

Mountain Views

Chronicles of the Consortium for Integrated
Climate Research in Western Mountains

CIRMOUNT



Informing the Mountain Research Community

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Goshawk, East Humboldt Range, Nevada, by Mackenzie Jeffress

Front Cover: Wizard Island—Crater Lake, Oregon, by Jim Blanchard

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Back Cover: Crater Lake Highway Snow Shadow Patterns, by Jim Blanchard

Read about the contributing artists on page 69.

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

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EDITOR'S INTRODUCTION

For many parts of the mountainous West, the winter of 2016-2017 achieved epic significance through relentless atmospheric rivers that yielded record snowdepths. Coming as it did on the heels of record drought years, the wet winter brought welcome relief to water- and snow-stressed mountain ecosystems, and also now affords abundant opportunity for curious mountain scientists to observe the effects of extreme interannual variability. In this issue of *Mountain Views Chronicle* we present articles, Brevia, and imagery centered around the theme of snow. Our CIRMOUNT colleagues, Adrian Harpold, Mike Dettinger, and Seshadri Rajagopal, proposed a useful distinction in the relationships of snow, water, and drought through their 2017 article in *EOS* on dry snow drought (low winter precipitation) and warm snow drought (lack of snow accumulation due to warm temperatures). We are pleased to reprint this article on page 2, and include Brevia articles that summarize recent papers on a diversity of snow issues as well. The Voices in the Wind section for this issue also responds to ideas in the *EOS* article.

I draw your attention to two interviews of notable CIRMOUNT colleagues. Greg Greenwood has recently retired after thirteen years as Executive Director for the international Mountain Research Initiative. Greg was an important founder and supporting coordinator of CIRMOUNT; we have looked to

his guidance and strategic thinking for many years. Here is a chance to honor and thank Greg for his support and dedication to mountain science and sustainability around the world. Another longtime CIRMOUNT colleague, Chris Daly, creator and arch-genius of the PRISM climate model, also generously offered responses to the open-ended questions I posed about his career and the path to developing PRISM.

I am especially grateful to Toni Lyn Morelli for her thoughtful and carefully-researched essay on the role of women in science. Unconscious biases lurk where we least expect them, and with humor and compassion Toni Lyn helps to uncover those. As a pika enthusiast, I am delighted that Nifer Wilkening was willing to share her adventures seeking the Royle's pika in the high Himalaya. Along with other contributions of art and prose, we usher in the spring melt and welcome summer. May your travels be prosperous and contain many mountain adventures.

—*Connie Millar*, May 30, 2017



ARTICLES

The following article is reprinted with permission from the American Geophysical Union. Harpold, A. A., M. Dettinger, and S. Rajagopal. 2017. Defining snow drought and why it matters, Eos, 98, <https://doi.org/10.1029/2017EO068775>. Published on 28 February 2017.

Defining Snow Drought and Why It Matters

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Swings from snow drought to extreme winter rainfall make managing reservoirs, like the Oroville Dam, incredibly difficult. But what exactly is "snow drought"?



A snowboarder threads his way through patches of dirt at Squaw Valley Ski Resort on 21 March 2015 in Olympic Valley, Calif.
Photo: Max Whittaker/Getty Images

On 12 February, water resource managers at the Oroville Dam issued an evacuation warning that forced some 180,000 Californians to relocate to higher ground. The story of how conditions got to this point involves several factors, but two clearly stand out: the need to prevent water shortages during a record drought, followed by one of the wettest October–February periods in California history.

The situation at Oroville Dam highlights difficulties that many reservoir managers face in managing flood risks while simultaneously storing water to mitigate severe droughts and smaller snowpacks. Central to this difficulty is the idea of “snow

drought,” a term that’s gaining traction in both scientific and lay literature.

Snow drought refers to the combination of general drought and reduced snow storage. However, among references to snow drought, we observe conditions that reflect

- a lack of winter precipitation or
- a lack of snow accumulation during near-normal winter precipitation

We propose a new classification to differentiate “dry snow drought” from “warm snow drought.” These two uses of snow drought have different scientific underpinnings and different implications for water supply forecasting and management. To clarify future uses of this terminology, we propose a new classification to differentiate “dry snow drought” due to lack of precipitation from “warm snow drought,” where temperatures prevent precipitation from accumulating on the landscape as a snowpack.

Here we use snow conditions during winter 2015 on the West Coast of the United States to illustrate the difference. We also show how snow drought, if not properly incorporated into management decisions, can heighten the potential for emergency situations like the one unfolding at Oroville Dam.

Subtle Definitions with Important Implications

Drought means different things in different contexts.

“Meteorological drought” is defined as a period of below-average precipitation. “Hydrological drought” refers to water storages and fluxes falling below long-term averages.



Students from the University of Nevada, Reno, learning how to measure streamflow at Sagehen Creek Field Station in California's Sierra Nevada during a small rain-on-snow event in March 2016. Winter rain during drought, or warm snow drought, has different management implications than dry winters, or dry snow drought. Photo: Adrian Harpold

Then there's "anthropogenic drought," the phenomenon of how most projections of future drought include increases in severity and duration that reflect increasing water demand due to warming (Diffenbaugh et al., 2015). Add to this the emerging terms of "snow drought," and you now have a pretty complex picture.

Although meteorological droughts remain difficult to predict in the western United States, widespread declines in snowpack have been observed across the region. These declines, which have been attributed to warming air temperatures and related trends, reflect earlier snowmelt and shifts from snow to rain (e.g., Hamlet et al., 2007; Harpold et al., 2012).

Despite decades of research on changing snowpacks, recent extreme lows in snowpacks have revealed the extent of the unique challenges that snow droughts pose for water managers. To help scientists and resource managers plan for challenges to come, they need to be equipped with solid definitions of all forms of drought, snow drought included.

Winter 2015 on the West Coast: A Tale of Two Snow Droughts

The 2015 winter (from November 2014 through March 2015) highlighted two types of snow drought and their challenges

for water management in the westernmost United States. The winter was abnormally warm, with temperatures in the Pacific Northwest (Washington, Oregon, and Idaho) averaging 3.0°C above normal and temperatures in the Sierra Nevada (California and Nevada) averaging 3.4°C above normal.

Winter precipitation, on the other hand, varied considerably from north to south, with the Pacific Northwest receiving 70% to 120% of its normal precipitation while the Sierra Nevada received only 40% to 80% of normal (Fig. 1).

Despite large differences in the amounts and timing of winter precipitation, the snow water equivalent (SWE) in both regions was less than average. On 1 April 2015, snowpack contained between about 50% of the water it usually holds in the Pacific Northwest and a startlingly low 5% in the Sierra Nevada (Fig. 1).

These low SWE amounts resulted from two distinct drivers of snow drought. Snow drought in the Pacific Northwest reflected a lack of snow accumulation due to warm temperatures that increased rainfall and melted snowpacks, despite near-normal precipitation. Snow drought in the Sierra Nevada also reflected similarly warm temperatures but was enhanced beyond the Pacific Northwest's deficits by the lack of winter precipitation.

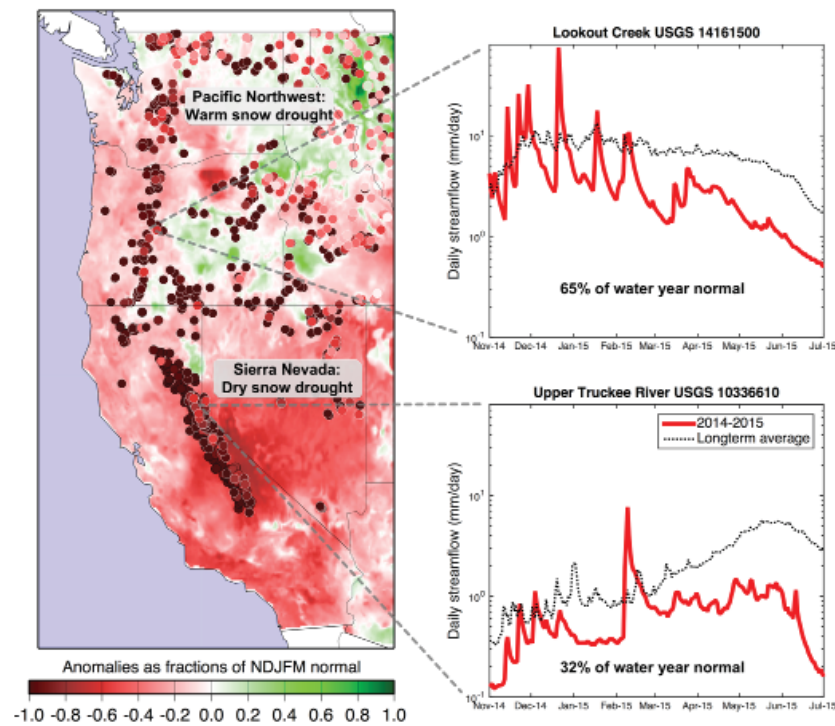


Fig. 1. (left) Precipitation from 1 November 2014 to 31 March 2015 was near normal in the Pacific Northwest and well below normal in the Sierra Nevada (colored map), whereas 1 April 2015 snow water equivalent was below average across the domain (colored dots). (right) These differences in precipitation and snowpacks led to starkly different streamflow responses at two characteristic U.S. Geological Survey stream gauges. Credit: PRISM, NRCS/CA DWR; USGS

2015 Effects on Downstream Water Resources

Streamflow responses to the different snow droughts differed considerably between the regions.

The rainfall that replaced snowfall in the Pacific Northwest yielded large winter peak streamflow events (Fig. 1). With most of the water leaving basins in winter rather than during the usual snowmelt season, summer streamflow was far below normal. With less precipitation and warmer temperatures, streamflow in the Sierra Nevada lacked both large winter flows and its usual spring snowmelt pulse and fell to extremely low levels early in the summer.

Few drought metrics include storage and release of snow water. Streamflow responses generally depend on topography and geology of a given basin but in this case reflect these different snow conditions across both regions. The distinct responses illustrated here have large implications for water management and ecological water availability.

However, the same term, snow drought, was used to describe snow conditions in both regions. A more nuanced definition of

snow drought could facilitate discussions, planning, and response for droughts and changing snowpacks.

Defining and Quantifying Snow Drought

We propose more precise terms to distinguish between the two different snow droughts observed in the Pacific coast states in winter 2015: dry snow drought for precipitation-driven snow drought and warm snow drought for temperature-driven snow lack. Both types of snow drought have SWE that is notably less than normal.

In a warm snow drought, scenarios where SWE is low but precipitation (P) is not (thus a low SWE:P ratio) reflect a larger than normal amount of precipitation has fallen as rain rather than snow or an unusual amount of melt has occurred or both [e.g., Cooper *et al.*, 2016]. If the SWE and precipitation are nearly equal (SWE:P is close to 1) and SWE is below normal, winter precipitation must also be below normal, and the lack of SWE is likely a reflection of low precipitation—a dry snow drought.

Because several of the storms were warm rainfall, snowpack in California by 1 January was only 64% of normal. The challenge

of differentiating dry and warm snow droughts using drought monitoring networks highlights a common weak point: few drought metrics include storage and release of snow water. For example, the Palmer drought severity index (PDSI) used by the U.S. Drought Monitor treats all precipitation as rain. This simplification in the PDSI means it cannot distinguish between warm and dry snow droughts.

Physically based models, such as the North American Land Data Assimilation System (NLDAS) drought monitor, represent accumulating and melting snowpacks, but their results remain spatially coarse and challenging to verify over large areas. Given different effects of warm versus dry snow drought on water-related decision-making, drought monitoring needs to better distinguish the two.

Snow Drought and Water Management

A reservoir manager is faced with balancing the following:

- capturing inflows to reservoirs so that they will still be available for use in the summer
- maintaining enough empty space in reservoirs to capture or ameliorate large flood flows, requiring that large winter flows pass immediately through the reservoirs to maintain extra storage

Snow reservoirs, the water stored in mountain snowpacks, aid both management purposes. Snowpacks are particularly important to western water supplies because they historically persisted into summer when water demand is the highest and prediction of flows is more accurate (being based on snow on the ground rather than on rains to come). The natural reservoirs of water formed by the snowpacks expand the usefulness and reliability of man-made reservoirs by releasing water predictably and closer to times of high demand.

Winter precipitation that falls as rain generates much greater flood risk than when storms deliver snowfall. So most western water management decisions, such as the amount of water to release from a spillway, rely on accurate forecasts of near-term rains and eventual seasonal streamflow amounts, the latter of which depends on the amount of water in the region's "snow reservoirs," which is reduced by snow droughts of either flavor.

In the context of reservoir management, snow drought presents different challenges. During a dry snow drought, streamflows are low, and inflows to reservoirs are reduced all year long. If one knew that such a drought would occur, precipitation and streamflow moving downstream might be captured and stored in dam-impounded reservoirs.

In a warm snow drought, streamflow arrives earlier than normal, but the prospects of a rich spring snowmelt season are limited. Reservoir management is then faced with immediate flood risks followed by subsequent drought conditions.

California and the Case of Oroville Dam

Western water woes are dynamic. To illustrate how quickly fortunes can change, consider the remarkable transition that this fall and winter have brought to California's snowpacks and streamflows.

October through December 2016 were very wet months in northern California (with precipitation totals about 170% of normal by 1 January 2017), but because several of the storms were warm rainfall, snowpack in California by 1 January was only 64% of normal. The extra precipitation quickly ran off into impoundments and wetted the landscape. A long string of storms that followed in January and February filled reservoirs, in some cases to the brim.

The early winter snowpack deficits, however, signaled a real possibility that this coming summer might end up being a return to drought conditions, as many of the region's reservoirs were still below average following the 2012–2015 drought. So there was a need to impound as much water as possible to provide water during what might be a summer drought.

In the case of the Oroville Dam, water managers are currently battling with a reservoir that is now filled to (and beyond) capacity but that contained only 46% as much water on the same date in 2015 in the midst of the snow drought described above (and only 30% as much water by water year's end). Not knowing how the winter would play out, California's water managers began by storing water during fall rains to buffer against a potential developing snow drought, but instead, they got a record wet winter up to now.

The (Unknown) Hydrological Effects of Snow Drought

The definitions of warm and dry snow drought help to frame science that is fundamental to water management challenges facing snow-dominated regions:

- Which form of snow drought (dry or warm) is likely to dominate in different areas under future climate scenarios?
- How and where can monitoring and management infrastructure be updated to meet the challenges associated with increasing warm or dry snow drought?

Climate models suggest that shifts from mostly dry to increasingly warm snow drought could be a consequence of regional warming (Pierce and Cayan, 2013). However, shifts to warm snow drought are expected to depend unevenly on elevation, moisture sources and transport, and the timing of precipitation.

Thus, retrospective analyses of warm versus dry snow drought are needed to identify areas that have begun to shift from dry to warm (or to warm and dry) snow drought predominance, and networks and sensors for monitoring the full range of snow conditions are critical to better characterize current and future snow droughts.

We also need better measurements of what phase (rain or snow) is falling during precipitation events. Mixes of rain and snow from place to place, storm to storm, and year to year are almost always inferred indirectly from temperature or changes in SWE (Rajagopal and Harpold, 2016). But direct knowledge could help water managers manage today and plan for the future.

Another monitoring challenge is the scarcity of precipitation and SWE measurement at the highest elevations. Although emerging snow remote sensing methods are suited for filling in gaps in traditional observation systems, expanding ground-based observations of precipitation, SWE, and phase into higher elevations soon will be critical to developing the long-term records needed to define snow drought and its causes over time (Dettinger, 2014).

Concerted efforts by scientists, agency-run monitoring networks, water managers, and policy makers will be needed to address the pending prospects of snow drought and how it fits into decision-making. For example, what should water managers do to deal with nearly record breaking snow droughts and flood years in rapid succession? We have only to look to the reservoir behind the Oroville Dam over the last 3 years to see these challenges illustrated in dramatic ways.

In response to changing snowpacks and more extreme droughts, we will need a common but nuanced definition of snow drought to facilitate efforts and better manage our water supplies. With such definitions in hand, we may be better equipped to face future water woes in the West.

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Advances in Snow Hydrology and Water Management with the NASA Airborne Snow Observatory (ASO)

<https://aso.jpl.nasa.gov/>
(as relayed by Connie Millar, Editor)

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Tom Painter presented an overview of the NASA Airborne Snow Observatory (ASO) at the last MtnClim climate conference (MtnClim 2016; <http://www.mtnclim.org/>) in Leavenworth, WA. The information he shared is extremely important to CIRMOUNT colleagues, and although Tom hasn't had time to develop an article for Mountain Views Chronicles, I offer a brief overview (with his approval) of the program so as to alert our community to this valuable resource that continues in development.

MtnClim 2016 Abstract (modified)

Tom presented scientific and water resource applications of data and modeling from the NASA Airborne Snow Observatory (ASO) in the Western US, as well as the ecosystem, geomorphology, glaciology, and infrastructure applications of these data. ASO is a measurement and modeling system developed to breakthrough to comprehensive snow water equivalent mapping and quantitative physically based runoff forecasting. The measurement component combines scanning lidar, imaging spectrometer, and snow physical modeling to produce unprecedented distributed mapping of snow water equivalent and snow albedo across mountain basins. The modeling component assimilates these data into distributed snowmelt and runoff models of varying complexities and purposes. Tom presented results from the Sierra Nevada, Colorado River and Rio Grande River, Olympic Peninsula, and the Oregon Cascades. These results show the first examples of marked improvements in understanding of snow distribution, snowmelt distribution, water allocation, runoff forecasting, and ecosystem functioning.

From the ASO Website

Methods

The two most critical properties for understanding snowmelt runoff and timing are the spatial and temporal distributions of snow water equivalent (SWE) and snow albedo. Despite their importance in controlling volume and timing of runoff, snowpack albedo and SWE have been largely unquantified in the US and not at all in most of the globe, leaving runoff models poorly constrained. NASA/JPL, in partnership with the California Department of Water Resources, has developed the ASO, an imaging spectrometer and scanning lidar system, to quantify SWE and snow albedo, generate unprecedented knowledge of snow properties for cutting edge cryospheric science, and provide complete, robust inputs to water management models and systems of the future.



ASO flight departing Mammoth-Yosemite Airport

Instruments

NASA/JPL has created the ASO, a coupled imaging spectrometer and scanning lidar system. ASO uses the imaging spectrometer to quantify spectral albedo, broadband albedo, and radiative forcing by dust and black carbon in snow. The scanning lidar is used to determine snow depth against snow-free acquisitions and quantifies snow water equivalent when combined with in-situ constrained modeling of snow density

Imaging Spectrometer

ASO uses an ITRES CASI-1500 imaging spectrometer, which captures imagery in 72 spectral bands from the visible to the near-Infrared. Ground pixel size is approximately 2m from a flight altitude of 15,000ft above ground level. This provides spectral albedo of the snow surface, which is used to determine the energy absorbed from incoming sunlight. This, combined with energy balance modeled from meteorological conditions, yields snowmelt rates.

