and Tandong Yao has been considering the aspects of such a campaign and will likely convene a focused workshop on the topic later in 2013. Jim Miller and several colleagues have proposed a session on climate warming at high elevations at the 2013 AGU Fall meeting to complement the focused workshop.

Why do we care if warming is faster at higher elevations? The potential impacts are large. If warming at high elevations is proceeding faster than projected by models and in assessments, forecasts regarding the future time course of water quantities (e.g. temporal shifts in annual hydrographs, timing of peak water from receding glaciers, probabilities of extreme events) will be similarly biased. A significant portion of the world's population will be affected by these changes, especially in Central, South, East and Southwest Asia, South America and southwestern North America, Africa, and much of southern Europe.

Similarly, a more rapid than expected loss of frozen water and potential changes in extreme precipitation events may render mountain environments, already among the most hazardous, even more exposed to landslides, debris flows and floods. More rapid than expected warming will also accelerate ecological change in these regions, leading in some cases to the loss of alpine ecosystems, shifting biome boundaries with subsequent repercussions on ecosystem function and ecosystem services and in some cases total loss of existing ways of life for mountain peoples.



The International GLORIA Project monitors impacts of warming at high elevations. Sierra Nevada target region. Photo: C. Millar

While the question has commanded the attention of several authors, the results have often been equivocal and almost always invoke various hindrances to comprehensive answers:

- inherent complexity of mountain regions
- insufficient, or at least inaccessible, ground observations with current bias to low elevations
- difficulty for satellite-based measurements to capture high-resolution detail of mountain-and-valley systems
- competing surface and free-air influences, and their influence on differences between datasets (e.g. surface stations, satellites, radiosondes).
- high elevation microclimatic issues
- cryospheric changes feed-back that possibly superpose to the elevation effect

In light of the motivation for this program key areas are those mountain regions of the world that supply critical water resources to adjacent populated areas:

- Tibet
- Hindu Kush/Karakorum/Himalaya
- Heng Duan (SW China)
- Pamir/Tian Shan
- Tropical Andes
- Central America
- Southwestern North America
- Southern Europe
- East and Central Africa
- Oceanic islands (e.g. Hawaii, Tenerife, Papua New Guinea)

Other high elevations could provide interesting contrasts:

- Yukon/Alaska
- Western North America
- Altai and Siberian mountain ranges
- Japan
- Caucasus
- New Zealand Alps

The network of researchers participating in this campaign will include:

- atmospheric scientists with particular thematic expertise related to the mechanisms of accelerated warming;
- GCM/RCM modelers who can present, interpret & explain the models' amplification of temperature with elevation, mainly in the Tropics;
- data stewards for the key regions shown above and other relevant mountain regions as yet to be identified;
- researchers with relations to related networks or efforts;
- experts with close working relationships to national and international research funding and research prioritization organizations.

For more information, contact Greg Greenwood: green@giub.unibe.ch



Alpine glaciers, such as Collier Glacier in the Three Sisters, OR, respond rapidly to warming. Photo: C. Millar

A Global Fair and Workshop on Long-Term Observing Systems of Mountain Social-Ecological Systems; Tentative Plans

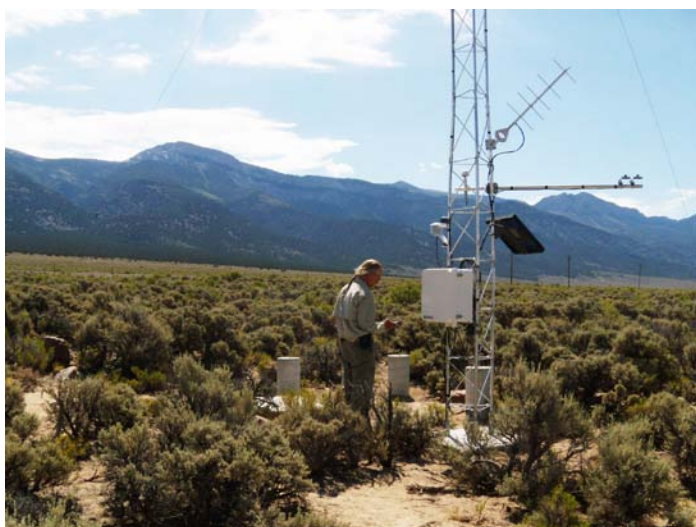
Greg Greenwood¹ and Franco Biondi²

¹ Mountain Research Initiative, University of Bern, Bern, Switzerland

² Department of Geography, University of Nevada, Reno, Nevada, USA

Plans are underway for a 4-day *Global Fair and Workshop on Long-Term Observing Systems in Mountains* to be held in Reno, Nevada, USA, during July 2014. Observing networks designed with the purpose to last longer than a typical 3-yr scientific study are key elements to determine predictability in complex systems. Mountains concentrate critical economic resources (particularly water), are extremely dynamic, and exist within a wide variety of institutional settings. Informed management of social-ecological systems in mountain regions requires accurate and integrated data on the state and dynamics of both the social and ecological sub-systems.

The underlying logic of the Fair and Workshop is that a more comprehensive mountain observing system will arise through the interplay of both bottom-up activities, in which those managing current observing systems expand those systems through collaboration with others, and top-down activities, by which researchers lay out the requirements of comprehensive mountain observing systems.



The NevCAN Program of the University of Nevada has installed a series of climate monitoring stations in the Snake and Sheep Ranges, NV.
Photo: C. Millar

The research community has a history of top-down pronouncements (e.g. the GLOCHAMORE Monitoring proposal in 2004, the IGBP Merton Initiative in 2012). This history does not, however, imply that all the requirements of mountain observing systems have been specified or that mountain observing systems are implemented or properly maintained. Much remains to do in terms of common protocols, data sharing, developing creative financing options, and other topics, and the Global Fair and Workshop are designed to further these goals.

The assumption of the Fair and Workshop is that discussions will be more productive when they occur within the "real world" context of existing on-the-ground observing systems. Thus the "Fair" component of this event is meant to provide that "real world" bottom-up context while the "Workshop" component provides a venue for top-down discussions.

The Fair

1) Trade show/poster session

The goal of the trade show/poster session is for participants to learn what each other does. Sessions would start with "One Minute Madness", a plenary session in which each of the presenters has one minute available to present what they do (possibly using 1-2 slides; timing will be strictly enforced). During "One Minute Madness", circulating participants take note of the presenters whom they wish to visit during the trade show/poster session.

2) Bi-or multi-lateral discussions

The goal of these discussions is the formation of new collaborations and their eventual declaration.

The Workshop

1) Presentations

The goal of the presentations is to present state-of-the-art thinking regarding mountain observations. Presentations will

address the full extent of top-down topics: overall rationale, sensors, protocols, data management, data integration, data policy, display. These presentations could, for example, present observing rationales based on Global Land Project Science Plan or the description of social-ecological systems, assessments of the state-of-the-art of observing mountain climate, hydrology, ecology, economy, governance; crowd sourcing and citizen science; data management; agreements/best practices for data sharing and distribution; remote sensing options; and so on.

2) Ateliers

The goal of the Ateliers is to promote discussion by participants and to generate products related to observations. Ateliers are the real "workshops" in which participants with a common interest work together to develop components needed by a global mountain observing system. These Ateliers might focus on standards for sensors, protocols and data management, on methods of integrating biophysical and social data, on a common basis for presenting data (e.g. Wikipedia, Global Mountain Biodiversity Assessment "mountain regions", etc.).

Field Trips

The goal of field trips would be to showcase existing observing systems in the Sierra Nevada/Great Basin region and to promote more opportunities for interaction between participants.

Field trips tentatively might include visits to

- NEVCAN
- GLORIA sites
- WRCC CRN sites
- Sagehen Field Station
- CZO on the west side of the Sierra
- Mono Lake/SNOTEL
- White Mountain Research Center
- Walker River Dendrohydrological Research Sites

The Global Fair and Workshop on Long-Term Observing Systems of Mountain Social-Ecological System is being organized and sponsored by the international Mountain Research Initiative, the University of Nevada, Reno, DendroLab, and the Desert Research Institute, together with the collaborative partnership of regional, federal, and international organizations. Contact Greg Greenwood for information: greg.greenwood@giub.unibe.ch



Integrated monitoring of the Mono Lake, CA ecosystem has been ongoing since the 1980s. This is one of the possible destinations for field trips during The Global Fair. Photo: C. Millar

Postgraduate Study in Sustainable Mountain Development

Martin Price

*UNESCO Chair in Sustainable Mountain Development, Director, Centre for Mountain Studies
Perth College, University of the Highlands and Islands
Perth, UK*

Since 2004, the University of Highlands and Islands, Scotland has been running a part-time on-line MSc in Sustainable Mountain Development. In 2007, it was validated for delivery across Europe, and students from Bulgaria, France, Germany, Italy, and Spain have joined the course. In 2012, it was validated for global delivery, and students from the USA have joined. The course has international recognition through the UNESCO Chair in Sustainable Mountain Development.

As a former resident of Colorado and Alberta, I believe that the course will be of interest to individuals from North America who are currently working in, or interested in working in, mountain areas - whether in government agencies, as land managers, or in the fields of environmental or community development. It may also be of interest to educators, as well as people who just like mountains!

Part-time on-line study allows students to fit their academic work around all the other demands on their time: work, family life, and recreation. The flexibility of on-line study also provides students - who are all 'mature' and bring a lot of experience to the course - with many opportunities for interactions both with each other and with the module tutors: the degree of personalised attention is much greater than on many face-to-face degrees. While nearly all modules are delivered on-line, there is an optional field studies module in Scotland, probably on the Isle of Harris or in the Cairngorms.

Students take either one or two modules per semester (September to December and January to May) and can exit at three levels:

- * Postgraduate Certificate (3 core modules)
- * Postgraduate Diploma (3 core + 3 optional modules)
- * MSc (3 core + 3 optional modules + 15,000 word dissertation)

The core modules are: Environmental and social issues in mountain areas; Sustainable development; and Policy analysis. The optional modules are: Biodiversity management; Developing communities; Developing potential through placement; Field studies; Geographic Information Systems (GIS); Local economic development; Participatory approaches to community engagement; People and nature; Research methods and techniques; Sustainable deer management; Sustainable rural land use and energy; Sustainable tourism; Water management. Not all of these run every year, depending on demand.