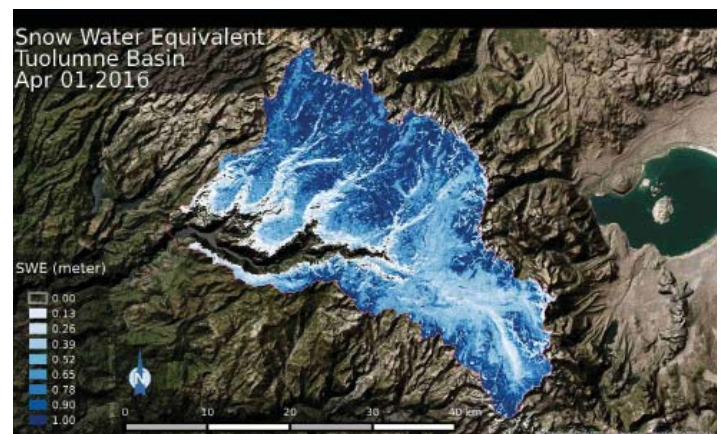
LIDAR

ASO uses a Riegl Q1560 scanning lidar, which captures the surface topography with < 10 cm vertical accuracy. Depth is calculated by subtracting a summer “snow-free” dataset from each winter “snow-on” dataset. The accuracy of these data is dependent upon precise knowledge of the aircraft position

during the measurements. An integrated Applanix Inertial Measurement Unit (IMU) and GPS provide aircraft attitude and position information, and this information is combined with error corrections from an existing network of GPS base stations at fixed locations near the survey area. This combined use of the IMU for high-speed attitude information, along with the differential GPS solution for absolute position, yields the sub-decimeter aircraft trajectory accuracy necessary for LiDAR snow depth measurements.

Products

ASP produces maps that are georeferenced and date-stamped. See <https://aso.jpl.nasa.gov/> "maps" for products such as this:



Sierra Crest View 2016-09-22 at 9.16.34 PM



Sierra Crest View 2016-07-10 at 10.11.29 AM

Reprinted from *Crown of the Continent and the Greater Yellowstone Magazine*,
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Snowshoe Hares: A Deadly Game of Hide and Seek

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Caught still wearing winter white after the early onset of snowmelt, a snowshoe hare is easy prey. Photo: Sneed B Collard III

hares across the West year-round, learning where they moved, where they hid, who ate them and how often. We studied them across different forest types and full moons and blizzards and heat waves. Really, what we did, year after year on snowshoes and snowmobiles, up and down steep slopes with mosquitoes in our ears, was to learn – scientifically speaking – the implications of the many ways that hares can die.

Over time, we increasingly saw bright white hares hopping around on a snowless brown forest floor in late October or mid April. We had been studying the ways that predation shaped hare behaviors and population

trends, but those mismatched, light bulb bright critters got my mind spinning. Paul Griffin, my PhD student back in 2000, found that hares died more in fall and spring than in deep winter or summer. We wondered: Why? Could it be because they have mismatched coat colors on snowless ground?

For me, these early musings about the potential costs of coat color mismatch eventually collided with emerging findings from the field of climate science in a reverberating “ah-ha!” moment. Pouring out of climatology labs from around the world (including Steve Running’s at the University of Montana) came clear evidence that the duration of seasonal snow cover is decreasing fast. And the thing is, you don’t need to believe in any climate model to know this is true. Just go anywhere in the world with seasonal snow (Montana, Maine, Mongolia, Alberta, Scotland, Italy), find a person who has spent a lifetime observing the seasons (perhaps a hunter, birdwatcher, logger, or skier), and ask them if the duration of winter is shorter now, on average, than when they were young. I’ll bet 50 bucks they say yes.

With the realization of the globally shortening snow



A perfect match for winter. Mills Research



First week of June molting stage. Nate Steiner/Flickr

duration, I dug into what was known about seasonal coat color. Lab studies had shown the timing of the coat color molt was, like migration, hibernation, and other seasonal (phenological) traits, driven by changing day length. This makes sense, as day length is a reliable cue, long term, of the comings and goings of snow. Over time, snow has come early or late in different years, but on average, the shortening days of fall indicate that snow will soon arrive, and the lengthening days of spring herald the coming thaw.

What does it mean if the timing of the molt is set by photoperiod, but snow duration is rapidly

decreasing? Will coat color mismatch increase in the future? Does mismatch make animals easy targets for predators, and could it lead to the eventual decline of a species? Do animals have tricks (we call it “plasticity”) up their furry sleeves that help them deal with mismatch, perhaps by adjusting molt timing year to year or behaving in ways to minimize mismatch or its consequences? Could natural selection change the timing of the molt, prompting “evolutionary rescue” that decreases mismatch fast enough to prevent species declines? In the end, will climate change be likely to send coat color changing species toward oblivion, or will they be able to adapt? These are questions that have yet to be answered for snowshoe hares, or for that matter, any species facing climate change.

*By the way, right about here some folks will say: “of course these rabbits will be fine, because they breed like rabbits!” But, hares are *not* rabbits. Hares are born above ground—exposed to predators from birth—and have modest litter sizes compared to rabbits.*

Therefore, my research team is throwing everything, including the kitchen sink, at answering the question of whether or not wild animals can locally adapt to rapid climate change. Over the past six years, we have radio-collared more than 300 snowshoe hares so we can find their locations once per week. If they're dead, we figure out who killed them, and where. If they're alive, we record their coat color so we can quantify the timing and speed of the coat color change, and we record snow around each hare to quantify the mismatch between the hare and the ground. We also measure behaviors to test whether or not hares can perceive their own mismatch and act to decrease the chance of becoming someone's next meal.

Out in the field with my graduate students Marketa Zimova and Alex Kumar and dozens of hard-core field helpers and collaborators, we've already learned a lot. The fall molt to white starts with the ears and lower abdomen, then spreads through the body, with the face and back the last to turn white; spring molt is roughly

in reverse order, except more splotchy and mottled. The total time from start to finish is about 40 days for both the fall and spring molts. As expected, for a seasonal trait timed to changing day-length, we do not see a chameleon-like ability to adjust the beginning date of the color molt in years when the snow comes late or leaves early. Whether it was the monster long snow year of 2010-2011 or the historically short snow year of 2009-2010, the molt in the western Montana Seeley Lake hares begins like clockwork about October 10 and the spring molt about April 10.

We also find the coat color change is adapted to track local average snowpack. In our Gardiner study site outside Yellowstone National Park—about twice the elevation of our western Montana study site and with much longer snow duration—hares remain white about five weeks longer.

When hares are mismatched, they are indeed more vulnerable to being killed by raptors, lynx, bobcats, foxes, coyotes, and marten that prey on them. Our field



Over the past six years, we have radio-collared more than 300 snowshoe hares so we can find their locations once per week.

Researchers use telemetry to locate collared hares in the rugged Swan Mountains. Mills Research

studies show that for every week a hare is mismatched, it is seven percent more likely to be killed than other individuals who are matched against their background. As to whether hares can perceive that they are mismatched and then take actions (like hide, or flee, or pick a spot to be better matched), they don't seem to know what's going on.

What happens when we put the cost of mismatch up against the rigorous, locally downscaled climate change projections of shortened winters in the future? Assuming the color molt timing stays as it is now, over the next 50 or so years, the number of days that white hares will be mismatched on a snowless background will be four to eight times more than it is now, and that mismatch will be deadly.

But wait... we also found that within hare populations, individuals are remarkably variable in their coat color timing and rate of molt—some start earlier, or later than others. This is exactly what you would expect: because snow has always differed in when it comes and goes each year, an inconstancy in coat color timing has allowed the persistence of these populations through those long and short winters. And the within-population variability is mirrored across populations, where we find that molt timing is shaped to local snow conditions like Seeley Lake versus Gardiner.

Could evolution rescue species from the rapidly shifting conditions of climate change by altering the timing of the molt to track reduced snow duration? We are pushing hard to answer this question. In addition to the field-based measurements, another key piece includes unravelling the genetic basis of the coat color change. For this part, I am collaborating with Dr. Jeff Good at the University of Montana and Drs. Paulo Alves and Jose Melo-Ferreiro at the University of Portugal. Also, here at North Carolina State University we've built a one-of-a-kind experimental facility where animals can be kept in photoperiod and sub-zero temperature controlled conditions like those found in the north. We have



Snowshoe hare education in the field.
Snead B. Collard III

Montana and Washington hares undergoing their normal color molts, allowing us to tease out key questions regarding genetic inheritance, ability for animals to adjust behaviors or molt, and other questions. We're also expanding the project globally, with new coat color change research collaborations underway in the Northeast on weasels, in Scotland and other parts of Europe on mountain hares, and in Sweden on Arctic foxes.

The charismatic poster-child of climate change is mismatched white animals on a brown snowless background. On the one hand, the picture underscores a direct and real consequence of climate change. But on the other, it implies that natural selection may play a powerful role in determining how this story unfolds in the years ahead.

For the good of both humans and non-humans, we clearly must continue to address the underlying causes of climate change. However the potential role of natural selection implies very real steps that could be taken in the meantime to foster evolutionary rescue. Adaptive evolutionary change requires populations to be relatively large, with connectivity across the landscape with other populations, and with reduced stressors coming from other factors (such as land use change, invasive species, and habitat fragmentation). While we fill in the details of the science behind this story, we can say for sure that any actions taken to foster evolutionary response by maintaining large, connected populations will increase the chance for wild animals to persist in the face of rapid climate change. That's the hands-on, hopeful story that the hares have told me.

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For technical articles, see:

Mills, L.S., Zimova, M., Oyler, J., Running, S., Abatzoglou, J.T. and Lukacs, P.M. 2013. Camouflage mismatch in seasonal coat color due to decreased snow duration. *Proceedings of the National Academy of Sciences* 110:7360-7365.

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Elevated Precipitation Uncertainty: Differences in Gridded Precipitation Datasets across the Mountainous West

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Henn, B., A. J. Newman, B. Livneh, C. Daly, and J. D. Lundquist. An assessment of differences in gridded precipitation datasets in complex terrain, Journal of Hydrology, doi:<https://doi.org/10.1016/j.jhydrol.2017.03.008>. See online version of the article for interactive and downloadable maps of differences between datasets.

The use of spatially distributed precipitation datasets has grown in many areas, e.g., in driving distributed hydrologic models, in evaluation of remotely sensed precipitation datasets, and in assessments of climatic variability. But, as will come as no surprise to the mountain climate community, quantitative radar and satellite-based precipitation estimates typically are unreliable over the mountainous West, and so distributed datasets are based on measurements made at points (precipitation gauges). It will also not be surprising that this distribution of precipitation is challenging due to high spatial and temporal variability in the mountainous climates (Frei and Schar 1998, Roe 2005, Minder et al. 2008), sparse precipitation gauge networks in high-elevation and mountainous areas (Lundquist et al. 2003), and gauge undercatch in snow-dominated and windy areas (Sieck et al. 2007, Rasmussen et al. 2012). Thus, there is the potential for substantial uncertainty in gridded precipitation datasets, and the magnitudes of these uncertainties are often not well known. Because gridded precipitation datasets use topography as a predictor, and precipitation gauges tend to be located at relatively lower elevations, we hypothesized that uncertainties and differences between datasets will be larger at higher elevations.

Due to the challenges in estimating precipitation over complex terrain, studies have demonstrated significant uncertainty or biases at specific locations in gridded datasets using independent precipitation observations (Gutmann et al. 2012, Livneh et al. 2014, Lundquist et al. 2015). In particular, hydrologic modelers should be cognizant of the potential for biased precipitation forcing data, and systematic evaluation of differences among gridded precipitation datasets would help estimate the magnitudes of the uncertainty associated with these datasets. Some datasets explicitly estimate and publish the uncertainty in the methodology used to generate them (Newman et al. 2015), but we were not aware of prior studies that have evaluated the

differences between high-resolution gridded precipitation datasets over a comprehensive spatial domain and extended time period.

We compared six gridded precipitation datasets over the Western United States: Hamlet et al. (2010), which extends an earlier dataset (Hamlet and Lettenmaier 2005); Livneh et al. (2015), which extends the earlier dataset of Maurer et al. (2002); the Parameter-Elevation Regression on Independent Slopes Model (PRISM) 2.5 arc-minute (~4 km) monthly historical dataset (Daly et al. 1994, 2008); the North American Land Data Assimilation System Phase 2 (NLDAS-2) (Cosgrove et al. 2003, Xia et al. 2012); and the ensemble dataset Newman et al. (2015); and Daymet (Thornton et al. 1997). We chose these datasets because they have sufficient spatial resolution, 1/8° (about ~12 km) or higher resolution, to capture precipitation in the complex terrain of the West, and because they represent independent efforts to distribute precipitation across complex terrain from gauge observations. All of the datasets use daily precipitation gauge observations from the National Weather Service Cooperative Observer program (though some include additional gauge networks), and so differences between them largely should be due methodological choices in the spatial interpolation.

PRISM (Daly et al. 1994, 2008) also provides 30-year spatial precipitation climatologies at 800 m resolution over the continental United States, using multiple gauge networks and weighted linear regression of precipitation with elevation that take into account empirical influences on the long-term mean spatial pattern, which for precipitation includes topographical aspect and coastal proximity. The PRISM precipitation climatologies inform the interpolation in some of the other gridded datasets (Hamlet et al. 2010, Livneh et al. 2015, and NLDAS-2), though Newman et al. (2015) and Daymet do not use PRISM. Other methodological differences between the datasets are discussed in the paper.

To compare the datasets against one another, we aggregated higher resolution datasets to the coarsest grid (the 1/8° NLDAS-2 grid). The six datasets have a temporal overlap which covers water years 1982-2006. For each water year and each grid cell in the domain covering the mountainous West, we calculated water

year precipitation totals, and then pairwise differences between the datasets for each year. We were interested both in the absolute differences in water year precipitation totals, and in the relative differences, which we calculated as absolute differences divided by the six-dataset average.

Figure 1a shows that the highest absolute differences between the datasets occur in the maritime mountain ranges of the Western United States (Sierra Nevada, Coast Ranges and Cascades), with additional significant differences over the Rockies. Thus, (and perhaps not surprisingly) the largest absolute differences occur in areas with the highest mean precipitation, where methodological interpolation techniques can produce larger differences. These are predominantly higher-elevation and coastal regions. In contrast to absolute differences, relative differences (Fig. 1b) tend to be greatest in the rain shadows and deserts of the inter-mountain West, while relative differences are smallest in coastal lowlands and windward foothills of the maritime ranges. (Maps of these differences are available in GeoTiff format as supplementary materials and as interactive maps in the online version of the article).

Figure 2 shows absolute and relative differences plotted against elevation for the Colorado Rocky Mountains and the Cascade Mountains of Washington and Oregon (boxed in Fig. 1). In both regions, absolute differences increase with elevation; the relationship with elevation is stronger in the Rockies than in

the Cascades. While there is still greater relative uncertainty at higher elevations, the relationships are weaker than for absolute differences; relatively dry regions on the lee of the Cascades have higher relative differences despite being lower in elevation than the crest of the range itself.

We also examined monthly differences between datasets in Figure 3. The absolute and relative differences in Figure 3 were averaged over a spatial domain covering the Sierra Nevada mountain range of California (also boxed in Fig. 1). The monthly analysis shows that absolute differences are greatest during the winter months, when most of the precipitation falls in the Sierra Nevada. Relative differences, however, are much greater in the summer, when precipitation amounts are small and often driven by convective storms, which are likely more difficult to represent in gauge interpolation.

One independent method of evaluating gridded precipitation datasets is by their match to streamflow observations at the watershed scale (e.g., Henn et al. 2016). In Figure 4, we compare basin-mean, water year-total precipitation from the gridded datasets to streamflow volumes normalized by basin area for three unimpaired alpine watersheds in the Sierra Nevada: the North Fork of the American River at North Fork Dam, Cherry and Eleanor Creeks, and Bear Creek. For the North Fork of the American, the six datasets tend to cluster closely for each water year, and when compared against streamflow observations,

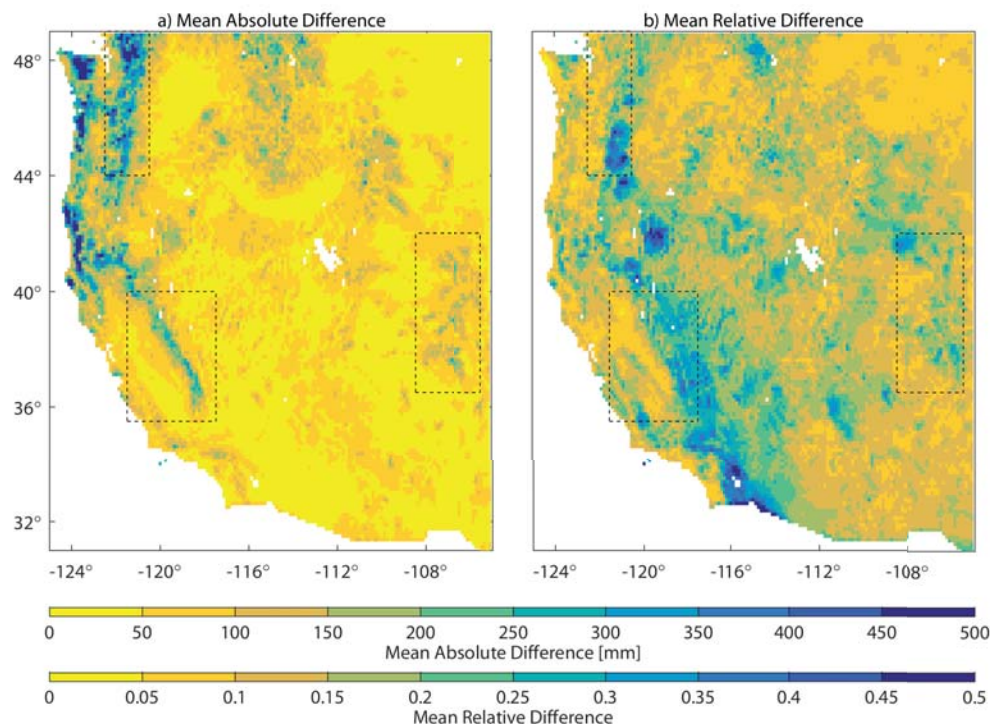


Figure 1. a) Absolute differences between datasets averaged over all dataset pairs and years. b) Mean relative differences averaged over all dataset pairs and years. The boxed areas indicate subsets referenced in the Figures 2 and 3.

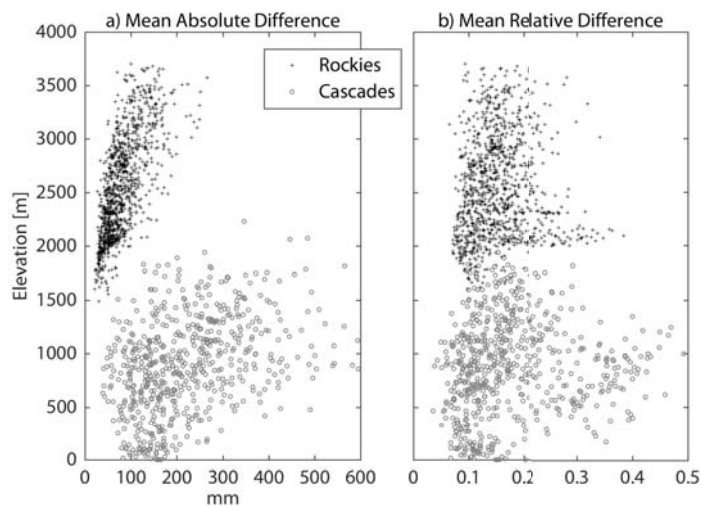


Figure 2. a) Mean absolute differences between datasets for two subset areas plotted against elevation. b) Mean relative differences between datasets plotted against elevation for the subset areas.

the datasets' water year totals mimic the observed temporal variability between wet and dry years, and generally are greater than streamflow by 500—1,000 mm per year, a plausible estimate of evaporative losses for this basin (Goulden et al. 2012). However, for Cherry-Eleanor, the gridded datasets' precipitation is of a similar magnitude to streamflow, implying implausible near-zero evapotranspiration in these basins. This is an example of all of the gridded datasets likely underestimating precipitation to various degrees. In the Bear Creek basin, the agreement among the gridded datasets' water year precipitation is poor, with differences of over 500 mm, or 40%, appearing for many years. Over 1982—2006, the mean relative differences of water-year total precipitation were 11% for the North Fork of the American, 17% for Cherry-Eleanor, and 24% for Bear. However, actual uncertainties between the datasets estimates and true basin-mean precipitation may be higher if the datasets are collectively biased low or high on average.