In the next academic year, starting in September 2013, the fee per module is £740 (c. US\$1200), so that the fees for a complete MSc will be around £6660 (c. US\$ 10,500). Further information can be found at: <http://www.perth.uhi.ac.uk/specialistcentres/cms/MSc/Pages/default.aspx> or contact Martin Price at: Martin.Price.perth@uhi.ac.uk



Caltha leptosepala. Photo: J. Blanchard

Southwest Climate Assessment Report

Over 120 scientists banded together several years ago to pull together a comprehensive report describing the state of climate-change science as applies to the U.S. Southwest Region. The resulting report has recently been released at <http://swcarr.arizona.edu>

Individual chapters are available along with factsheets, slides, and other information. As of May 2, the entire report has been available to be downloaded, and print-to-order hardcopies are available for purchase.

Of particular interest to the mountain climate community are the following reports, which are part of the overall assessment project:

Cayan, D., M. Tyree, K. E. Kunkel, C. Castro, A. Gershunov, J. Barsugli, A. J. Ray, J. Overpeck, M. Anderson, J. Russell, B. Rajagopalan, I. Rangwala, and P. Duffy. 2013. Future Climate: Projected Average. In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 101–125. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Gershunov, A., B. Rajagopalan, J. Overpeck, K. Guirguis, D. Cayan, M. Hughes, M. Dettinger, C. Castro, R. E. Schwartz, M.

Anderson, A. J. Ray, J. Barsugli, T. Cavazos, and M. Alexander. 2013. Future Climate: Projected Extremes. In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 126–147. A report by the Southwest Climate Alliance. Washington, DC: Island Press. (copy at http://tenaya.ucsd.edu/~dettinge/ACCSWUS_Ch7.pdf)

Hoerling, M. P., M. Dettinger, K. Wolter, J. Lukas, J. Eischeid, R. Nemani, B. Liebmann, and K. E. Kunkel. 2013. Present Weather and Climate: Evolving Conditions. In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 74–100. A report by the Southwest Climate Alliance. Washington, DC: Island Press. (copy at http://tenaya.ucsd.edu/~dettinge/ACCSWUS_Ch5_0.pdf)

Overpeck, J., G. Garfin, A. Jardine, D. E. Busch, D. Cayan, M. Dettinger, E. Fleishman, A. Gershunov, G. MacDonald, K. T. Redmond, W. R. Travis, and B. Udall. 2013. Summary for Decision Makers. In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 1–20. A report by the Southwest Climate Alliance. Washington, DC: Island Press. (copy at http://tenaya.ucsd.edu/~dettinge/ACCSWUS_Ch1.pdf)



Sunrise from 3 Sisters, Oregon. Photo: J. Blanchard

***MtnClim 2014* to Convene September 15-18, 2014 in the Wasatch Range, Utah**

MtnClim 2014, the seventh biennial mountain-climate conference sponsored by CIRMOUNT, will convene September 15-18, 2014 at the Homestead Resort in Midway, UT, in the heart of the Wasatch Range of north-central Utah. The main program will start Monday night (9/15) with dinner and an evening program, and will run to noon Thursday (9/18). Satellite meetings and field trips are in planning as well. Despite its rural mountain location, Homestead Resort is less than an hour's drive from the Salt Lake City international airport. We will be working on the conference program in the coming months. As program, registration, and travel details develop, we will post them on the MtnClim website, so watch www.fs.fed.us/psw/cirmount/meetings/mtnclim for updates.

For questions, suggestions, or if you would like to participate in planning, contact Connie Millar, cmillar@fs.fed.us



Soldier Hollow in October, near Midway, Utah

2013 Parsons Memorial Lodge (22nd) Summer Series in Natural and Cultural History



Lake of the Shining Rocks III, by Penny Otwell, acrylic on canvas, 2012, www.pennyotwell.com

If you happen to be in Yosemite National Park this summer, you'll be lucky if you can catch one (or more) of the 2013 Parsons Memorial Lodge Summer Series in Tuolumne Meadows (free and open to the public). Each year, Ranger Naturalist Margaret Eissler, who grew up summers in Yosemite, organizes this "celebration of natural and cultural history, philosophy, art, music, poetry, and cutting edge thoughts about what it means to live in this world, on this Earth, in these urgent times". As an example of the offerings, geologist Greg Stock (Yosemite National Park) will speak on "The Fate of Yosemite's Melting Glaciers" (July 13) and climatologist Mike Dettinger (USGS/Scripps Institution) will talk on "The New Science of Atmospheric Rivers" (August 4); other talks include natural history of Sierran birds, traveling the 38th Parallel water line, painting the high mountains by Penny Otwell, and many more. See the full schedule at: www.nps.gov/ose/planyourvisit/programs.htm.

Pacific Northwest Climate Science Conference Convenes September 5-6, 2013

We are pleased to announce that the 4th annual Pacific Northwest Climate Science Conference will be held in Portland 5-6 September 2013. The conference provides a forum for researchers and practitioners to convene and exchange scientific results, challenges, and solutions related to the impacts of climate on people, natural resources, and infrastructure in the Pacific Northwest. The conference attracts a wide range of participants including policy- and decision-makers, resource managers, and scientists, from public agencies, sovereign tribal nations, non-governmental organizations, and more. As such, the conference emphasizes oral presentations that are comprehensible to a wide audience and on topics of broad interest. This conference is an opportunity to stimulate and showcase decision-relevant climate science in the Pacific Northwest.

Previous conferences were held in Portland in 2010, Seattle in 2011, and Boise in 2012. This conference will feature a keynote address by US Senator Jeff Merkley of Oregon, and invited plenary talks by several other distinguished speakers.