Finally, gridded datasets may be used for assessments of climate variability and trends. We compared linear best-fit trends in each dataset's water year precipitation totals over 1982—2006 (Fig. 5). Qualitatively, some similarities are noticeable between the datasets' trends: all show increasing precipitation in coastal Southern California and decreasing precipitation over the deserts of interior Southern California and Arizona and parts of the Great Basin and Rocky Mountains. However, the trends are also substantially different across the datasets, with some exhibiting higher-frequency spatial variability. In Figure 5g, we show the mean absolute differences between trends in the six datasets, but aggregated over a range of grid scales. As the grid scale is increased, the differences between trends in datasets decline, particularly at grid scales of 1° or coarser. This suggests that the

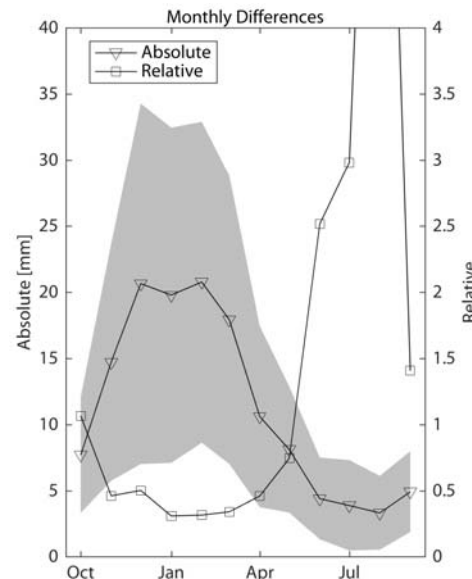


Figure 3. Absolute and relative differences between datasets by month, shown as the average over a spatial domain encompassing the Sierra Nevada (see Fig. 1 for domain). For each month, the mean absolute differences over the spatial domain are shown, with the shading indicating plus or minus one standard deviation of differences over the grid cells in the domain. For the relative differences, months with zero precipitation in each dataset are excluded from the analysis, and the median relative difference over the spatial domain is shown, as the mean would include very large values due to dividing by small precipitation amounts in summer.

datasets' disagreement in trends occurs primarily at smaller ($<1^\circ$) scales; the trend disagreement may be related to differences in handling changes in precipitation gauge networks over time.

Thus, we find that gridded precipitation datasets—which interpolate gauge data across complex terrain—may have mean absolute differences in precipitation of several hundred mm per year in high-elevation areas, and mean relative differences of 10—30% over many of the same areas. Absolute differences are consistently larger for higher elevation areas than for nearby lowlands. The true uncertainty may be even higher if the datasets collectively underestimate or overestimate precipitation. Consistent differences between the datasets were found in how precipitation is distributed over the windward and leeward sides of mountain ranges. For example, the PRISM climatological pattern is wetter on the windward slopes of the maritime Coast Ranges, Cascades and Olympics, and is drier on the leeward slopes, as compared to N15 and Daymet. Rain-shadowed lee areas of mountain ranges have some of the greatest relative differences between datasets, often exceeding 30–40%.

One factor that did not appear to systematically influence the estimation of precipitation over complex terrain was the spatial resolution of the gridded datasets. One hypothesis to explain

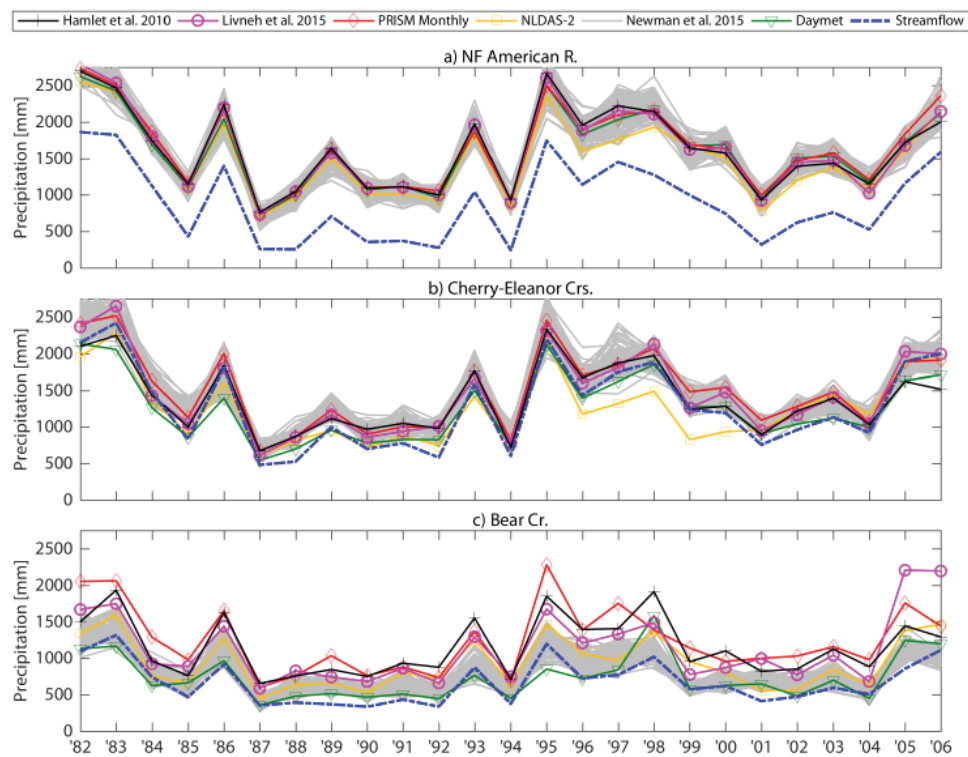


Figure 4. 1982-2006 time series of water-year total precipitation for the six datasets and three unimpaired, alpine watersheds in the Sierra Nevada. Newman et al. (2015) ensemble spread indicated by the gray shading. Water-year total streamflow observations per unit basin area shown in blue.

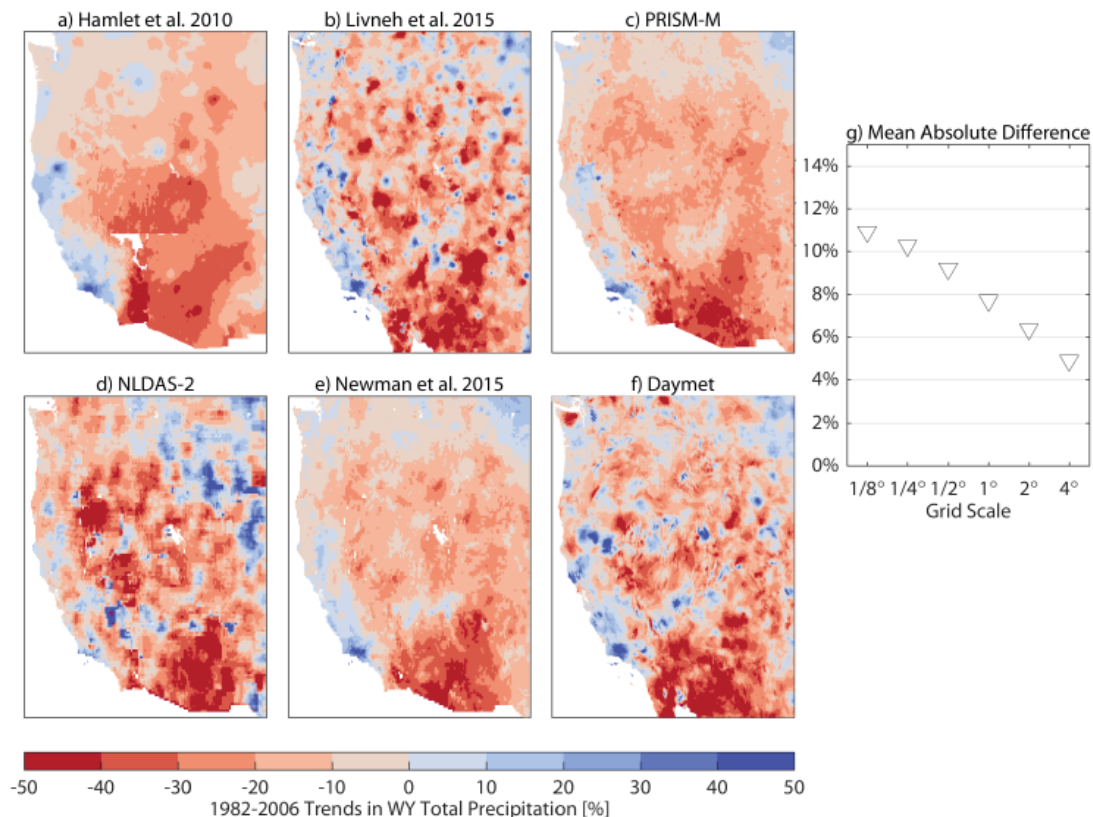


Figure 5. a)-f) 1982-2006 linear least-squares fit of trends in water-year total precipitation for each of the six datasets. g) Mean absolute differences in trends between the datasets, averaged over all dataset pairs and grid cells, using each dataset aggregated to different grid scales.

the differences in precipitation would be that coarser datasets (Newman et al. 2015 or NLDAS-2 at 1/8°) fail to resolve the topographic sufficiently to capture orographic patterns. Daymet, the highest resolution dataset at 1 km, does show more finescale detail in the precipitation fields. However, Daymet did not produce any more precipitation over the streamflow basins examined in Figure 4—in fact, in these limited examples it appears to suffer from more severe underestimation than the coarser datasets. We thus did not find evidence that spatial resolution higher than 1/8° necessarily improves representation of high-elevation patterns interpolated from precipitation gauges.

The high uncertainties in gridded precipitation datasets over complex terrain have implications for their use in evaluating scientific hypotheses related to precipitation in these regions. While the datasets may describe the results of leave-one-out type uncertainty estimation conducted during dataset development, all of the gridded precipitation datasets considered here except Newman et al. (2015) are deterministic, and so there may be a tendency to accept these estimates as “truth” when they are applied to force a hydrologic model or for some other purpose. However, it is clear that users of these data should be aware of the potential for substantial uncertainties and consider how this may influence their results. We also argue that it is useful to examine proxy data related to precipitation that may help to reduce the uncertainty in gridded datasets, e.g., streamflow and snow observations. Additionally, precipitation estimates based on numerical weather prediction models, e.g., the Weather Research and Forecasting Model (WRF) (Skamarock and Klemp 2008), may provide useful information about precipitation when run in reanalysis mode where gauge-based estimates are uncertain (Hughes et al. 2017). In short, the results of this study suggest that datasets based on gridded interpolation of precipitation gauges have significant differences across the high-elevation terrain of the mountainous West in spatial patterns, inter-annual variability and long-term trends.

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Snowmelt Rate Dictates Streamflow

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Mountain snowpack and snowmelt-derived streamflow are a critical water resource for approximately one-sixth of the global population (Barnett et al. 2005). However, trends in observed peak snow water equivalent (SWE) and the timing of spring snowmelt indicate that the western United States (U.S.) mountain snowpack is declining and that snowmelt onset is occurring earlier in the year (Clow 2010, Harpold et al. 2012). Correspondingly, trends in streamflow records show that snowmelt-driven streamflow is also occurring earlier in the year both in the western U.S. and globally (Cayan 1996, Stewart et al. 2004, 2005, Stewart 2009). Declining mountain snowpack and earlier snowmelt across the western United States has implications for downstream communities.

We present a possible mechanism linking snowmelt rate and streamflow generation using a gridded implementation of the Budyko framework. We computed an ensemble of Budyko streamflow anomalies (BSA) (Zhou et al. 2015) using Variable Infiltration Capacity model-simulated evapotranspiration, potential evapotranspiration, and estimated precipitation at 1/16° resolution from 1950–2013 for ten ecoregions across the western United States (Figs 1, 2a; Liang et al. 2003, Livneh et al. 2013). See Barnhart et al. (2016) for a full explanation of model validation and analysis of techniques.

In a lumped analysis considering all ecoregions together, BSA was correlated with snowmelt rate ($r^2=0.42$, Fig. 2b), snowmelt rate was correlated with baseflow efficiency (baseflow/precipitation, $r^2=0.73$, Fig. 2c), and BSA was correlated with

baseflow efficiency ($r^2=0.64$, Fig. 2d). The strong correlation between snowmelt rate and baseflow efficiency serves as a link between snowmelt rate and a possible streamflow generation mechanism wherein greater snowmelt rates increase subsurface flow. Rapid snowmelt may thus bring the soil to field capacity, facilitating below-root-zone percolation, streamflow, and a positive BSA.

At the scale of the individual ecoregions, we see that there is a range of regression slopes and percentage of variance explained for the snowmelt rate-BSA relationship (Fig. 3a). This shows that the sensitivity of streamflow production to a unit change in snowmelt rate varies considerably between ecoregions with

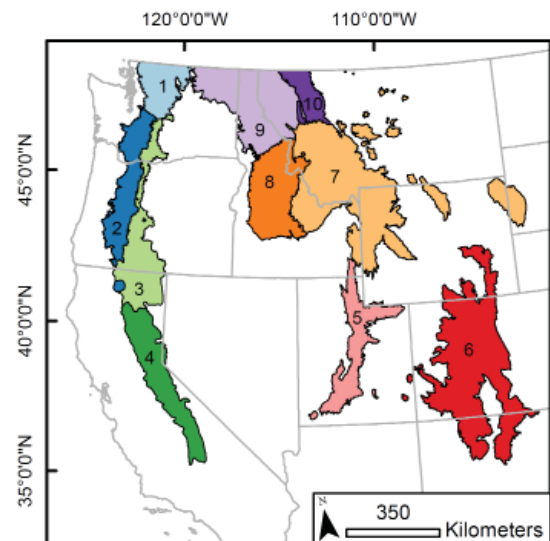


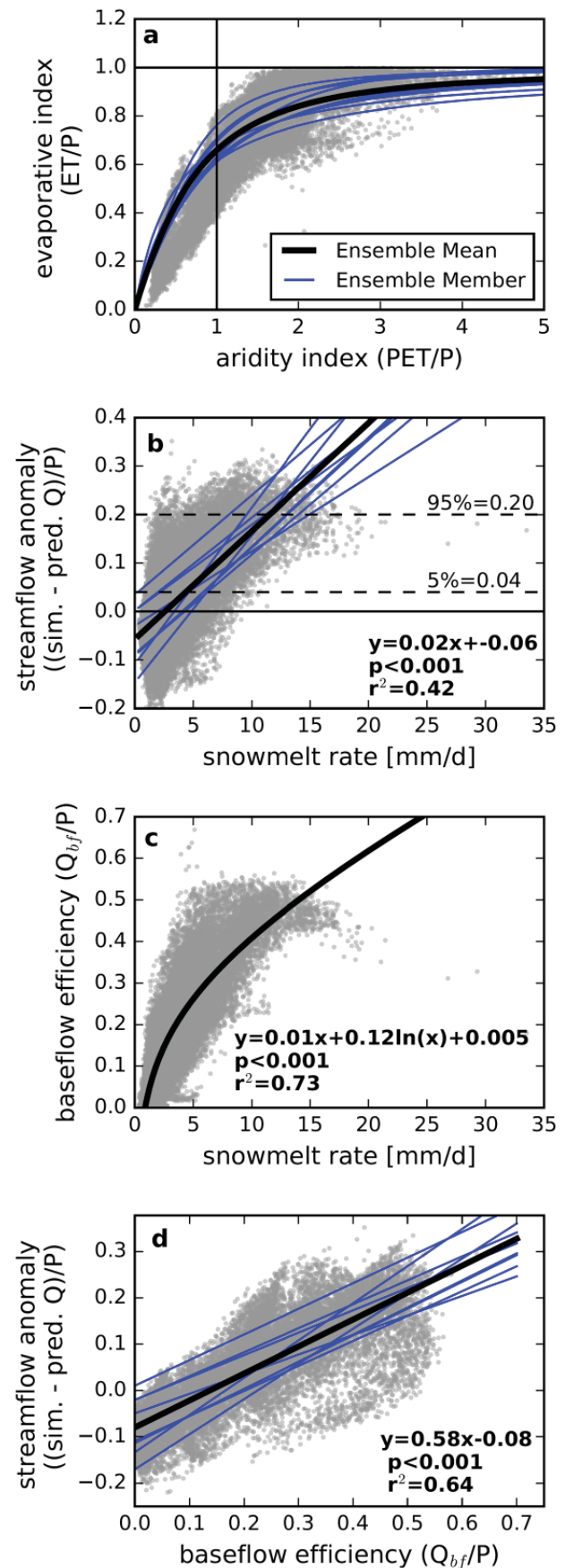
Figure 1. The simulation domain covers the mountainous ecoregions of the western United States. Included ecoregions are (1) North Cascades, (2) Cascades, (3) Eastern Cascades Slopes and Foothills, (4) Sierra Nevada, (5) Wasatch and Uinta Mountains, (6) Southern Rockies, (7) Middle Rockies, (8) Idaho Batholith, (9) Northern Rockies, and (10) Canadian Rockies.

the Southern Rockies and the Northern Rockies displaying the greatest and least sensitivity to a unit change in snowmelt rate, respectively. Snowmelt rate also explains only 9% of the variance in BSA in the Northern Rockies suggesting that other processes may control streamflow production in this region.

To investigate how snowmelt rate controlled hydrologic partitioning in another way, we fit Zhang et al. (2001) Budyko-type equations to each ecoregion and extracted the position of each curve asymptote on the y-axis as a metric of each region's maximum hydrologic partitioning to evaporative fluxes (Fig. 3b). Mean ecoregion snowmelt rate explained 87% of the variance in Zhang et al. (2001) asymptotes with more rapid snowmelt rates resulting in lower asymptotes and slow snowmelt rates resulting in larger asymptotes (Fig. 3c). This suggests, through an alternate analysis pathway at the regional level, that snowmelt rate exercises a strong control on hydrologic partitioning of precipitation across the western United States.

This work suggests, as snowmelt from the mountains of the western United States occurs earlier in the year and at a slower rate (Trujillo and Molotch 2014, Musselman et al. 2017), that streamflow production will be diminished across the region as a whole (Fig. 2b) and that streamflow in each ecoregion will decline proportionally to the sensitivity of each ecoregion (Fig. 3a). The range of streamflow production sensitivities to changes in snowmelt rate suggests that regional differences in meteorology and soil properties may influence the linkage between snowmelt rate and streamflow production. We also show that snowmelt driven streamflow production across the western United States may occur via a subsurface pathway where it is insulated from atmospheric demand. This study provides a means to relate future changes in snowpack to streamflow dynamics across the western United States and elsewhere, towards the goal of constraining the expected streamflow response to climate change.

Figure 2. (a) Simulation grid cells (grey dots) plotted in Budyko space and the mean Budyko curve (black line). The ensemble of Budyko-type equations is shown as blue lines. (b) Relationship between snowmelt rate and mean BSA (black line). The same relationship for each Budyko-type equation is shown using blue lines. (c) Relationship between snowmelt rate and baseflow efficiency (baseflow/precipitation). (d) Relationship between baseflow efficiency and mean BSA (black line). The same relationship for each Budyko-type equation is shown using blue lines.



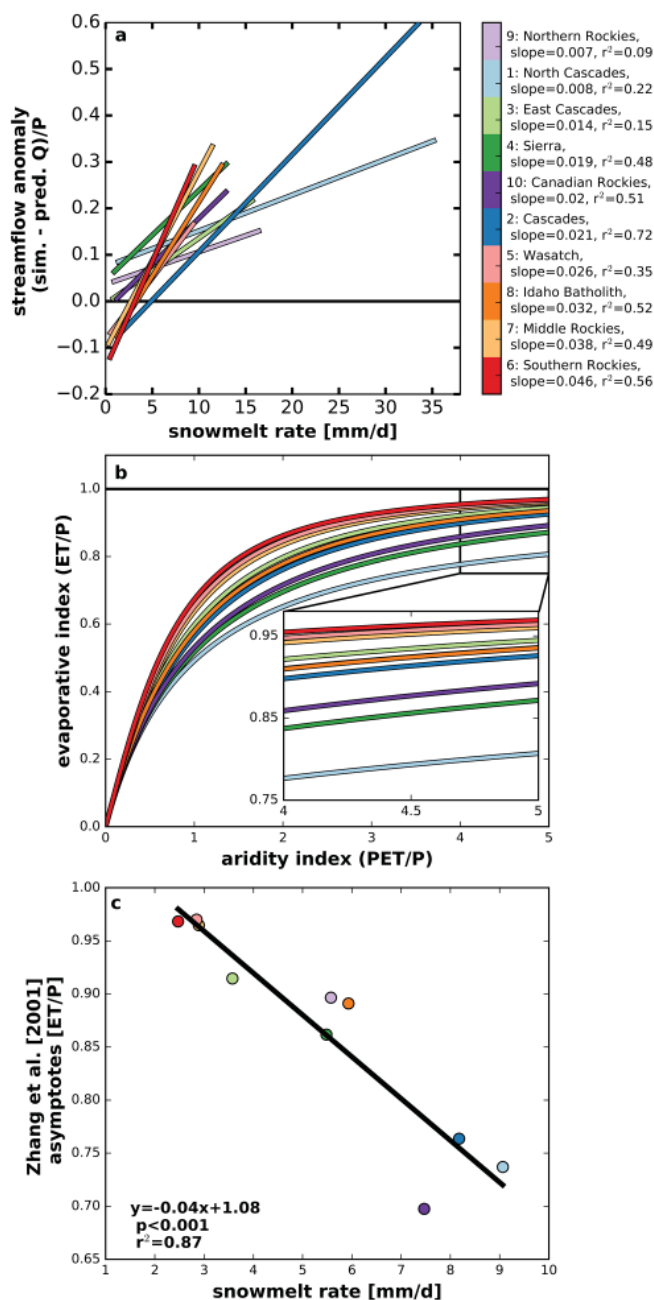


Figure 3. (a) Regressions between snowmelt rate and mean BSA for each ecoregion. Index numbers for each ecoregion (right) are the same as in Figure 1. All regressions are significant ($p < 0.001$). Regression lines extend to the range of the data. (b) Zhang et al. (2001) Buydco-type equations fitted to each ecoregion with inset highlighting variability in the asymptotes. (c) Relationship between ecoregion asymptotes and mean ecoregion snowmelt rate. All panels use the same color scheme.

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Sturm, M., Goldstein, M., and Parr, C. 2017. Water and life from snow: A trillion dollar science question. Water Resources Research 53, doi:10.1002/2017WR020840.

Water and Life from Snow: A Trillion Dollar Science Question

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Abstract

Snow provides essential resources/services in the form of water for human use, and climate regulation in the form of enhanced cooling of the Earth. In addition, it supports a thriving winter outdoor recreation industry. To date, the financial evaluation of the importance of snow is incomplete and hence the need for accelerated snow research is not as clear as it could be. With snow cover changing worldwide in several worrisome ways, there is pressing need to determine global, regional, and local rates of snow cover change, and to link these to financial analyses that allow for rational decision making, as risks related to those decisions involve trillions of dollars.



Measuring Sierra snow water

Key Points

- Snow is a critical but often unappreciated resource used by humans, and it is changing due to global warming in worrisome ways
- Work presented here suggests the valuation across many years of western US snow resources exceeds a trillion dollars
- More research is needed to help society make sound decisions on expensive major climate-driven snow resource changes

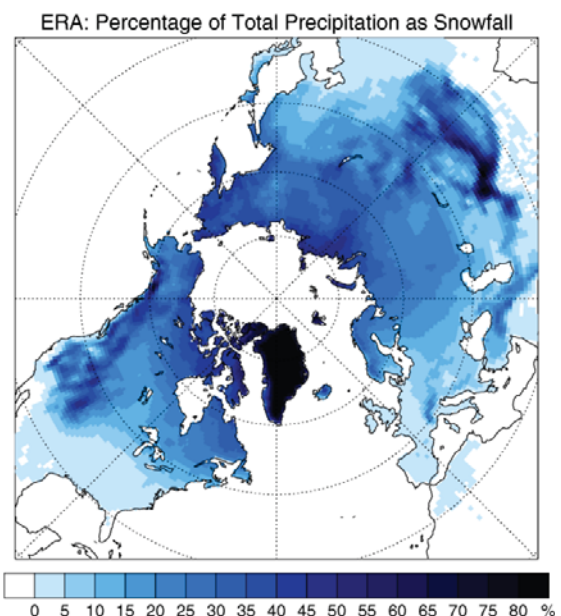


Figure 1. Annual precipitation falling as snow (%) for the period 2000–2010 computed from ERA-Interim data. The area where 40% or more of the precipitation comes as snow exceeds 15×10^6 km² in the Northern Hemisphere. At peak, over 57×10^6 km² of the Northern Hemisphere are usually blanketed with snow. Credit: Drew Slater, NSIDC.

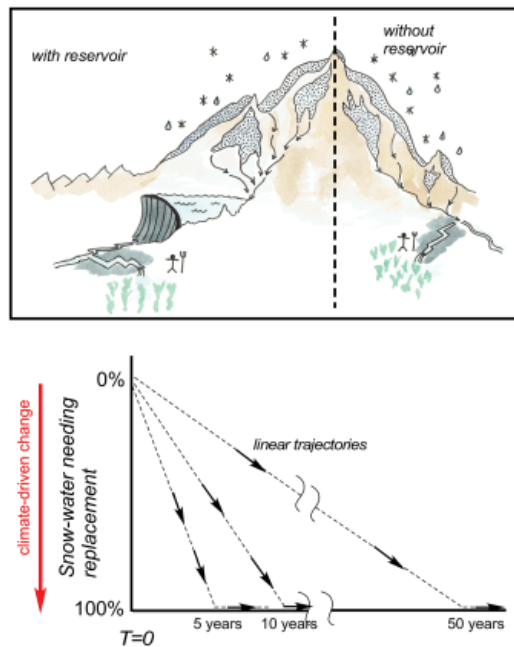


Figure 2. (top) We examine the mountain snow cover of the western U.S., where both dammed and undammed basins exist and provide water for irrigation. (bottom) In many of these basins, winter precipitation, formerly coming as snow, is now increasingly arriving as rain, which can result in more rapid runoff. The rate of the snow-rain transition is uncertain, so we assume multiple change trajectories (5, 10, 15 years, etc.) during which the snow water loss (W) increases from 0 to 100% of the total, then remains at 100% in perpetuity.

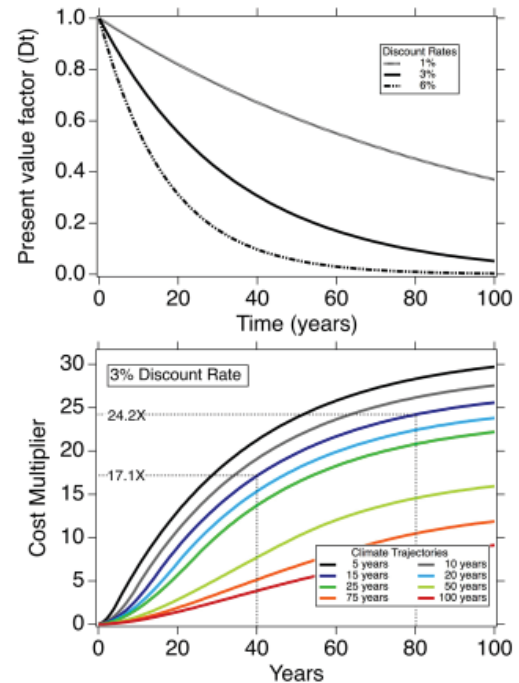
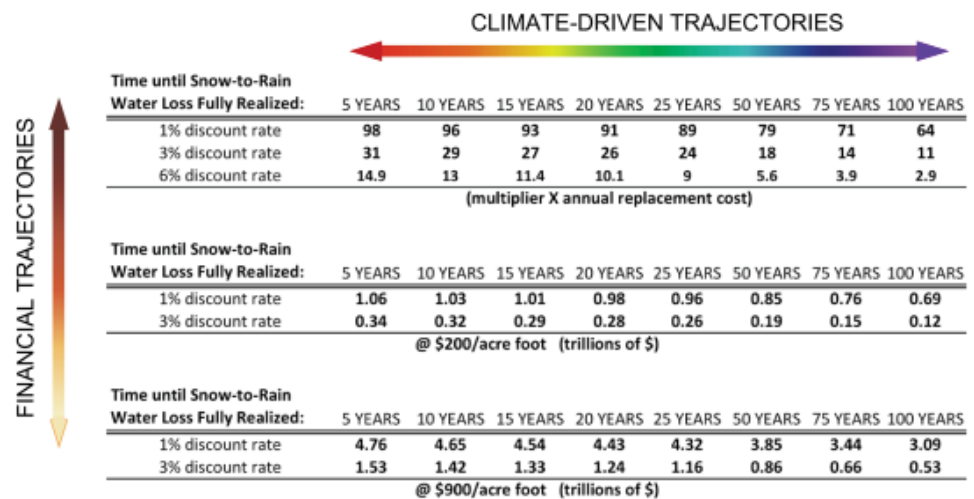


Figure 3. (top) Present value factors for 1, 3, and 6% discount rates. (bottom) The PV cost multiplier for a range of climate change trajectories (5, 10, 15 years, etc.) and a 3% discount rate. The PV cost multiplier for a 15 year trajectory, for $T=40$ years (dotted lines) is 17.1 and increases to 24.2 at 80 years. These factors continue to increase for larger values of T , but evermore slowly.

Figure 4. top) PV cost multipliers for snow water lost due to climate change, western U.S. computed over the next millennium. (middle and bottom) Water loss costs (in \$trillion) for the same area and period (@ \$200 and \$900/acre foot replacement cost). A more complete description of the model appears in Appendices A and B. In computing actual \$values, we omit 6% discount rate because it is fairly extreme and unlikely to be correct in a water-stressed future world.



Life in the Snow: Characterizing Microbial Communities in the Subalpine Zone of the Sierra Nevada, California

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Carey, C.J., Hart, S.C., Aciego, S.M., Riebe, C.S., Blakowski, M.A., and Aronson, E.L. 2016. Microbial community structure of subalpine snow in the Sierra Nevada, California. *Arctic, Antarctic, and Alpine Research* 48:685-701.

Snowpack covers over a third of Earth's land surface, making it the largest component of the cryosphere (Hinkler et al. 2008). Mounting evidence suggests that snowpack is crucial to the ecology of montane ecosystems, influencing the local climate (Cohen and Entekhabi 2001, Dery and Brown 2007), underlying soil (Buckeridge and Grogan 2008), and adjacent ecosystems including streams (Brown et al. 2007). However, the degree to which snow acts as an ecosystem itself remains largely unknown (Larose et al. 2013); this is especially true for seasonal snowpack, which is inherently ephemeral and experiences more direct solar radiation than high-latitude glacial snowpack.

Recently, researchers have begun to explore the microbial world to better understand the biology and ecology of snow. Many microorganisms are adept at surviving harsh conditions typical of snowpack, including freeze-thaw cycling, desiccation, high solar radiation, and low nutrient concentrations (Miteva 2008). As a result, snow can harbor diverse and active microbial communities. For example, Lopatina et al. (2013) revealed that up to 46% of bacteria were viable in snow samples collected from Antarctica. Because these microorganisms may alter surface albedo (Yallop et al. 2012), catalyze in-situ nutrient cycling (Amoroso et al. 2010), and colonize local plants or soil, characterizing snow-associated microbial communities in subalpine systems is critical for understanding current and future dynamics of mountain ecosystems.

We conducted an exploratory study to assess bacterial community structure (i.e., composition and diversity) in different layers of subalpine snow in the Sierra Nevada, California, U.S.A (Fig. 1). Specifically, we collected two samples in February 2015 from 0-15 cm and 15-30 cm depth, following a month-long

period of inter-storm snow ripening. We then analyzed each sample via high throughput sequencing of the 16S rRNA gene. We expected to find a diverse microbial community composed in part of stress-tolerant and putative cold-adapted taxa. We further expected to find shifts in composition by snow depth that would reflect differences in predepositional microbial dispersal or postdepositional selection due to vertical changes in physicochemical properties of the snow.

Our results demonstrate that microbial community membership was distinct but overlapping between the shallow (0-15 cm) and deep (15-30 cm) snow layers (Fig. 2). Consistent with findings from other cold environments (e.g., Moller et al. 2013, Sheik et al. 2015), Proteobacteria dominated both snow depths and 11 of the most abundant phylotypes were Acetobacteraceae (a family of Proteobacteria). The high relative abundance of Acetobacteraceae in both snow depths not only illustrates their ability to withstand the relatively harsh conditions of snow, but also suggests that they may be ecologically and functionally significant within this environment. Indeed, the most abundant phylotype within both samples shared 96.8% sequence similarity with *Asaia siamensis*, a dinitrogen (N₂) fixing Acetobacteraceae species (Fig. 3), suggesting that there may be the genetic potential for biological N₂ fixation in this snow environment.

A number of the relatively abundant phylotypes in our samples were closely related to sequences previously recovered from desert environments, and others were closely related to sequences previously recovered from cold environments (Fig. 3). For example, one phylotype was closely related (>99% sequence similarity) to a bacterial sequence previously recovered from the Sahara (del Carmen Montero-Calasanz et al. 2013), a desert that is a large source of dust globally (Goudie and Middleton 2001). Other phylotypes shared high (>98.5%) sequence similarity with bacteria isolated from the air and soil in Korea, which is a known source of dust for the western United States (Kellogg and

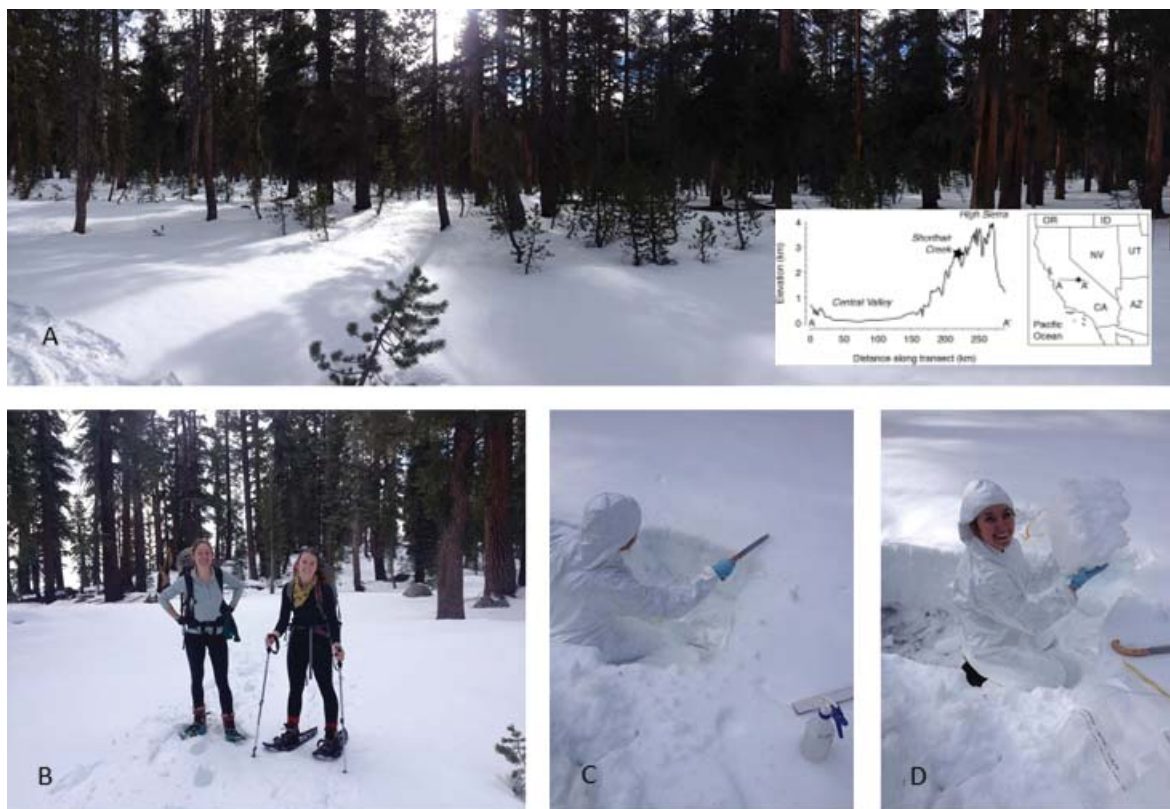


Figure 1. (A) Picture and map (inset) showing location and elevation of Shorthair Creek study site (37.06698°N, 118.98711°W) in the Sierra Nevada, California. (B) Molly Blakowski and Erin Stacy snowshoeing to the site. (C) and (D) Excavation of the two snow depths using a sterilized saw. Molly Blakowski (pictured) is wearing a Tyvek body suit and latex gloves, so as not to contaminate the samples.

Griffin 2006). Similarly, thirteen dominant phylotypes matched with >98% similarity to sequences recovered from glaciers, polar deserts, and the arctic tundra. While it is possible that these phylotypes are cosmopolitan (i.e., they are found everywhere), growing evidence suggests that many microorganisms display biogeographic patterns (Martiny et al. 2006). Thus, our data suggest that part of the microbial community in the subalpine Sierra Nevada snowpack is derived from distant desert sources (Griffin 2007). Our results further confirm that cold-adapted microorganisms can disperse globally and survive in geographically diverse cold environments.

Not all dominant phylotypes occurred in both snow layers. While many factors can influence the relative abundance of microbial groups with depth, in our study both the upper and lower snow layers were likely deposited from similar sources (Pacific storm events from Asia); as such, it is conceivable that post-depositional selection or redistribution within the snowpack played a larger role than place of origin in developing vertical stratification. For instance, Cyanobacteria (a phylum of photosynthetic bacteria) were constrained almost entirely to the shallow snow layer (Fig. 2), likely due to decreasing light availability with increasing snow

depth. Moreover, many phylotypes that occurred more frequently in the bottom snow layer were Actinobacteria, one of which shared >99% similarity with *Geodermatophilus siccatus* and another that was similar to *Galbitalea soli*. The elevated relative abundance of *Geodermatophilus* spp. may reflect the ability of Geodermatophilaceae to tolerate stressful conditions (Ivanova et al. 2010). Similar tolerance for extreme desiccation may explain the higher relative abundance of Actinobacteria and Firmicutes in the deeper snow layer (Connon et al. 2007).