The conference will transcend the typical, discipline-based science conference to stimulate and develop a place-based understanding of the connections between climate and decisions

that affect the people and resources in the region. We seek presentations, either oral or poster, that describe the region's climate variability and change over time; connections between climate and forest, water, fish, and wildlife resources; climate-related natural hazards such as wildfire, drought, flooding, invasive species and shoreline change; and the emerging science of ocean acidification.

We also seek case studies of efforts to incorporate science into planning, policy, and resource management programs and decisions; new approaches to data mining or data development; decision support tools and services related to climate adaptation; and fresh approaches or new understanding of the challenges of communicating climate science. We invite you to suggest or organize a cluster of abstracts around a theme that might be used to design a special session.

Abstract submission is now open. Registration and lodging information will be available soon. See <http://pnwclimateconference.org/>

For more information, contact Philip Mote, pmote@coas.oregonstate.edu



Oregon Coast Range. Photo: J. Blanchard

Traversing New Terrain in Meteorological Modeling, Air Quality, and Dispersion

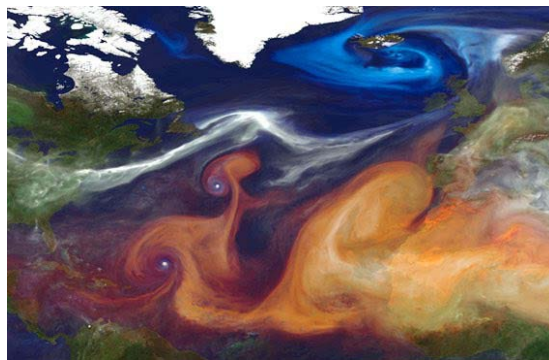
A new biennial conference sponsored by the UC Davis Air Quality Research Center with support from the California Air Resources Board.

September 10-12, 2013; University of California, Davis, CA

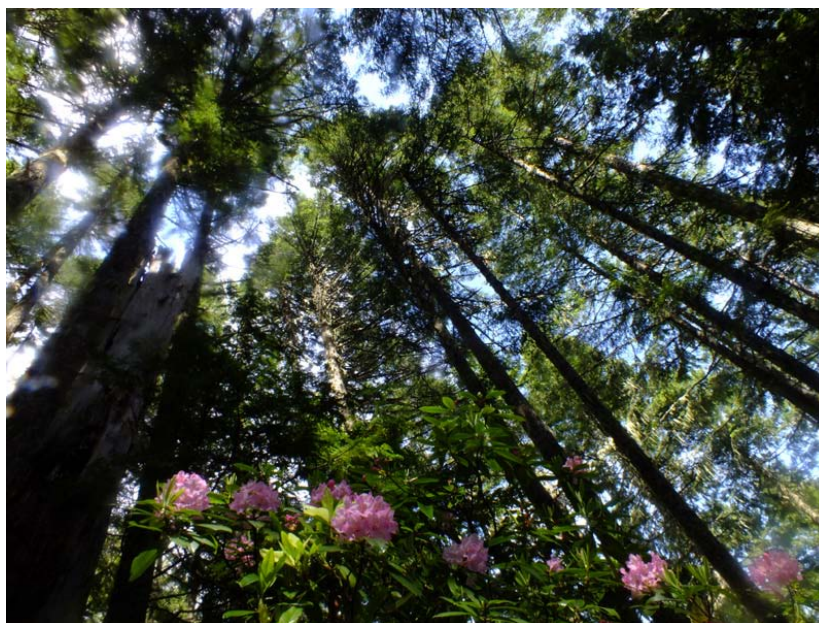
This conference will interest those involved in a wide array of research areas that utilize meteorological and climatological data. The primary focus will be on the modeling and prediction of regional climate and air quality - with a special emphasis on understanding what is “under the hood” in the models and how to improve them. Sessions will cover:

- * climate modeling and down scaling
- * modeling in complex terrain
- * regional prognostic/diagnostic modeling
- * the intersection of meteorological modeling and CFD, and
- * using simulated meteorology fields in AQ simulations

The preliminary program, abstract submission details, and location information can be found on the conference website:
<https://sites.google.com/site/meteorologyandairquality/home>



Credit: NASA GEOS-5 "Portrait of Global Aerosols" Still frame from NASA's animation of global aerosols using GEOS-5, NASA's high-resolution global atmospheric model, run on the Discover supercomputer at the NASA Center for Climate Simulation at Goddard Space Flight Center, Greenbelt, Md. William Putman, NASA/Goddard.



Slkyview. Photo: J. Blanchard

Changes in Alpine and Arctic Flora Under Climate Change

Share, learn and discuss recent research findings and their practical implications at two conferences in a charming art-nouveau hotel in the breath-taking alpine landscape of the south-eastern Swiss Alps (Bergün).



1st conference:
International Tundra Experiment ITEX
More than 20 years of tundra vegetation change research

17th - 20th September 2013

The ITEX network has focused on the impacts of climate change on plant species in tundra and alpine vegetation. We welcome all researchers to this conference who are interested in changes in arctic and alpine tundra. Contributions are welcome that range from observations of variability to experimental manipulations.



For more details see <http://www.wsl.ch/alpine-arctic-flora/>

Contact: alpine.arctic.conf@wsl.ch

2nd conference:
Faster, Higher, More?