Overall, our exploratory study provides new information on microbial dynamics of snowpack in California's Sierra Nevada, highlighting the diversity of bacteria that reside in this relatively harsh environment. Our study also raises several notable questions. For instance, is there genetic potential for N_2 fixation in ephemeral montane snowpack, and does this result in ecologically meaningful rates of in situ N_2 fixation? Moreover, are changes in microbial composition with depth consistent across space and time, and what are the processes that govern these patterns? Addressing these and other questions will provide critical information on microbial structure and function in this potentially important, but poorly studied, component of montane ecosystems.

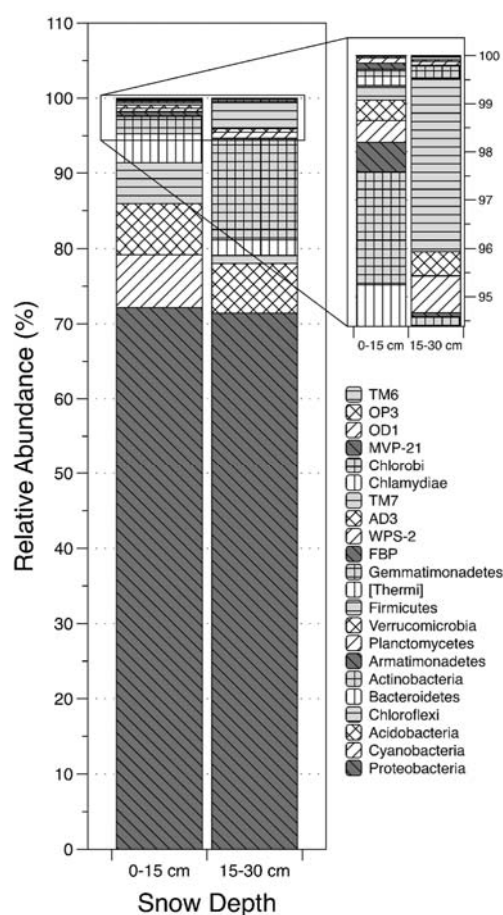


Figure 2. Relative abundances of the 22 phyla recovered between both snow depths (0-15 and 15-30 cm) from the Shorthair Creek study site. Both graph and legend share the same order, sequential from top to bottom. Proteobacteria dominated both samples, while Cyanobacteria were more abundant in the upper snow layer and Actinobacteria and Firmicutes were more abundant in the deeper snow layer.

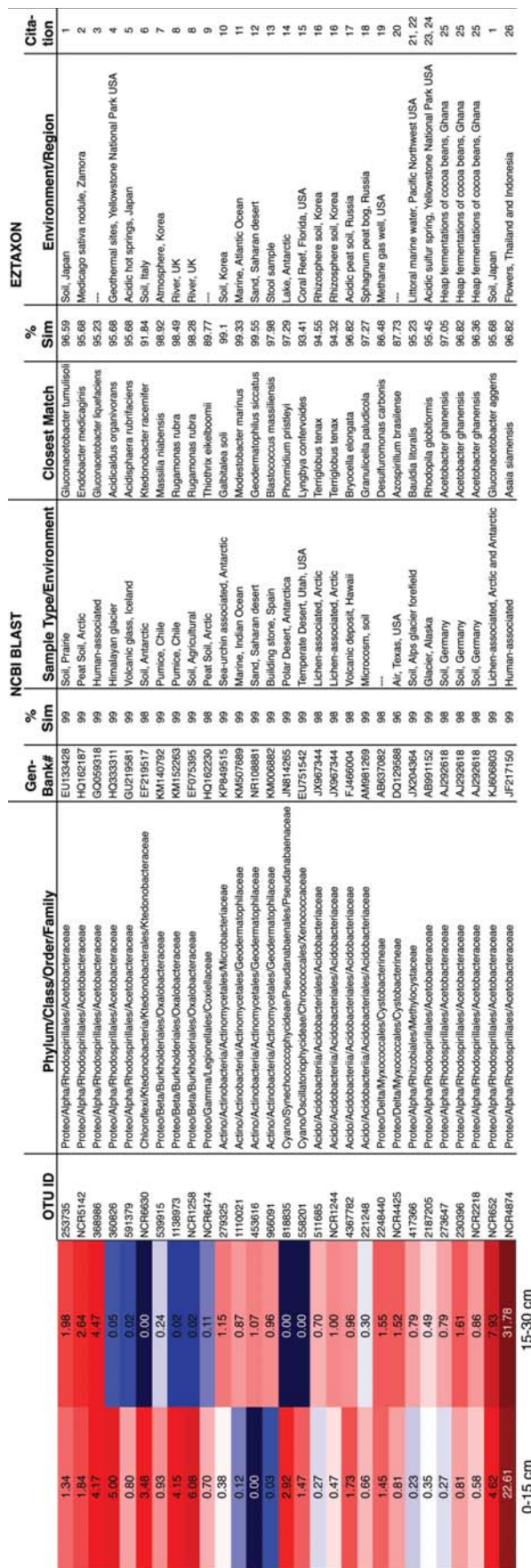


Figure 3. Heatmap showing the numerically dominant phylotypes (>200 sequences) across both snow depths (0-15 and 15-30 cm) and their relative abundances as percentages of all 16S rRNA sequences recovered within their respective depth. The color spectrum ranges from dark blue (the lowest relative abundance) to dark red (the highest relative abundance). OTU ID numbers are also listed (NCR = new cleanup reference OTU as designated during the OTU picking process). Also included are the (1) taxonomic assignments, environment from which it was isolated, and the associated reference. OTU NRC4874, an Actinobacteriaceae, was the most abundant phylotype across both samples, accounting for 22.61% and 31.78% of sequences in the upper and deeper snow layers, respectively. % sim = % sequence similarity, Proteo = Proteobacteria; Actino = Actinobacteria; Acido = Acidobacteria; Alpha, Beta, Delta, Gamma denote classes of Proteobacteria. Full citations can be found in the Appendix.

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Autumn Snowfall Controls the Annual Radial Growth of Centenarian Whitebark Pine (*Pinus albicaulis*) in the Southern Coast Mountains, British Columbia

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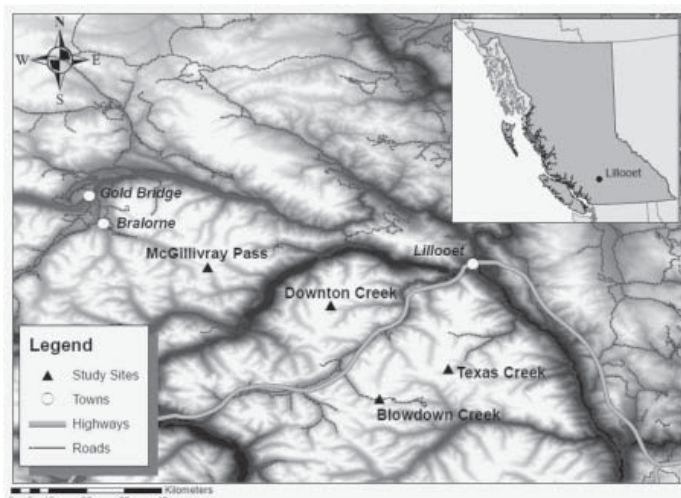
²*University of Arizona Tree-Ring Laboratory, Tucson, Arizona*

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Whitebark pine (*Pinus albicaulis*), an endangered keystone subalpine tree species, faces multiple threats across its western North American range, including climate change. Dendroclimatological investigations in the interior Canadian Cordilleras (Luckman et al. 1997, Youngblut and Luckman 2013), central Coast Mountains of British Columbia (Larocque and Smith 2005), and northern American Rocky Mountains (Kipfmüller 2008), suggest that annual radial ring width and density parameters of whitebark pine are generally limited by variations in summer temperature, and one Idaho study documented snowpack limitation relating to the influence of snowmelt quantities on soil moisture availability in spring and summer (Perkins and Swetnam 1996). Little is known of whitebark pine in the southern Coast Mountains of British Columbia relative to well-studied Rocky Mountain populations, especially with regard to the effects of climate on annual radial growth.

To create a whitebark pine chronology representative of regional-scale growth variability, we collected tree cores at four study site locations: Blowdown Pass, Downton Creek, McGillivray Pass, and Texas Creek in the southern Coast Mountains of British Columbia during July and August of 2011 and 2012 (Fig. 1). All stands were open-canopy patches growing above continuous treeline at approximately 2000-2100 m elevation on steep, southerly aspects. Trees were young (generally less than 120 years at diameter breast height). Tree cores from the four sites were combined into a regional chronology (number of series = 61, number of trees = 61, average mean sensitivity = 0.25, chronology interval = 1920-2011; Stokes and Smiley 1968). We used time series correlations and partial correlations calculated using the program Seascorr (Meko et al. 2011) to evaluate the association of the regional chronology with monthly and seasonalized precipitation-as-snow (PAS), total precipitation, and mean temperature data obtained from the program ClimateWNA (Wang et al. 2012). We also compared the chronology to climate teleconnection patterns known to affect the climate of the Pacific Northwest USA and adjacent Canada, including the Pacific Decadal Oscillation (PDO; Mantua and Hare 2002).

A.



B.

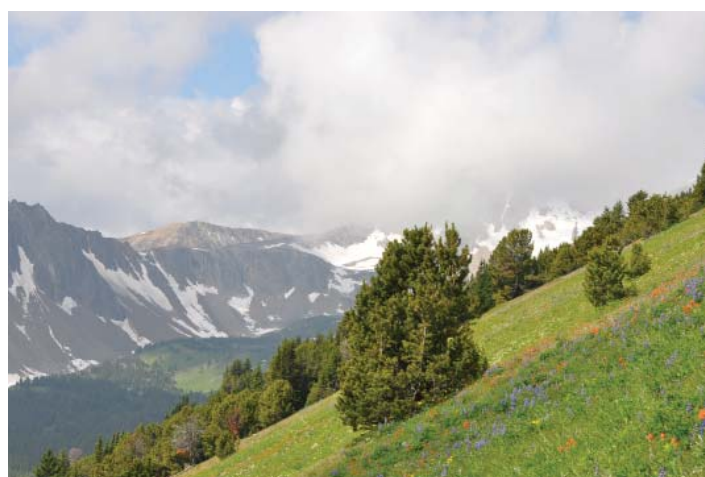


Figure 1. (A) Location of the four study sites in the southern Coast Mountains of British Columbia. Lighter areas are mountain tops and darker areas are rivers and valley bottoms. Inset map shows the location of Lillooet (50.686°N, 121.936°W) in British Columbia. (B) Photograph of whitebark pine at Texas Creek. Each site shared similar open-canopy and herbaceous groundcover characteristics.

Of the climate variables tested, whitebark pine annual radial growth in the British Columbia Coast Mountains study region is most strongly correlated with PAS in the October through December season of the year prior to growth ($r = -0.50$, $p = 0.01$, Figs. 2, 3). Relationships with PAS weaken after December, and partial correlations suggest temperature has no significant impact on growth that is independent from the PAS influence during the prior autumn (Fig. 3). Radial growth is also significantly correlated with PAS in those three single months, and in no other single month ($p = 0.01$, Fig. 3). Notably, no strong relationships exist with growing season climate variables, including temperature (Fig. 3). Both tree-ring widths and winter PAS were significantly influenced by winter PDO conditions, positively and negatively, respectively (Table 1). Analyses of snow and tree-ring

relationships to PDO during different phases of the oscillation suggest the influence of the PDO is strong and statistically significant only during cool phases.

Our results present evidence that snowfall antecedent to the growing season negatively impacts whitebark pine growth in the maritime band of the species' distribution, a climate-growth response that has not been observed in studies conducted on older trees in other parts of the species' range. This unusual growth limitation likely stems from the truncation of the prior year growing season and reduced physiological preparedness for growth in the following year. The termination of the prior growing season by early snowfall and soil cooling likely reduces photosynthate storage for the following year (Fritts 1976). The

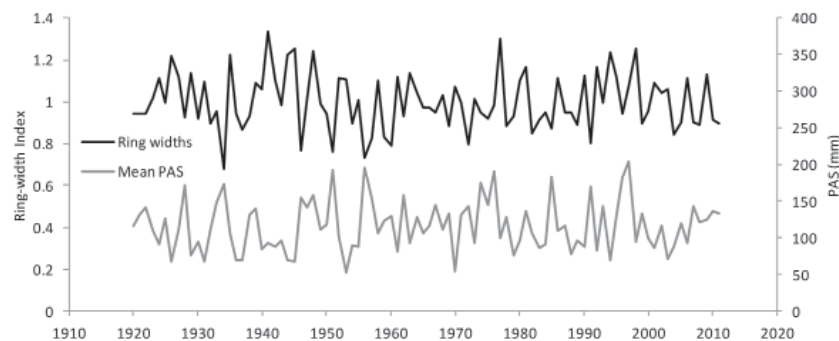


Figure 2. Time series of regional ring widths and mean autumn (previous October through previous December) precipitation-as-snow (PAS).

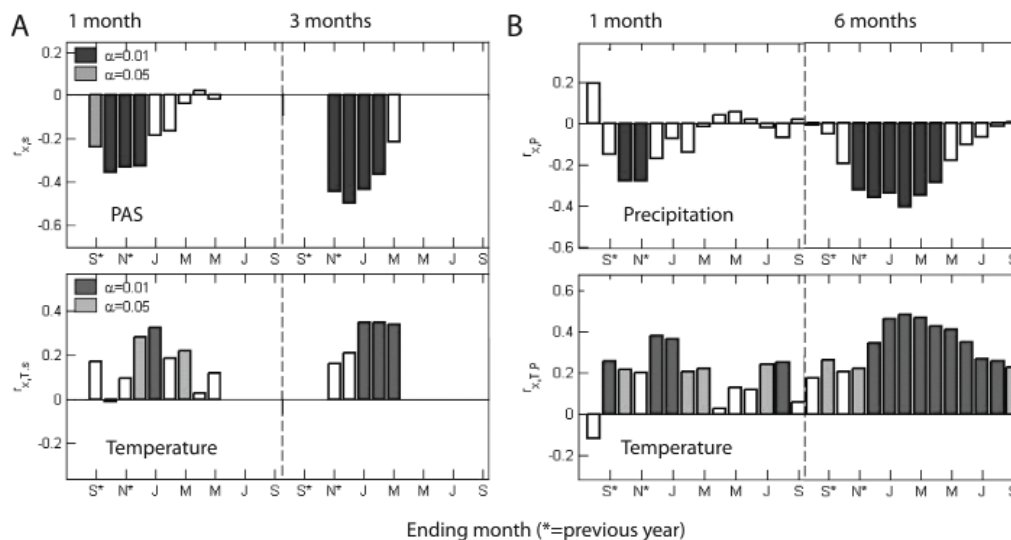


Figure 3. Single-month and strongest seasonal correlations (top) and partial correlations (bottom) of the whitebark pine chronology with total PAS, mean temperature, and total precipitation data (1920–2011). Note that the y-axes have different scales. (A) Correlations with PAS (top) and partial correlations with mean temperature that are independent from the influence of PAS (bottom). Months and seasons that are not plotted could not be evaluated due to a lack of data. The strongest correlation with PAS is during prior October through December, and the strongest partial correlation with temperature is during December through February. (B) Correlations with precipitation (top) and partial correlations with mean temperature that are independent from the influence of precipitation (bottom). The strongest correlation with PAS is during prior October through December and the strongest partial correlation with temperature is during December through February. Note the overall absence of temperature sensitivity during the growing season, with the strongest single or seasonal summer correlation being $r = 0.23$ ($p < 0.01$).

Table 1. Associations of whitebark pine ring widths and October–December PAS with instrumental winter Pacific Decadal Oscillation (PDO) variability.

	Full period	Cool phase	Warm phase	N_1, N_2^a	p^b
Whitebark pine chronology	$r=-0.45$ ($p<0.05$)	$r=-0.58$ ($p<0.05$)	$r=0.24$ ($p<0.05$)	26, 22	0.18
PAS	$r=-0.48$ ($p<0.0$)	$r=-0.72$ ($p<0.05$)	$r=-0.25$ ($p<0.05$)	26, 22	0.04

^aEffective sample sizes for early and late periods.^b p -value for a test of the null hypothesis that the population sample correlations for the cool and warm phases are the same. Significant where $p<0.05$.

onset of winter conditions may also reduce mycorrhizal activity (Peterson and Peterson 1994) and prevent proper maturation of leaf tissue and the cuticle leading to greater transpiration (Sowell et al. 1982). Autumn snowfall is moderated by temperature and the PDO, which controls large-scale winter weather patterns in the study region. The relationships we observed between PDO, tree rings, and PAS are consistent with antecedent snowfall-related limitation of whitebark pine growth. Cool phases of the PDO are associated with greater snowfall, shorter growing season lengths, and reduced radial growth in various alpine conifers throughout the Pacific Northwest USA and adjacent Canada (Mantua and Hare 2002, Koch et al. 2004, Starheim et al. 2013). Our results are distinct from studies of mature whitebark pine trees in continental populations where growth is typically limited by summer temperature, or occasionally by winter snowfall due to a reliance on snow meltwater during spring and summer. It is not known whether the sensitivity to prior autumn snowfall we observed is related to the younger ages of the trees growing in the Coast Mountains, or due to earlier timing or greater autumn snowfall quantities in the Coast Mountains relative to interior sites.

We suggest that predicted warmer and wetter climate and reduced snowpacks in the southern Coast Mountains may benefit the growth of the young population of maritime whitebark pine over the next few decades. However, the impact of disease, pests, and increased competition (as less-tolerant species become established or species from lower elevations migrate upward) on whitebark pine might lead to reduced annual growth in parts of its range, even if climate becomes more favorable (Kipfmüller and Salzer 2010, Littell et al. 2010). The dissimilar climate response of the trees analyzed in this study may suggest that maritime trees will be affected differently by a shifting climate in coming decades. This highlights the importance of using local-scale studies in place of general species-wide approaches when developing management and restoration plans for whitebark pine in different parts of its range.

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A bird's-eye view of the Blowdown Pass study site, Coast Mountains, British Columbia, Canada

Competition and Facilitation May Lead to Asymmetric Range Shifts with Climate Change

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What are the ecological impacts of climate change? Climate is thought to constrain performance at range boundaries; thus, range shifts poleward and uphill are expected to result from climate change. Indeed, range shifts in response to climate change in the Holocene (Davis & Shaw 2001) and recent anthropogenic warming (e.g. Parmesan & Yohe 2003, Harsch et al. 2009) support the assumption that future warming will result in wide-spread range shifts of the organisms with which we share our planet. However, there is also increasing recognition that factors beyond climate play a role in determining where species are, and thus, how they might respond to warming (Sexton et al. 2009, Gilman et al. 2010, HilleRisLambers et al. 2013, Ford et al. 2017). The goal of our recent article in *Global Change Biology* was to use a large-scale manipulative experiment to assess how two of these non-climatic factors, local adaptation and competition, will complicate climate-change-induced range shifts of tree species in mountains of the Pacific Northwest. Below we briefly summarize the experiment we conducted and important findings that came from it, as well as open questions that continue to intrigue us.

The Experiment

We established our experiment on the south slope of Mount Rainier National Park, focusing on three conifers that are abundant in the Pacific Northwest: western hemlock (*Tsuga heterophylla*—abundant at lower elevations up to 1200 meters ASL); Pacific silver fir (*Abies amabilis*—occurring from 700 to 1600 meters ASL); and mountain hemlock (*Tsuga mertensiana*—occurring from 1200 to 1600 meters ASL). For each species, we transplanted seeds and seedlings at sites (elevations) representing five different range positions: above and below range limits, at upper and lower range limits, and in the center of the range (Fig. 1A). To assess how local adaptation influences performance, we used three seed origins per species, collected from the lower, center, and upper portion of the range (Fig. 1B). To assess how competitive interactions influence performance, we monitored the fate of seeds and seedlings relative to canopy cover (gap, closed canopy) and understory

cover (removed, present; Fig. 1C). This experimental design allowed us to assess how seed germination, seedling growth, and seedling survival were influenced by three factors: range position (5 levels), seed origin (3 origins) and competition (2 treatments with 2 levels each yielding 4 different levels total).

No Evidence of Local Adaptation

Initially, we had hypothesized that different seed origins would perform best (i.e. highest germination, growth and survival) in their ‘home’ elevations, because we assumed that populations have experienced selection across this steep climatic gradient. Although we did find evidence of performance differences related to seed origin, especially at germination stages, we did not find any evidence of a ‘home site’ advantage. In other words, one origin generally outperformed other origins at multiple transplant locations, not only in locations most similar (climatically) to where those seeds were collected. This was surprising to us, given that many studies have found strong evidence of local adaptation to climate in similar tree species (e.g., Rehfeldt et al.

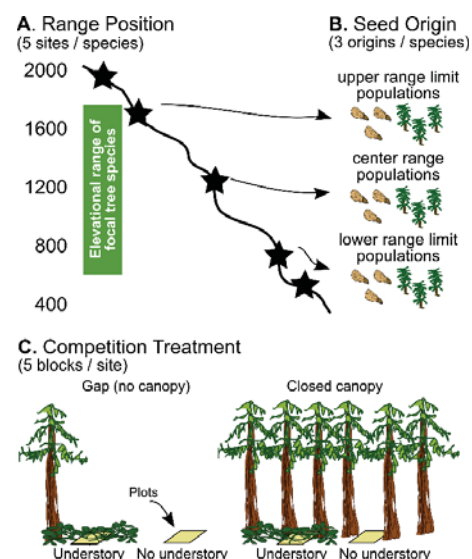


Figure 1. Experimental Design. We located transplant sites at five elevations per species (sites), representing five range positions (A). For transplants seeds and seedlings, we used three seed sources per species, representing upper range, center range, and lower range populations (B). At each site, we established five blocks, each with four transplant plots experiencing a different combination of canopy (gap, closed canopy) and understory cover (removed, present).

1999, Holliday et al. 2010). However, many of these studies were conducted along latitudinal gradients, where gene flow is much more limited compared to our sites, which were separated by 20–30 km, a relatively small distance compared to pollen dispersal. In all, these results suggest that local adaptation will not strongly constrain the range shifts of our focal conifers up mountain slopes.

Competition May Slow Range Shifts at Low Elevations

Ecologists have long posited that biotic interactions have the largest impacts in benign environments, whereas abiotic factors like climate are a predominant constraint in harsh climates (Dobzhansky 1950, Connell 1961, MacArthur 1972). Our previous work (using tree rings) demonstrated that tree growth is strongly constrained by climate at upper range limits, but unaffected by climate at lower range limits (Ettinger et al. 2011). Our experimental data confirmed that seedling growth rates decline at high elevations, presumably due to climatic constraints. Thus, we wanted to assess whether competitive interactions had the strongest (negative) impacts at the lower range limits of our focal species. This would be manifested by strong negative effects of our competition treatments, especially at and below lower range limits. We found that seedling growth and survival were depressed under closed canopy and with dense understories, but that competitive interactions did not limit seedling performance more strongly at or below species' lower range limits. Thus, it remains a mystery what factor(s) drive the lower distributional range limits of our focal conifers. Because competitive effects of trees on seedlings throughout their lower range are large, this could slow the 'invasion' of seedlings from lower elevation and latitude species, and thus, climate-change induced range shifts (Fig. 2).

Facilitation May Accelerate Range Shifts at Treeline

Our most surprising result was that at treeline, survival and growth of two of our focal species actually increased in what we had assumed were high 'competition' treatments! In other words, we found evidence of facilitation at treeline, in addition to competition (at low elevations), similar to findings by Callaway and colleagues on alpine plants (Callaway et al. 2002). After detailed analyses of how environmental variables critical to plant performance (light, snow duration, temperature) varied with our treatments, we concluded that facilitation likely occurred because neighboring trees and the presence of an understory increase the growing season length at treeline (by ~30%), but not at lower elevations. This is because at high elevations at Mount Rainier National Park, snow can linger far into the summer growing season (mid-July), but melts earlier under trees and a dense understory. Other explanations for facilitation are also possible (e.g. mycorrhizal mutualists, photoprotection). Regardless of the mechanism, this suggests the possibility of accelerating tree invasion into meadows as climate warms (at least in the short term). Thus, climate change may result in an initially slow rate of tree recruitment in meadows, with a local scale positive feedback between tree density and seedling survival eventually resulting in rapid change (Fig. 2).

Open Questions

In all, our study adds to a growing body of work demonstrating that although climate-change induced range shifts are likely to be complex (and not just driven by climate), we may still be able to generalize responses if we embrace (through careful study), rather than ignore, the complexity. Of course, there is always

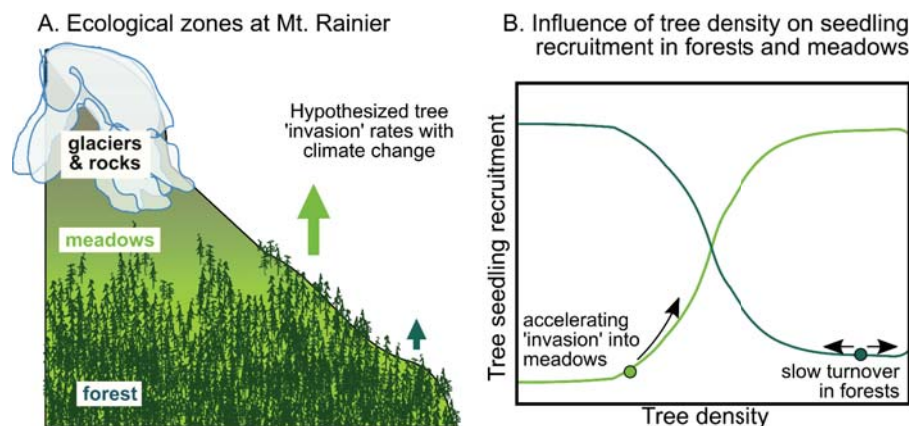


Figure 2. At Mount Rainier National Park, dense forests at low elevations give way to meadows with sparse trees, and eventually, glaciers and rocks (A). Tree seedling recruitment is influenced by tree density in both forests and meadows, but in opposite ways (B). At low elevations, tree density is high, limiting light and seedling recruitment. At treeline and in meadows, adult trees increase the growing season length (by hastening snowmelt) and seedling recruitment. This implies that competition with trees at low elevations could slow climate-change induced turnover (dark green arrow), while a positive feedback between trees and seedling recruitment accelerates tree encroachment into meadows (light green arrow).

more to do—and below we provide a (non-exhaustive) list of complexities we continue to examine in this (and other) study systems.

- Several focal tree species we have studied (e.g. Pacific silver fir, yellow cedar, mountain hemlock, and subalpine fir) have obvious lower distributional range limits, suggestive of climatic controls. Despite several years of study, we have not been able to find much convincing evidence that climate constrains performance of these species below their ranges, either directly (through physiological effects) or indirectly (through competition). We are still working to identify the factors that control these lower range limits.
- Biotic interactions other than competition, such as seed predation, herbivory, and mycorrhizal associations, also affect our focal species. We are curious whether and how such interactions affect range limits and may alter range shift dynamics with future climate change (HilleRisLambers et al. 2013).
- Given the long lifespans of our focal species (many individuals are 800 years old or more), the climate they experience changes throughout their life. It is unknown whether long-lived organisms are likely to be more- or less-sensitive to climate change, and whether and how their long generation times may constrain the pace at which range shifts occur. Regardless of the sensitivity of adult trees to climate, range contractions of long-lived, slow-growing tree species common to Mount Rainier National Park may not occur rapidly, unless disturbance regimes change (HilleRisLambers et al. 2016).
- As climate change progresses, novel combinations of climatic variables are expected to occur. In addition, more rapid future rates of climate change may lead to non-linear responses of tree species, with multiple climate variables interacting to drive responses. For example, at much higher temperatures, drought stress may become limiting at low elevations on the south side of Mount Rainier, even though we have seen little evidence of drought reducing tree growth to date. Forecasting the responses of focal tree species to climatic conditions outside of the historical range of climate observed at our site will likely require data from other locations or experimental manipulations (e.g., actively warming sites and/or altering snow accumulation levels).

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INTERVIEW

An Interview with Greg Greenwood, Former Executive Director of the Mountain Research Initiative

Greg Greenwood retired in December, 2016 after thirteen years as the second Executive Director of the international Mountain Research Initiative, MRI, based in Berne Switzerland. Under his productive guidance, the MRI significantly expanded its coordination and communication efforts, connecting more than 10,000 mountain global-change researchers in regional networks of North- and South America, Europe, and regional initiatives in the Carpathians and South East Europe. Greg further promoted important science synthesis efforts, for instance, on the role of elevation-dependent warming. Greg and I first met in the early 1990s when we worked together on the Sierra Nevada Ecosystem Project; subsequently Greg was an important co-founder and dedicated supporter of CIRMOUNT. See you on the slopes, Greg, and thanks for your decades of valuable contributions and leadership! —Editor

GREG GREENWOOD



Connie: Can you give us an outline of your career positions before you landed in Switzerland as Executive Director of the Mountain Research Initiative (MRI) in 2004?

Greg: My professional life has had three acts: international development, principally in Africa but also in South Asia, California state resource assessment and policy, and finally research promotion and coordination at MRI in Switzerland.

The international development act ran for a decade and involved drilling water wells and working with herders north of Lake Chad, followed by an MS in Range Science from Colorado State University, and then another multi-year stint in the Mauritanian Sahel living in an isolated rural town with my new wife, who, believe or not, wanted to go there! In Mauritania I worked on forestry and livestock as part of an integrated rural development project.

Development work was physically hard but engaging. I lived in places visited by few people from the developed world, learned both French and Arabic, and confronted social-ecological systems with difficult problems of drought and conflict but which also seemed to have unutilized potential. For instance, better runoff management in Mauritania could greatly increase and stabilize crop and forage yields, but fear of ethnic conflict stymied attempts to manage surface water. While many of my friends continued their careers in development, I concluded that most of the problems in the developing world required political rather than technical innovation and so I moved toward the second act. Still this chapter left a strong mark on my life.

The second act ran for twenty years and began with a PhD program in Ecology at the University of California, Davis, where I worked with Tag Demment on ruminant grazing. I continued to dabble in development work, with contracts with the Asian Development Bank that took me to Pakistan where I saw for the first time in the Karakorum the scale of Asian mountains. This development work delayed the completion of my PhD but supported my growing family while I was still a grad student. After the PhD and a short stint in DC for a consulting firm, I finally completed my switch away from development work with a position related to hardwoods and range management with the Forest and Rangeland Resources Assessment Program of the California Department of Forestry (FRRAP).

While this second act didn't involve crashing around the African bush in Landrovers or on motorcycles, it did involve delving deeply into the resource attributes of a large part of California—everywhere not urban or irrigated ag. I learned a great deal about, on one hand, GIS and remote sensing and; on the other, the policy processes at local, state and federal levels that influenced those resources. I again confronted complex social-ecological systems,

but here was able to play a more productive role within my own culture by bring research to bear on the framing and answering of resource related questions, for instance, through my participation in the Sierra Nevada Ecosystem Project (SNEP).

I spent 10 years at FRRAP and thereafter moved up to be Science Advisor to the California Resources Agency for several years before the move to MRI. I don't recall giving too much advice while at the Agency but rather worked a lot on decision support for state conservation programs, on state-federal forestry relations, on the development and integration of climate change into the operation of Resource Agency departments, and on the integration of resources concerns into the decision-making of other state agencies, for instance, CALTRANS. The work at the state was what I have termed my political science post-doc: that is, I had to develop some framework by which to understand how social and especially policy changes occur. My short answer is that policy change is less like rational planning and more like the entrance of new gene into a population. Contingency and context modify and can even nullify the gene's additive effect on fitness, and the same holds true for proposed policies. While the what, the content, usually matters, the who, when, where, how, and why often matter more in the success of a proposal. And the proposals are happening all the time, just as are mutations.

Connie: What attracted you to the MRI post?

Greg: This is a question of push and pull. The push was the elimination in late 2003 of my Science Advisor position at the Resources Agency. I like to say that it had to do with the election that recalled Gray Davis and installed Arnold Schwarzenegger as Governor, but really it devolved from a much more prosaic budget dispute between the Agency and the State Senate. I had the option to return to the Department of Forestry, which I did just long enough to get a \$40 million grant program for wildland-urban interface fuels management through the Legislature. Usually when this happens, the proponent gets him or herself set up as grant program manager, but by that time I had already learned about the MRI position and was quite ready to move on from the state. In any event, it is considered poor form to return to ordinary civil service after a Career Executive Assignment at something like the Agency: you are supposed to use the CEA as a stepping stone to something else and in the end that's what I did.

The pull came in several ways. First, my wife's European roots had led us to take our kids to Europe many times in the mid 90s to see family there and to impress upon our offspring that while they were certainly California girls, they were also part of a much larger world, one where people often speak funny. So we were all primed to live in Europe at some point. But Connie Millar's email to me in late 2003, telling me that this Swiss entity focused



Climbing with the Swiss Alpine Club on Glacier de Moiry

on 1) global change 2) in mountains was looking for a Director made it all very concrete.

Here was an opportunity to work on issues that interested me from a very different perspective—the research community rather than the government—and to get at least a decade's jump on what we were likely to do anyway. In government service most of us executed what people above us decided and while there is pleasure in execution I was looking forward to being more of a free agent, able to shape the direction of a program. To be honest there wasn't much of a plan among the MRI principals at the time. Indeed I think that my desire to impose some form on the program, even constrained by its small budget, was a main reason why the principals offered me the job.

Connie: What projects or progress do you feel most satisfied with during your tenure at MRI?

Greg: It is important to preface my response here with my conception of MRI as a framing and convening entity rather than a knowledge-producing entity. While some might think that MRI's job was to generate products—papers, briefs, datasets, etc.—I felt that our job was to consult with the research community and to create critical social mass around issues or approaches that commanded attention and participation. MRI's program was to somehow catalyze the community around projects that would themselves produce papers, briefs, datasets, etc.

The MRI strategic plan and MRI's Science Leadership Council (SLC) were thus two aspects of what I consider to be one of the most important projects. The project doesn't have a name per se:

you could just call it strategic direction.

“If you don’t know where you are going, any route will do.” Maybe it was because I had lived through the California government strategic plan push in the 90s that I found the elucidation of how “we” wanted the world to be different because MRI was in it to be an important effort. The “we” was the “mountain research community”, a characterization probably more aspirational than accurate. But aspiration is important in a volunteer program and the “we” became personal in the form of the Science Leadership Council.

MRI had had previous “boards” but they had always acted as if MRI needed was their advice about how to spend our miniscule budget. I came to see that we did not need so much advice, but rather engagement by key researchers in the development of what we wanted to get done, and as important, the specification of what we would not do, either because it was out of our scope or beyond our means. Thus when we recruited people for the SLC we made sure that candidates understood that we wanted them to lead rather than just advise.

Beyond trying thus to conjure a more unified mountain research community, a few key themes stand out.

First I tried to bring China into the MRI circle. China is the largest nation on the planet with more than 50% of its land mass as mountains. As iconic as the Alps are in Europe, so too are Chinese mountains in the art and literature of this most populous and oldest civilization.

We experienced several false starts before achieving a more lasting relationship with the Chinese Academy of Science Institute for Tibetan Plateau Research just as Prof. Yao Tandong

was launching the Third Pole Environment Project. As always it is difficult to measure the impact that we had on ITP and TPE, but perhaps the most telling indicator is that the SLC now has three members from China, none of them from ITP! While there are still immense cultural and linguistic gaps between researchers in the West and their colleagues in China, the Chinese research enterprise in mountains is simply too large and too well funded to ignore.

Second, MRI has tried to make operational calls for the integration of social and biophysical sciences that heretofore had remained largely rhetorical. MRI is far from done on this front but we have come a long way from the time when MRI was dominated by physical scientists, scientists who, while recognizing the importance of the social system, didn’t actually know what to do with social science or scientists. We started down this social-ecological system (SES) road with Synthesis Workshops, one in Estes Park, CO, USA focused on modeling social ecological systems and run by Julie Klein, Anne Nolin, and Catherine Tucker, and a second in Möschberg, Bern, Switzerland, focused on ecosystem services and run by Sandra Lavorel, Adrienne Grêt-Regamey, and Ariane Walz. The latter generated several papers and the former spawned an NSF-funded Research Coordination Network focused on mountain social-ecological systems. The presence of some of these researchers on the MRI SLC has solidified the MRI’s commitment to the SES approach.

Third, everyone thinks that data are important and so MRI has attempted to shape a project that puts the considerable resources and expertise of the Group on Earth Observations (GEO) into the development of a mountain SES data portal. I was always skeptical of calls by earlier advisors for MRI to create such a data portal itself, but creating a GEO project with Italian colleagues that then took on that work seemed exactly like what MRI



First crossing of Sefinenfurgga
between Muerren and Kiental, 2006

should be doing. The GEO Global Network for Observations and Information on Mountain Environments (GEO-GNOME) provides the mountain community with an opportunity, a vessel that it can fill with data if it can work together.

Connie: As a CIRMOUNT co-founder and advisor as well, what recommendations could you offer for CIRMOUNT's next five years or so? Do you have ideas for strengthening the ties of CIRMOUNT and MRI?

Greg: In my humble opinion, CIRMOUNT is much like MRI: it serves a convening function, and if it convenes the right people around a few themes with traction, then those people will themselves form proposals and projects to do the heavy lifting. CIRMOUNT, unlike MRI, however, has no paid staff and while this doesn't render convening impossible it shifts the burden directly onto members.

That said, the *MtnClim* conference and the *Mountain Views* publication do exemplary convening work. Just keeping these two vehicles going is a major contribution. If that's all CIRMOUNT achieves, that still a lot.

If there were interest in going further, here are a few possibilities.

CIRMOUNT could run its own mini-strategic planning process. MRI accomplished this through two dedicated meetings with a fair amount of staff work in between. The advantage of such a process is that it makes very clear what the participants want to do and more importantly what they don't want or can't do.