Past, Present and Future Dynamics of Alpine and Arctic Flora under Climate Change

22nd - 25th September 2013

The conference aims at presenting current research in climate-driven changes in species distribution in alpine and arctic environments. It further intends to link research efforts across disciplines and regions and to discuss potential implications on conservation efforts and land management in the respective areas. The conference is open to all interested researchers and practitioners.

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. We welcome your comments on processes and observations described, and encourage submissions for future issues.

The articles in this issue highlight a weather pattern in the Mono Basin and elsewhere that can be both stunning (from the outside) and gloomy (from within). I am especially proud to feature the work of Lee Vining elementary school students, Caelen McQuilkin and Jordyn Harper, whose science fair project on cold-air-pooling events of winter 2013 won gold medals at the local, county, and regional fairs, and fourth-place at the California state fair. They submit their project to the national level in June. – *Editor*

Mono Basin Poconip and the Big Chill of 2013

Connie Millar

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

Those who frequent mountain country are familiar with thermal inversions, where vertical temperature gradients reverse from expected, and low elevations become colder than high. Although such cold-air drainage can occur anytime of the day and throughout the year, it most commonly evolves at night, in winter, and under conditions of high atmospheric pressure characterized by clear skies and calm air. Where topographic basins lie adjacent to slopes, or deep canyons occur with flat bottoms and constricted slopes, cold air that drains downslope can become trapped in pools that may last for many days.

The finite package of air that flows downslope derives from a shallow zone above ground level on the ridge slopes. At sundown, and as evening progresses, the ground cools faster than air at the same elevation, which holds heat from the day. Radiative cooling chills the land surface, which then cools the air layer directly above the ground (less than ~0.5m deep). Being denser than the warmer air around it, the cooled air layer slides downslope and collects in low basins or closed canyons. If warm air moves over the pool of cold air it can further cap the cold pocket, shutting off convection that might otherwise occur below.

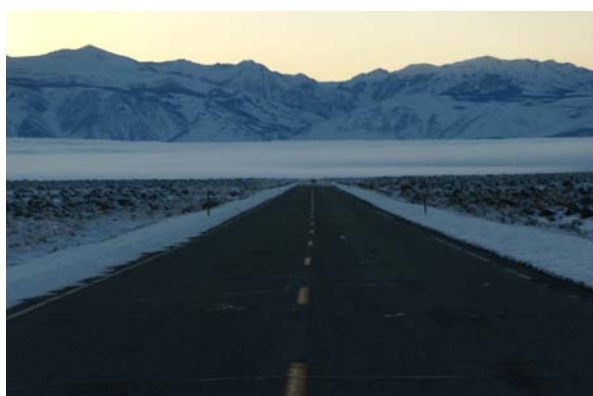
In the Mono Basin, California, inversions are regular winter phenomena and characterize periods between storms or turbulent weather. During late December 2012 and early January 2013, inversions persisted for many days, and temperatures became unusually cold (see McQuilkin and Harper, below). With large Mono Lake filling the west part of the basin, the Mono Basin develops another, less common, aspect of cold-air pools, namely, inversion fog. This super-dense, icy fog zone, with a discrete upper-elevation cap, is locally known as “poconip”. The origin

of this name is somewhat obscure, being more commonly written “pogonip”. The latter traces to Native American roots with first historic note in 1865 (DARE 2013). The “k” sound appears more common in the region of Paiute languages (i.e., the Mono Basin). In an effort to trace Mono Basin useage, local Kutzadika-Paiute Raymond Andrews queried tribal elders, and found their accepted word to sound as “paginabi” (Dunaway 2006). Kutzadika words that have “pa” sounds refer to some form of water, in this case, freezing fog.



Mono Basin poconip

Poconip forms in basins during inversions when adequate moisture exists in the atmosphere to create fog. This is common where lakes exist – especially saline lakes such as Mono that do not freeze. Warm air can hold more moisture than cold air, and the air under the inversion cools down to the dewpoint



temperature, becoming saturated so that droplets form. Inversion fog can occur in dry basins as well on occasions when inversions were preceded by inflow of moist air. This occurs in the Reno, NV area, for instance, when wet winter storms flow from the Pacific eastward over the Sierra Nevada, producing a temporary supply of moisture at the surface, and are followed by high pressure and clear skies that induce strong inversions.

Another feature of poconip is the formation of hard rime ice, a white ice that forms when water droplets in the poconip fog freeze to the outer surface of objects as temperatures drop below freezing. Hard rime forms mostly at night. As temperatures become colder, water droplets in the poconip are supercooled, but only condense as ice when they come in contact with a nucleating surface, such as tree branches, stones, or car windshields. The hard rime is a milky color, and though it looks fragile, it adheres tightly to surfaces and is very stable.

Thanks to Wally Woolfenden for conversations on the etymology of "poconip", and to Kelly Redmond and Jessica Lundquist for reviewing my weather notes and suggesting edits.



Left: Driving westward into the Mono Basin poconip.

Above: Inside the poconip.



Left: Rime ice. Photo: D. Dulen

Above: Poconip breaking up over Mono Lake. Photo: D. Dulen

Dunaway, D. 2006. Seeing through the fog. Mono Lake Newsletter. Spring 2006. Pgs 16-18.

DARE (Dictionary of American Regional English). Accessed May 16, 2013. <http://dare.wisc.edu/?q=node/133>

Higher Elevations = Colder Temperatures: True or False? Science Fair 2013

Caelen McQuilkin and Jordyn Harper

Lee Vining Elementary School, Lee Vining, California (6th & 5th grades, respectively)

The following is an excerpt from McQuilkin and Harpers' science fair exhibit.



Hypothesis: As you get higher in the mountains, the temperature usually gets colder.

Background: It's pretty much a fact that everyone knows: It gets colder as you get higher in the mountains. But is this really true? Here's some of the research we did on mountain temperatures. There are a lot of factors to temperature. Some are: sun/shade, weather (snow, rain, poconip, cold snaps, heat waves), and clouds. But if you put aside all of those factors, is it always colder in higher altitudes? Temperature inversions are the exceptions to "colder=higher". Here are some of the reasons why. Cold air is heavier than warm air, so on a calm night,

the cold air will sink down to all of the low places and valleys. This only happens sometimes, though, because it has to be really calm for the cold air to be able to sink down. This can occur for a few days, because the cold air can “pool” in the valleys.

Question: As you get higher in the mountains, does it always get colder?

Materials:

- | | |
|------------------------|--------------------------------------|
| 1. iButtons | 7. Wire Cutters |
| 2. Wire | 8. Ski Gear (downhill&cross country) |
| 3. Plastic Pipes | 9. Snow Shoes |
| 4. Screen | 10. Cross Country Skis |
| 5. Computer | 11. Mountain Bikes |
| 6. iButton Data Reader | 12. Snow Gear |

Procedure:

1. Get the iButtons and program them.
2. Place the iButtons in planned locations (at varied elevations).
3. Wait at least 6 days while they record the temperatures (every 10 minutes).
4. Collect the iButtons.
5. Download the data with the iButton reader and record it onto charts and graphs.
6. Compare elevations and temperatures (analyze data).

Results:

With our experiment, we found that...

- 10 of our iButtons were successful, but the eleventh one at Conway Summit had data problems, so we cut it out of our data.
- Our two Mammoth Mountain iButtons were frozen in rime ice when we went to get them, so we had to go back a second time five days later. One still recorded accurate data, but the other one (the 12th ibutton) recorded ice temperatures, so we threw out those data.

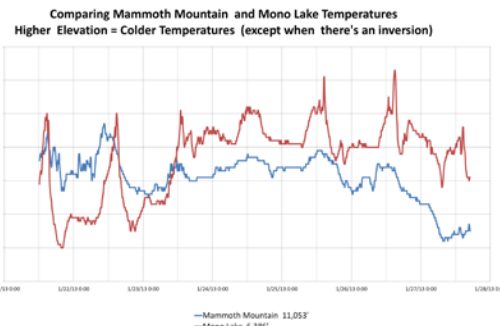


Figure 2. Temperature time series for high- and low-elevation stations showing inversion at the beginning of the period.

- We observed some heavy poconip ice fog at Mono Lake for the first few days of the experiment, and when the weather changed (increased winds), the poconip disappeared.
- We graphed all of the data, and it showed a clear pattern of the temperature changing as the elevation increased.
- Our graph shows that for the first two days, there were inversions (colder temperatures at lower elevations), then, there were just mixed up temperatures (as the weather changed), and for the last few days of our experiment, there were clearly colder temperatures at the higher elevations.

For example, at 6:00 am on January 22nd, it was -1.5°C at Mammoth Mountain, and -11.5°C at Mono Lake. This shows an inversion, which is an exception to “higher=colder.”

In contrast, another one of our graphs shows that at 6:00 am on January 27th, the top of Mammoth Mountain was -12°C , while Mono Lake was -2.5°C . The elevation difference is 4,667 feet. This supports our hypothesis.

- One more thing our graphs showed was that two different high elevation locations above the inversion still followed the general rule “higher=colder.”

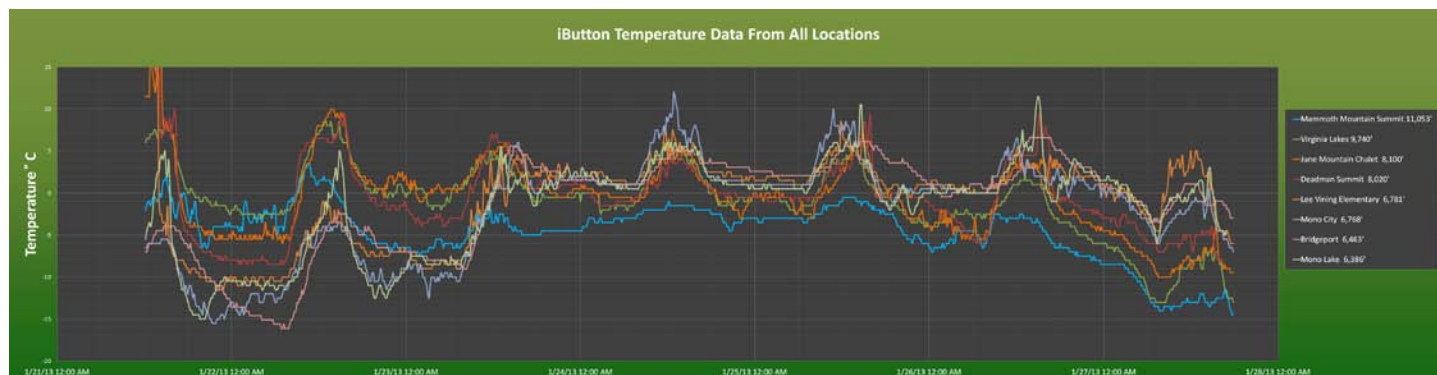


Figure 1. Raw temperature data from eight iButton stations ranging from 11,053 ft to 6,386 ft for the period 1/21/13 to 1/28/13. Cold air pooling occurred in the beginning of the period.