To the degree that such a strategic planning process revealed a CIRMOUNT that agrees with the interdisciplinary and transdisciplinary foci of MRI, CIRMOUNT's leaders might try to broaden the scope of *MtnClim* and indeed the *MtnClim* community with regards to social science. CIRMOUNT made some progress in that direction but it never really got past inviting selected social scientists to come educate us at *MtnClim*. To be honest I think the results of these efforts were mixed at best. To do better would require reaching out to social science colleagues in our respective institutions at the *MtnClim* planning level, and indeed probably rethinking the definition of *MtnClim* itself. MRI's strategic plan envisioned a serious intra-mountain community effort to bring the social and biophysical science communities together, and CIRMOUNT's effort in this direction would be in fact a great contribution to MRI.

In some ways, expanding the scope to include social scientists would most likely also include a more concerted effort to include place-based mountain organizations in CIRMOUNT and *MtnClim*. To date, CIRMOUNT's outreach has understandably

focused on agency personnel. However the social evolution of the mountain West has given rise to perceptions of place (in addition to allegiance to industries) and indeed the whole SES approach is one that links fundamentally with a sense of place: in this place, we see social systems interacting with ecological systems, and more to the point, we care about the outcomes of that interaction. Engaging and even promoting mountain place-based groups could hook the CIRMOUNT better into the policy world and even lead to benefits for CIRMOUNT itself.

Finally, one good project can have long-term benefits for the organization of the mountain research community (think of GLORIA). There are of course many possible projects, and indeed one of the outcomes of a strategic planning process could be the specification of one or two projects to which a good part of the CIRMOUNT membership could pledge allegiance. A mountain observatory network, based perhaps on the Global Network of Mountain Observatories (GNOMO launched at RMBL in Gothic CO in 2015), might be a sufficiently motivating project. Or the project might be something else: its essence is that the members want to pursue it. Once again such a network would require staff work and if there isn't someone who wants to provide that work, it will most likely fail.

Connie: What do you see as some of the biggest challenges for the mountain-climate science community at regional to global scales these days?

Greg: I think that the biggest challenge is actually to become the community that I and others have so blithely posited over the years! We have gone a long ways toward overcoming the structural divisions, but we have not yet achieved the level of coherence and cohesion that seems to exist among polar or oceanic researchers. If we asked researchers in mountains to choose between their disciplinary community and their "landform" community, I suspect a majority would still choose their disciplinary community. Of course we don't want to make people choose between the two, as we need both perspectives, but we have yet to see the mountain research community act as a community as for instance have other communities have done, coalescing around big pieces of research infrastructure, such as research vessels or satellite missions. Thus a big infrastructure project can be both a means and an end: of course we want what the project will produce, but the very act of advocating for the project serves to catalyze the community.

I suspect that federal funding for research in the USA will be very difficult to get over the next few years and indeed it is possible that programs that we heretofore thought as well established may even disappear. Thus in the US, it will be imperative to close with loop with the other beneficiaries of mountain research, be

they state or local governments, place-based NGOs or climate-sensitive industries. Once again the central idea is to broaden support beyond the traditional agencies. But this will be very challenging as we would like to see a broader and more coherent scientific strategy but are constrained to implement it through many small and very focused projects.

Connie: What activities are you pursuing in your early months of retirement?

Greg: I have avoided inventing a new project as a substitute for work, at least right away! Instead of just shifting my focus to some new endeavors and thus continuing to “work” but calling it something else, I have opted for a long list of diverse activities. This means that I still have long daily to-do lists, which I still cannot complete in a day. That much hasn’t changed from when I worked, so perhaps I have not broken away completely from the working mindset.

Since I retired at the end of 2016, the logical activity for me was skiing. Alas, it was not a great ski season in the Swiss Alps—cold but dry—unlike the epic year on the West Coast. Still I got in some good days both on and off the pistes, both in the mountains behind Montreux but also in more distant regions, and look forward to next season.

Planning for the use of one’s time in retirement seems essential if one is to avoid the boredom that afflicted us all as kids toward the end of summer, just before school started.

My planning heuristic is the Seven F’s:

- Food, which covers gardening and experiments with fermentation and other delicacies like pastrami;
- Fitness, which covers skiing and daily exercise in the pre-Alpes behind my home, but also planning multi-day through hikes on the extensive “Grandes Randonnées” trail system in Europe;
- French, which involves achieving eloquence in my second language;
- Family, which covers visiting my children and grandchildren, but also includes continuing my daily blog, and for lack of a better term, writing my memoirs;
- Finances, which means making sure that we have enough money to live on;
- Formation, which is French for “training” and implies continued intellectual growth: I just completed an online course on fractals, and intend to read John Maynard Keynes treatise even if it kills me;
- Foment, which is related to resistance, as much of what I care about is under attack these days. I can’t believe that in 2017 we still have to be protesting and struggling but the forces of reaction and privilege are strong.

I am not bored.



Greg at the Mt Everest Base Camp in 2008 (with Dan Fagre)

INTERVIEW

An Interview with Chris Daly, Father of the PRISM Climate Model

Chris Daly is a household name, familiar to scientists and resource professionals of many disciplines within and far beyond our CIRMOUNT community. Chris is widely respected as the founder, developer, and continuing director and senior research scientist of the PRISM climate model project (Parameter-elevation Regressions on Independent Slopes Model) at Oregon State University. The PRISM Climate Group is an ongoing effort to gather climate observations from a wide range of monitoring networks, apply quality-control measures, and produce spatially gridded climate datasets for the U.S. that incorporate the effects of coastlines, topography, and other features. Data from 1895 to the present allow researchers to investigate short- and long-term climate patterns at multiple temporal and spatial scales. Chris' dedication to PRISM promotes the ongoing improvement of PRISM products, which are made available to the public at: <http://prism.oregonstate.edu/> —Editor

CHRIS DALY



Connie: Your name is widely known as the pioneering author of the PRISM climate mapping system. Can you give us a little background on how you birthed that project and its early development?

Chris: When I came to Oregon State University in 1990 to pursue my Ph.D. with Ron Neilson, we faced a difficult problem. Ron had developed a biogeographic model used to estimate potential changes in the country's vegetation under climate change scenarios. He was only able to run the model at weather station locations, which was problematic given that the areas of most interest were remote and had no stations. There were some simple methods for interpolating temperature to a regular grid, but nothing that captured the complex patterns of precipitation. I had a B.S. in atmospheric sciences from UC Davis, and previous experiences with mapping temperature as an air quality modeler in California, and training in mountain climatology from my M.A. work on Niwot Ridge in Colorado. Given my background, Ron was interested to see if I could come up with a method to produce gridded precipitation climatologies for the country. I spent the summer of 1991 trying to crack this nut. It quickly

became obvious that I could map precipitation fairly well by using a spatially smoothed elevation field as the predictor, and that terrain barriers created major dividing lines between regimes (e.g., rain shadows). One of my breakthroughs was developing a way to automate the process of dividing the country into what became known as topographic facets. At the end of the summer, the first version of a model called Precipitation-elevation Regressions on Independent Slopes Model, later generalized for other variables by replacing the word Precipitation with Parameter. Its initial application to the US allowed Ron to run his model on a wall-to-wall grid for the first time.

While I was developing PRISM, I went to George Taylor, Oregon State Climatologist at the time, to see if he had any climate data that would help me validate the model. That initial meeting with George led to a long association that helped me get funding from the USDA Natural Resources Conservation Service (NRCS) for the development of new official climate maps.

I did a post-doc with Ron from 1994-1997 involving ecosystem modeling. During that time I found myself working at two jobs: ecosystem modeling with Ron and PRISM with George. I needed to pick one or the other, or end up in the Home for Burned-Out Scientists. Ecosystem modeling was the more stable choice job-wise. PRISM, on the other hand, had no firm future, but I felt like I had something important to offer. As they say, I took the road less traveled.

Connie: Did you anticipate that PRISM would become so widely used, and that your career would be so closely associated with its development?

Chris: No, not really. Only one third of my Ph.D. dissertation was devoted to PRISM. It was there because there was a need for accurate spatial datasets of climate variables while working

on more important things, such as biographical and ecosystem modeling. Such datasets are usually taken for granted as being generated by canned statistical processes that require little thought or innovation. Doesn't sound very sexy, does it? I have been told more than once that generating input climate data is a thankless task with little upside potential, but in my mind it deserves to be elevated to a discipline all its own. I call it "geospatial climatology," which is the study of how the earth's physiographic features create the spatial and temporal patterns of climate and weather that we see on the ground. There are so many interesting problems associated with this discipline, so I've just stayed with it.

Connie: You mentioned in your recollections of Kelly Redmond (MVC, 2016, Vol 10) that Kelly was one of three important mentors. Would you be willing to elaborate on this?

Chris: I've briefly mentioned Ron Neilson and George Taylor, who were two of my mentors. I worked closely with them for many years and each made important contributions to my development. Outside of my workplace, Kelly ranks at the top of the list of influential people, not to mention a great friend. I first met Kelly in 1993 when George and I were working with Phil Pasteris at NRCS to form the PRISM Evaluation Group (PEG). The purpose of PEG was to evaluate new state precipitation maps for several western states developed with PRISM. There was a lot of early resistance to my approach. Some state climatologists had invested heavily in developing their own maps, and didn't want to see their work superseded. Kelly, as the Western Regional Climatologist, provided much needed leadership that led to an acceptance of the PRISM maps, but only after much constructive criticism and improvements to the model. This gave PRISM legitimacy, and allowed us to gain more support from NRCS. Over the years, he steadfastly supported me in every way he could, while at the same time providing important critiques when needed. His vision was for me to ultimately develop spatial climate products that were so good, you could treat each pixel as a reliable weather station unto itself. He felt that the road we were going down with PRISM, and with a little nudging from himself, could take us somewhere in that vicinity. I am still working towards that goal.

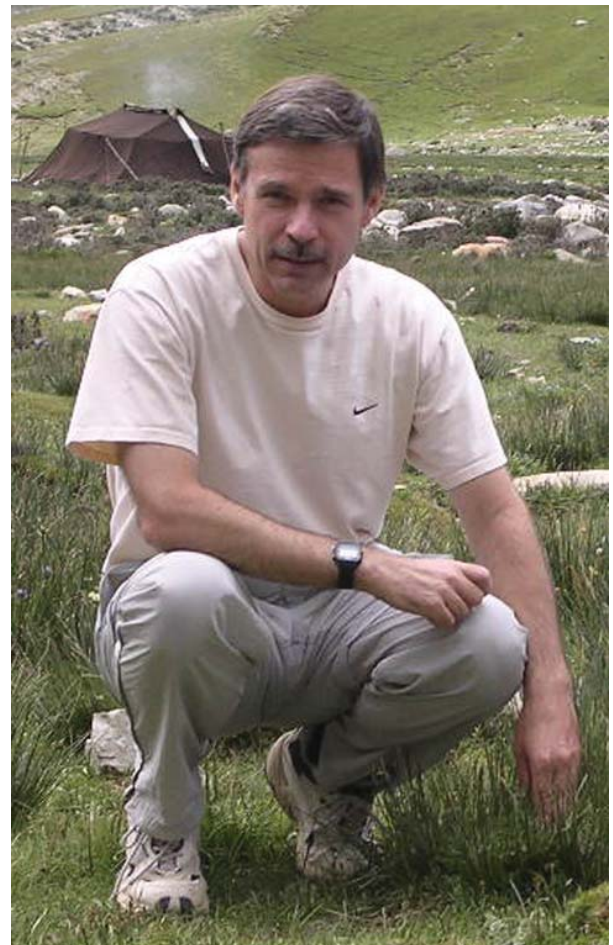
Connie: What are some of the current challenges and opportunities that you are addressing at PRISM headquarters?

Chris: Currently, most of our support comes from by the federal crop insurance program through the USDA Risk Management Agency (RMA). We provide insurance adjusters with weather and climate information needed to evaluate crop loss claims every day on every farm in the conterminous US. We also provide RMA with long-term climatological data on freeze dates

and growing season conditions that help formulate planting guidelines which reduce the risk of crop failures and save taxpayer dollars. The infrastructure needed to do all of this is quite complex, and we currently have ten people working full time to make everything go smoothly.

Our relationship with the RMA has enabled us to move our national maps from a monthly to a daily time step, add radar enhancement to our precipitation maps, and add new variables such as dew point and vapor pressure deficit. Solar radiation and wind are on the docket in a few years. Once we have a full suite of variables, we will be able to calculate potential evapotranspiration, and thus a full water balance.

While agriculture doesn't emphasize mountain climatology, we



Chris exploring native grasslands in Tibet

have not been ignoring that aspect. Once we have solar radiation maps will be able to implement a downscaling procedure we developed ten years ago to bring PRISM down to a much finer resolution and account for local slope and aspect. Along those lines, I have been working with Scotty Strachan at UNR to compare PRISM to data collected by his temperature sites in the Walker River Basin, and noting differences that occur over small spatial scales. I've not been satisfied with our modeled uncertainty estimates, so we are working with heavily instrumented watersheds such as the Coweeta Hydrologic Lab to see how PRISM precipitation estimates compare to actual ground truth. On the climate change front, we are resurrecting work we did in 2009 to account for the effects of differing synoptic flow patterns on lapse rates and precipitation patterns over complex terrain. The question here is how climate change might alter the frequency of cold air pooling episodes, which could fragment the landscape response to climate change into small scale features that depend on local topographic position. So far, much of this work has been focused on the HJ Andrews Experimental Forest, in the Oregon Cascades. We also have a longer-term project to produce what Kelly called a "climate change ready" PRISM dataset that researchers can use to assess with some confidence how the climate has changed over the century – a tall order, but we are working on it.

Connie: How would you describe your own central research interests, if they differ from challenges related to ongoing PRISM development, that is?

Chris: When I travel around the country and the world, I am strongly tuned into the different environments in which plants and animals live. What it is like to live here? What is it like to experience the turning of the seasons? How have the local flora and fauna adapted to the climatic conditions that make the landscape look like it does? My central interest is to try to define, as accurately as possible, the climatic conditions that produce these landscapes. These interests are closely aligned with what I am doing professionally, except that I spend way more time sitting at a computer than out looking at new landscapes.

Connie: I know you are an ambitious mountaineer. How do you view the relationship of your love of mountains and your work?

Chris: I am not a technical climber, but if I see a track leading up a mountain, I have a strong desire to hike or run it and see what is around the bend. I am fortunate enough to be able to spend at least part of my professional life trying to quantify what feeds my mind on a very basic level. I love topography, and how it creates a mosaic of environmental conditions, at many scales, large and



Chris inspecting the Keystone Ridge cooperative weather station near Fairbanks, Alaska

small. I live in Corvallis, Oregon, where I can get out into the hills and forests several days a week. There is something about looking at varying topography and the patterns of landscape and vegetation that makes me happy. It is a joy to be able to channel that sensory perception into a modeling framework that attempts to simulate the drivers of these patterns.

Connie: Any advice for early career mountain-climate scientists? Or, for us elder scientists as well?

Chris: There are two main things I have learned over my career that apply to anyone coming up in science, really. First, become

aware of how your mind works, and more specifically, what turns it on. What intellectual problems really get you excited, that you like to work on? You know, the ones that keep you up at night while your mind spins with possibilities. Your mind is saying “I like this and have something to offer.” Second, don’t let people convince you that your set of mental strengths are unimportant, and that your ways of thinking should be dismissed, just because they are different from the norm. It’s who you are, so how can you dismiss yourself? Figure out how your special skills can help solve problems you really care about. If there isn’t a name for how you do things, then name it yourself. Be persistent, work hard, and don’t get discouraged.



Chris checking out the topography on the summit of Mt Adams, Washington

NEWS and EVENTS



The 28th PACLIM Workshop

Michelle Goman¹ and Scott Mensing²

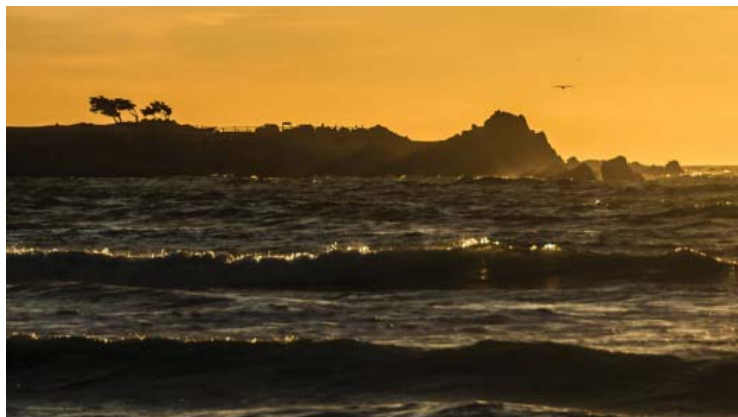
¹*Geography and Global Studies, Sonoma State University, Rohnert Park, California*

²*Ecology, Evolution and Conservation Biology, University of Nevada, Reno, Nevada*

The 28th PACLIM workshop convened March 5-8, 2017 at the Asilomar Conference Center in Pacific Grove, California. The theme of this year's meeting was 'Pacific meets Atlantic: Ocean-Atmosphere Interactions.' Four keynote presentations spoke directly to this topic in the opening morning's session and many contributed presentations touched on the importance of understanding the combined ocean-atmospheric system of both Pacific and Atlantic. The opening Sunday evening session included a period of recollections and memories of Kelly Redmond who traditionally gave his highly entertaining and beautifully illustrated the "State of the PACLIM Year"

presentation. This was always a highlight of the meeting, and we are thinking about how best to open the meeting in the future, since the Sunday night format is also a cherished tradition at the meeting.

This year we had 75 registrants to the PACLIM conference, with 30 oral presentations and 26 posters. Donations allowed us to fully fund the housing and meals for ten graduate students, seven early career faculty and one evening speaker as well as the registration costs for a number of our invited speakers. All funded students and early career faculty gave oral presentations



of posters. Each evening we had a two-hour poster-session/social that as usual was very well attended, sparking many conversations and allowing students to meet many of the researchers whose work they were building upon. Many of the senior researchers had attended PACLIM as graduate students, and contributions continue to build upon this legacy. This year an increasing number of attendees tweeted during the meeting (#PACLIM2017) extending the reach of the meeting. Presentations of those who consent are being posted at the CIRMOUNT website (<http://www.fs.fed.us/psw/cirmount/meetings/archives.shtml>) and we are working on a volume of

paper contributions once again as a special volume in *Quaternary International*.

During the meeting, we already began planning for the 2019 PACLIM, to again be held at Asilomar. We have reserved the venue and begun planning. A theme has not yet been selected, but given the continued high variability in the climate system in recent years will likely once again focus on projections for future climate, a critical topic that remains of utmost importance to society.



Photos by Scotty Strachan

New Book: Microclimate and Local Climate

By Roger G. Barry and Peter D. Blanken
University of Colorado, Boulder, Colorado

Cambridge University Press
 ISBN-13: 9781107145627

Book Review reprinted by permission from *Arctic, Antarctic, and Alpine Research*.