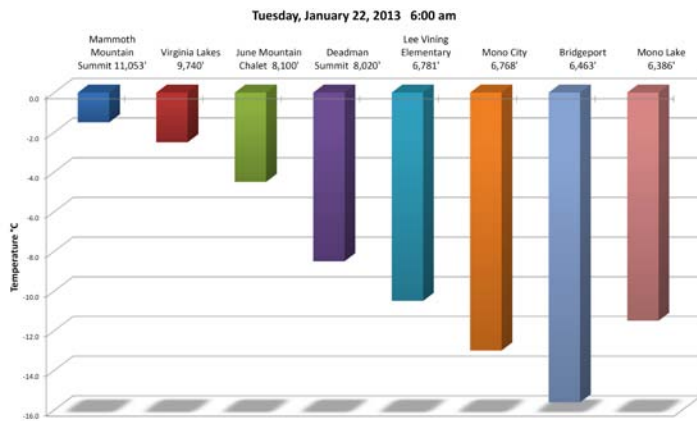


Figure 3. Temperatures along an elevational gradient at 6:00 am on a day of strong cold air drainage, January 22, 2013 (lower is colder).

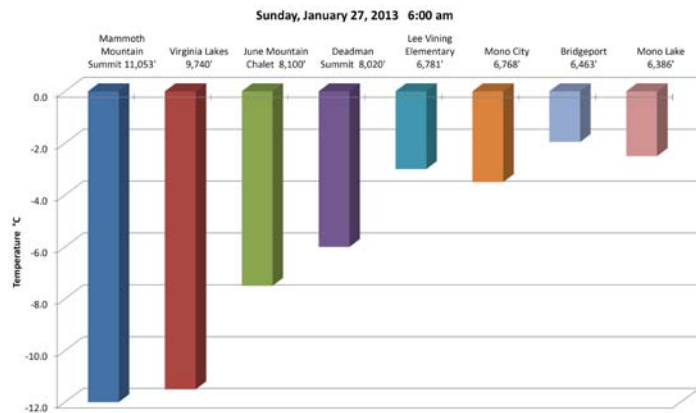


Figure 4. Temperatures along an elevational gradient at 6:00 am on a day of normal air conditions, January 27, 2013 (higher is colder).

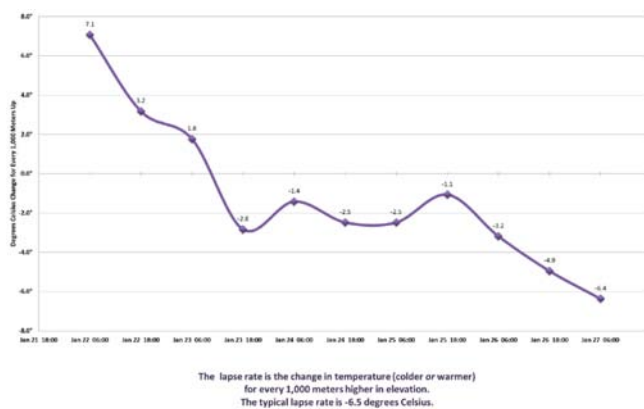


Figure 5. Lapse rates reveal strong inversion at the beginning of the period (positive values) and typical air flow later (negative lapse rate).

Conclusions:

- Our results support our hypothesis—it usually gets colder as you get higher in the mountains.
 - In our experiment, we found that when it *didn't* get colder as you get higher, inversions were the cause. The inversions caused the poconip that we had for the first few days.
 - Then the weather and wind mixed up the temperatures and the inversion went away, making it follow the pattern higher=colder (we learned that from Dr. Millar).
 - We wondered how often there are inversions. Dr. Millar told us that for an inversion to occur it has to be very calm so the colder, heavier air can pool in the lower locations, and it isn't that calm very often! If we wanted to test how many days there are inversions, we could leave out our iButtons for a whole year, and analyze when there were inversions and when there weren't.
- So, all of this adds up to: Our results supported our hypothesis!!



Figure 6. Caelyn (right) and Jordyn (left) preparing iButtons for deployment.



Figure 7. Biking and snow-hiking into mid-elevation sites.



Figure 8. Deploying iButtons at the highest-elevation site, Mammoth Mountain Ski Area.

Contributing Artists

Dean Davis retired from the US Forest Service in 2009 after 34 years working in the Pacific Southwest Regional forest-genetics program. His primary work was at the Happy Camp Outplanting Site in the Siskiyou Mountains, California, where he directed the installation and assessment of genetic test plantations. Currently he consults on disease evaluation, high-elevation white-pine cone collecting, and grafting work at the Placerville Nursery. Dean's work, *The Elders; Sugar Pine in the Morning*, graced the cover of a 2012 USFS publication entitled, "Proceedings of the Fourth International Workshop on the Genetics of Host-Parasite Interactions in Forestry: Disease and Insect Resistance in Forest Trees". Dean lives with his family off the grid in the northwest California mountains.

Jane Kim is artist, science illustrator, and founder of INK-DWELL (<http://ink-dwell.com/>), a studio based in San Francisco, California that "creates art that inspires people to love, appreciate, and protect the Earth". Kim began her art career early in life by obsessively painting flowers and bears on the walls of her bedroom. Later, she received formal training at the

Rhode Island School of Design in Printmaking, and then Cal State Monterey Bay, where she received a Certificate in Science Illustration. She combines rigorous observation of the natural world and meticulous attention to scientific detail with the spaciousness of street art. Jane's art is reproduced on the cover of this issue of MVN and scattered elsewhere; read about the Sierra Nevada Bighorn Sheep Migrating Mural project on page 52.

Jim Blanchard. I have known Jim since 1968 when we worked together at Hoodoo Ski Bowl in the Oregon Cascades as ski patrol (Connie) and ski instructor (Jim). A few years later we served as Wilderness Rangers together for the US Forest Service in the recently designated Three Sisters Wilderness. With degrees in science and outdoor recreation, Jim's career since 1979 was spent on the faculty of the Department of Physical Education at the University of Oregon, where he founded the Outdoor Pursuits Program and Outdoor Leadership Training Program. Jim was active for four decades in emergency medical services, serving as President of the Oregon Mountain Rescue and Safety Council. He retired from UO in 2009, and since then has honed his lifelong passion for mountain photography while he continues to forge new tracks into the Oregon wilderness.



Willie as a lamb. Painting by J.Kim



Willie at 6 years. Painting by J.Kim

Symphony of Science

A dance colleague of my daughter recently introduced me to a series of videos, *Symphony of Science*, that celebrates the awe of great science, mystery of timeless and universal questions, and glory of music and art. I hope you will be moved as I am by these joyous and hopeful works of art in the honor of science (or maybe you had to come of age in the 1960s ...)

Try starting with "A Glorious Dawn" and "Children of Africa", and you'll be hooked: <http://symphonyofscience.com/videos.html>

– Editor

About the Symphony of Science

(Adapted from Wikipedia, http://en.wikipedia.org/wiki/Symphony_of_Science)

The Symphony of Science is a music project created by Washington-based electronic musician John Boswell. The project

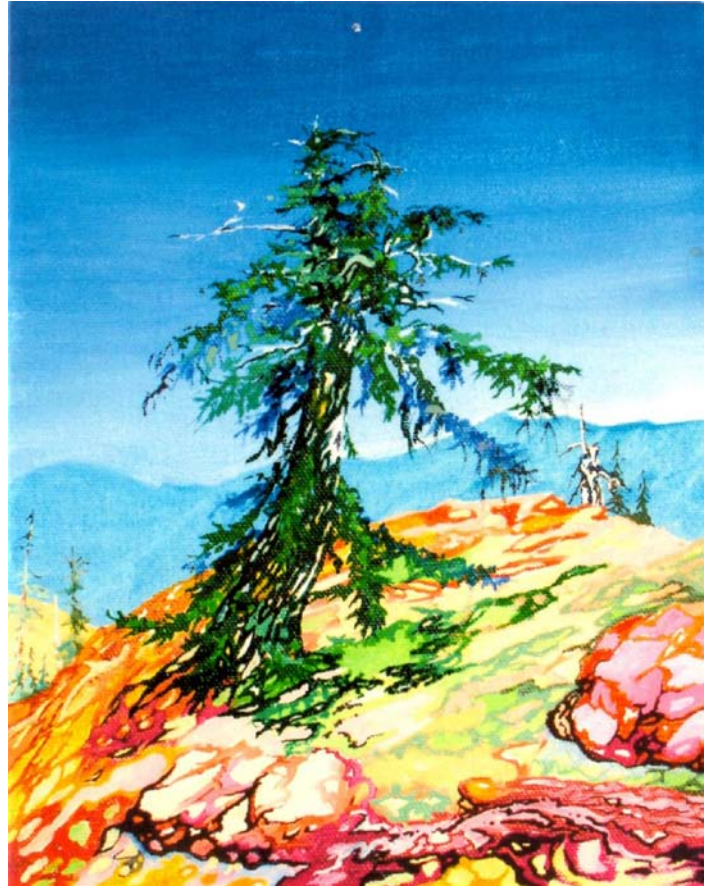
seeks to "spread scientific knowledge and philosophy through musical remixes." Boswell uses pitch-corrected audio and video samples from television programs featuring popular scientists and educators. The audio and video clips are mixed into digital mash-ups and scored with Boswell's original compositions. Two of Boswell's music videos, "A Glorious Dawn" and "We are All Connected", feature appearances from Carl Sagan, Richard Feynman, Neil deGrasse Tyson, Bill Nye, and Stephen Hawking. The audio and video is sampled from popular science television shows including *Cosmos*, *The Universe*, *The Eyes of Nye*, *The Elegant Universe*, and *Stephen Hawking's Universe*.

Unruly Media, a viral video tracking service, first charted "A Glorious Dawn" on September 21, 2009. A month later, the video had received more than a million views and was ranked in the music category on YouTube as one of the top rated videos of all time.



Orion Nebula

Mountain Visions
paintings by Dean Davis



Foxtail at Kings Castle



Ancient Foxtail



The Elders; Sugar Pine in the Morning



Sierra Nevada Bighorn Sheep. Photo: P. Yeager