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 University 302 Walker Building University Park, Pennsylvania
 16802, U.S.A. (2017) Microclimate and Local Climate. Arctic,
 Antarctic, and Alpine Research: February 2017, 49:187-188.
<http://aarjournal.org/doi/full/10.1657/AAAR0049-1-book1>*

MICROCLIMATE AND LOCAL CLIMATE represents a unique approach to the study of climate at its most fundamental level: it considers the physical processes of radiation and energy, moisture, and momentum exchanges at and near Earth's surface to be common to—and to interact across—both the microscale (“centimeters to meters”) and the local, or topographic, scale (from ≈ 10 m to 1 km). The spatial-scale context is fundamentally geographic, as befits the academic heritage of the authors, and Earth's physical and living environments are treated as a closely coupled system throughout the book. The subject matter draws upon concepts not just from physical geography and climatology, but also from a wide range of cognate disciplines: meteorology, biology and ecology, hydrology, environmental physics, biogeochemistry, soil science, and statistics. Moreover, this book has direct application and relevance to those same disciplines and to others, such as agriculture, forestry, landscape architecture and urban design, environmental history, and, I would argue, even the history and philosophy of science. The authors synthesize a large number of published studies, both recent and historical (i.e., pre-2000!), to comprehensively provide detail on the physical processes of micro- and local-scale climates, the associated spatial patterns, the implications for humans, and recent and anticipated future changes.

The book comprises three parts (Controls of Microclimate, Local Climates, and Environmental Change), with chapters and sub-chapters organized logically within each part. At the outset (Preface, Introduction) the authors make clear the time and space-scale distinctions between microclimates and local/topo-climates, and also the features unifying them. One can identify at least the following prominent themes running through the book: (1) radiation, energy and heat budgets; (2) boundary layers

(e.g., between atmosphere and Earth's surface, an organism and the air around it); (3) mass (e.g., water) and energy exchanges; (4) the “active surface” (e.g., a soil surface, vegetation canopy, roofs of buildings) at which radiation, energy, and moisture exchanges occur; (5) feedbacks (physical, chemical, biological); (6) environmental gradients, fluxes, and storage; (7) Ohm's Law as a useful analogy for environmental flows; (8) cross-spatial scale interactions; (9) upscaling vs. downscaling; (10) urban climates; (11) the dependence on Earth surface cover types, including snow, ice and water; and (12) the importance of global environmental changes, both anthropogenic and natural.

Although the presentation and discussion of meteorological processes are central to the book's subject matter, the main emphasis and applications are climatological. Biological processes are separated according to vegetation—discussed across a number of chapters—and “insects, reptiles, and mammals,” which warrant their own chapter (9, Bioclimatology). The book considers the theory and the applications of micro- and local-scale climate processes using in situ data and also remotely sensed observations. There is an entire chapter devoted to instrumentation and measurement techniques. Modeling, both to clarify underlying physical mechanisms and to compare with observations, includes statistical, physical/dynamical, and hybrid (empirical-physical) approaches. The modeling topic comprises much of Chapter 6, although it is also represented in other chapters and chapter sections. Urban micro- and local- to regional-scale climates are considered in three chapters (8E, 10, 11C) and involve not just the urban heat island effect but also gases, aerosols, energy and moisture budgets, and modeling of urban surface heterogeneity.

An additional strength of the book is the “Box” format—essentially sidebars—where important background or pertinent related concepts are explained in detail (e.g., “The Global Hydrologic Cycle,” and “Determining the Average Wind Speed and Direction Using Vectors”), which avoids disrupting the flow of the main discussion. Color photographs and maps, line drawings, and graphs are clear and uncluttered, always germane to the discussion at hand, and fully explained by their captions. Much use is also made of tables, which are highly

relevant and clear in the message they are intended to convey. Where detailed information on a topic is to be given later in the book or was provided earlier, those chapters and sub-sections are often mentioned in the text. Immediately following the last chapter there is a “Problems” section organized by chapter. These questions are of the written and numerical kinds, with answers available at the Cambridge University Press website. A comprehensive glossary, list of symbols, and an index complete the book.

The authors' intended audience is upper-level undergraduate and beginning graduate-level students, although even seasoned scientists and established academics will find this book an essential reference work. Accordingly, the book assumes at least some basic knowledge of environmental science and/or physical geography. Such a reader would already have the necessary understanding of, for example, atmospheric lapse rates and what makes air stable, unstable, and neutral. Moreover, such a reader would likely not be confused that the symbol λ can denote both radiation wavelength (p. 82, Symbols section) and the latent heat of vaporization (e.g., p. 99, Symbols section). Formulae are given and equations worked through that are mostly pre-calculus. Although there are a few partial differentials presented (e.g., measuring turbulent fluxes, p. 73), it is pointed out that finite differences are practical for most applications.

Given the book's structure, and the fact that microclimates and local climates are treated in successive parts and then together in the context of global change, there is inevitably some repetition of concepts and definitions. However, such repetition should be helpful both to those readers who will use the book primarily as a reference work, and to those who will read it from beginning to end and may need a reminder. I found relatively few

typographical errors, none of which affects the intended meaning. Note that the term S_{we} (“snow water content”) on pp. 138–139 means the same as the SWE (snow water equivalent) on pp. 36–37 and elsewhere (e.g., p. 199). Also note that, in keeping with the original literature, the symbol for albedo, or reflection coefficient α , is also the exponent in the wind profile power law relationship, the shape parameter of the gamma distribution, and the Priestley-Taylor value. Just a few times in the book is the definition of a concept or principle given sometime after its first mention (sensible heat, eddy covariance method, albedo).

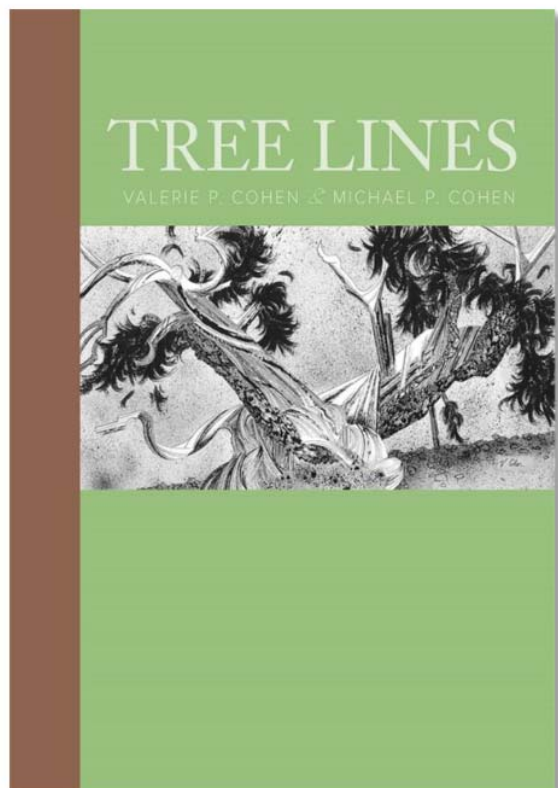
MICROCLIMATE AND LOCAL CLIMATE is so all-encompassing—almost encyclopedic—that I was hardpressed to find any related topics or issues that were omitted! I came up with only two possibilities, and both of these would be small extensions of points already covered in the book. One involves the role of horizontal gradients between land use/land cover in generating local-scale contrasts of sensible heat and Bowen ratio, which may result in cloud and precipitation gradients across those boundaries. The logical place for such additional discussion is toward the end of Part II, where Mosaic Landscapes are presented. My other suggestion would have been for a little discussion of the role of synoptic circulation types in micro- and local-scale surface energy budget differences, as an extension to the role of wind direction. However, both these suggestions are minor in the bigger picture; they in no way detract from the overwhelming strengths of this unique book, as described above, and its comprehensive treatment of the smaller-scale physical processes linking an active surface and sub-surface with its boundary layer(s) on climatic timescales. In short, this book is an outstanding, essential addition to the personal library of every student of climate and environmental science writ large!



Local climate at Ruby Marsh, Nevada. Photo: Connie Millar

New Book: Tree Lines

Valerie P. Cohen and Michael P. Cohen



ABOUT THE AUTHOR

Valerie P. Cohen is an accomplished artist who has written and illustrated several books. She splits her time between Reno, NV and June Lake, CA.

Michael P. Cohen is the award-winning author of *A Garden of Bristlecones: Tales of Change in the Great Basin* (1998), a finalist for the Western States Book Award in nonfiction. He is married to Valerie P. Cohen and is an avid rock climber and mountaineer.

Tree Lines

Valerie P. Cohen and Michael P. Cohen

*A blend of art and literature
that pays homage to majestic
high-altitude pines*

This is a book whose core is twenty-eight India ink drawings of pines that grow at high altitudes in the mountain ranges of the American West. Some of these trees—bristlecone pines—began life 5,000 years ago and are still alive. Other even older bristlecones still stand as graceful skeletons. These, by Valerie P. Cohen, will take you to desolate, silent wilderness where nobody has gone before, except Native American hunters long ago.

Brief narratives by Michael P. Cohen accompany the images, the writing well-researched yet spare and engaging. The artist and the writer will let you feel what it is like to be among these trees: calm, cold, alone, walking on shattered limestone above timberline, breathing the thinnest air, finding your way with or without a map, perhaps getting lost for awhile. And you will learn how an artist thinks and draws. Valerie Cohen and Michel Cohen bring a lifetime of scholarship in literature, history, and the environment to this work.

• • •

"This truly unique and powerful book is the culmination of a lifetime of close observation, scholarship, and artistry. This is a significant contribution to the literature, not just of California, Nevada, and the Great Basin, but to the world, and particularly to the crucial intersection of art, humanities, science, and the environment."

—Jon Christensen, UCLA



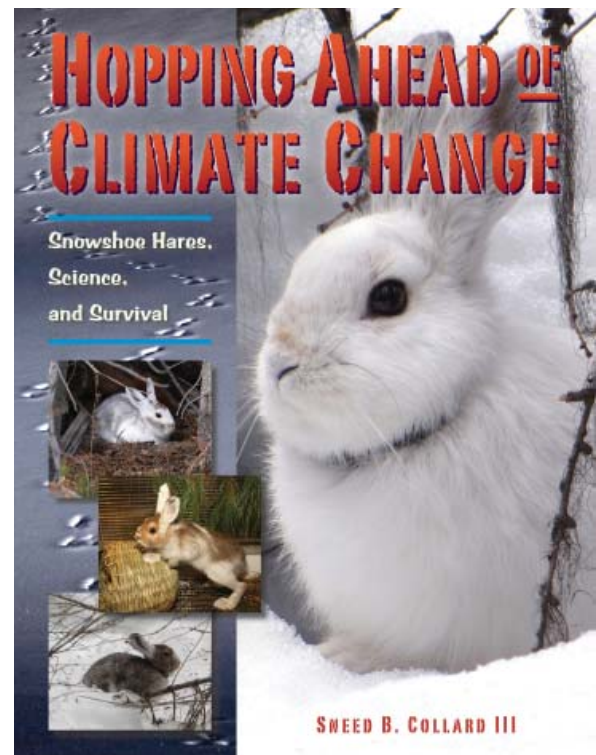
UNIVERSITY OF NEVADA PRESS

New Book: Hopping Ahead of Climate Change: Snowshoe Hares, Science and Survival

Sneed B. Collard III
Bucking Horse Books 2016

This delightful children's book (for children of all ages) describes and illustrates the pelage color asynchrony and challenges faced by snowshoe hares as temperatures rise and snows melt sooner than in recent centuries. The book begins by introducing Scott Mills, a CIRMOUNT colleague and professor of wildlife biologist at the University of Montana who studies the snowshoe hare. Read an overview article about Scott's work on page 9.

Find a book review printed in Science 2016 354, 1226 at:
<http://blogs.sciencemag.org/books/2016/12/05/shorter-winters-leave-snowshoe-hares-mismatched-with-their-habitat/>



CIRMOUNT UPDATES

Snowspotter: Citizen Scientists Help Hydrologists Analyze Forest Snow Interception Patterns

<https://www.zooniverse.org/projects/mozer/snow-spotter>

Longtime CIRMOUNT colleague, snow hydrologist Jessica Lundquist (Department of Civil and Environmental Engineering, University of Washington, Seattle, WA) is at it again. Jessica and her colleagues have developed a successful citizen-science project that is helping researchers assess snow interception patterns in different forest types of the West. The Snowspotter Project invites citizen scientists to submit photographs of mountain forests under diverse snow conditions. Three regional locations are currently in focus for the project: Olympic National Park, WA; Sequoia National Park, CA; and Niwot Ridge LTER, CO. Analyzing photos taken by citizens of snowy forests over time and space allows the researchers to assess interception patterns, and use this information to improve models. This, in turn, improves capacities to evaluate water storage and delivery, which are critical variables for water resource managers.

Background (modified from the project website): For the past two years the University of Washington Mountain Hydrology group has been working on the Olympex project. The Olympex project was a joint venture with NASA and had the goal of collecting detailed atmospheric measurements to evaluate how well satellites measure rainfall and snowfall from space. This last year researchers in the research group set up large, taped,

The researchers are now utilizing the images from the cameras to monitor the amount of snow in the trees. They want to determine how much frozen precipitation was intercepted. Watersheds can be dominated by forests and snow provides a natural storage of fresh water. Since the forest can intercept up to 60% of the total annual snowfall and 25-45% of the intercepted snow can be sublimated back to the atmosphere, forest interception plays a vital role in our understanding of how much snow is in forests. Watersheds can be dominated by forests and snow provides a natural storage of fresh water, therefore citizen contributions will allow scientists to better determine the overall water supply for the dry season.

Thus far all of the images from throughout the Olympic Mountains have been classified, which has entailed over 10,000 images and 150,000 classifications. Due to the resounding success and engagement Snow Spotter has gotten, the Project decided to add images from Sequoia National Park in California and Niwot Ridge in Colorado. The questions for these new images will be similar to the ones asked for the Olympics. However images from California and Colorado have less closed forest and more trees in the background, so the analyses will be slightly different than those for the Olympic Mountains. There is also a new question about the cloudiness of the sky which can be usefully assessed through photos. This will allow the scientists to determine when clouds may be interfering with satellite data, rendering them unreliable.

Added Value from the Project: Dr. Brooke Simons (University of California, San Diego), a collaborator with the Snowspotter Project, took forest interception to delicious new ends. In her *Notes from Nature Blog*, she shares a recipe for Snowspotter cookies. See: blog.notesfromnature.org/2013/12/21/cookies-from-nature



Mineral King/Sequoia National Park Snowspotter Webcam

PVC poles and time-lapse cameras to monitor snow levels on the ground throughout the year. As this project comes to a close a new one begins. (See also a background story in High Country News on related research here: http://www.hcn.org/articles/how-scientists-get-good-data/print_view).



Snowspotter cookies

VOICES IN THE WIND

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

Background: The concept of "snow drought" is gaining traction among scientists, resources managers, and the public. This term refers to the combination of general drought and reduced snow storage, which can derive either from low winter precipitation or lack of snow accumulation following otherwise normal (or near-normal) winter precipitation. Our CIRMOUNT colleagues have recently written an important article (reprinted from EOS on pages 2-6) that differentiates these types of snow drought, which they call "dry snow drought" (low winter precipitation) and "warm snow drought" (lack of snow accumulation due to warm temperatures).

Question: How do you think these types of snow drought have affected or will affect the systems you study, in particular, effects on forests/plants, animals, disturbance? What kinds of information about snow droughts and the different causes would be most useful to your research?

Reference: Harpold, A., Dettinger, M., and Rajagopal, S. 2017. Defining snow drought and why it matters. EOS: <https://eos.org/opinions/defining-snow-drought-and-why-it-matters>.

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

It would be most compelling to study the influence of snow drought on alpine plants and to monitor the effects and timing of snow droughts that last for just part of the winter. For example, does an early season snow drought expose plants to colder than usual temperatures? Does this influence the physiology of buds, which could then influence the resultant flowers and vegetative structures? Do plants experience increased herbivory? In a cold snow drought, the above and belowground plants will have less insulation from temperature extremes, less water from snowmelt, and more wind exposure, which could result in increased brittleness and breakage but could also increase wind dispersal of propagules. With snow drought, soil erosion may increase and the increased movement of soil may lead to changes in the distribution of rhizosphere-associated microbes. Belowground, the colonization of roots by mycorrhizal fungi may decrease. In a warm snow drought, roots may be active when they are usually dormant.

As for new information, a visual map of snow droughts would be useful, as would data on their timing and intensity. I think that



sensor networks measuring above and below ground parameters will be very useful. For example, aboveground sensors could be incorporated into the GLORIA design since with a snow drought, alpine plants could likely be exposed to greater temperature extremes and variations that may drive changes in alpine plant distribution, survival, and abundance. Information on the causes of snow droughts will be very welcome as will information on shifts between snowfall that accumulates and cold and warm snow droughts.

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

I think that we're all buckling up for life in a more volatile natural environment, replete with phenomena that are already present or anticipated as well as those vexing unknown unknowns. Our colleagues Harpold et. al. provide us with an important and useful framework for thinking about the former.

It is reasonable to think that, over a given short span of years, we will see dry snow droughts followed directly by warm snow droughts. I think that this sequence could be a devastating one-two punch for mountain



wetlands. During droughts, dry droughts in particular, montane and subalpine wet meadows can lose below-ground plant biomass, organic matter, and soil cohesion, and the abundances and diversity of mutualistic invertebrates are greatly reduced. Wetlands in this state will have lessened ecological resistance to disturbance from the large amounts of sheet flow that are present during warm droughts, and there will be increased susceptibility to head-cutting. Surface irregularities are common in wet meadows, but strong sheet flow can establish incipient head-cuts—essentially tiny waterfalls. Head-cuts can deepen, widen, and advance upstream and surprisingly quickly; a head cut is like a small knick that develops a nasty infection rapidly. Head-cuts, though formed by water, become drainage ditches that can dry wetlands at rates that would have made a reclamation engineer from the turn of the last century jealous. The problem is exacerbated by the many positive feedbacks involved.

I suspect that there are a lot of drought-associated phenomena like this. We'll probably be seeing more of both dry and warm snow droughts in the coming years. In addition to heeding the hazards posed by each, I think that we'll benefit from examining the interactions between the two drought forms. As is so often the case in science, we may find that the interaction is where the action is.

Tara Barrett, Pacific Northwest Research Station, USDA Forest Service, Wenatchee, WA

My current research uses forest inventory plots located throughout the western U.S. to analyze how forests are changing. The typical concern about snow drought, whether it is 'dry snow drought' or 'warm snow drought', is the impact on late summer soil water availability, which impacts mortality, regeneration, and growth of trees. But snow drought also has some less expected impacts, such as increasing the probability of freezing injury to species such as yellow cedar and yellow birch when low snowpack coincides with cold snaps. And then layered on top of the direct physiological impacts to trees are all the disturbances (fire, insects, & diseases) where things get complicated very quickly: e.g., snow reducing germination of dwarf mistletoe seeds or snow depth affecting overwintering survival of bark beetles. So I'd push the "dry snow drought" vs "warm snow drought" categories a little further, and say trying to understand the impacts on forests would benefit



from fairly high temporal resolution of precipitation, snowpack, & temperature.

The information I'd love to see: daily air & soil temperatures and precipitation separated as snow/rain at each of the FIA forested plot locations in the western U.S. The information I've used as a substitute: PRISM data and some home-made snow models I'm not very happy about. Hopefully improved battery life on data loggers will eventually solve the need for temperature info. So if someone could come up with better spatially explicit rain/snow models, particularly in higher elevations, it would be very helpful.

Dan Isaak, Rocky Mountain Research Station, USDA Forest Service, Boise, ID

As a fisheries scientist, I think of snow as future fish habitat once it's been gathered properly into a stream channel. Anything that affects that process, whether it's the timing or the amount of snow and resultant flow, is something fish populations have to adjust to and that I need to understand. Both types of snow drought—dry and warm—are likely to have important, but subtly different, effects on aquatic biota. Dry snow drought is probably worse for fish because it translates to less water on the landscape and in channels, which directly reduces the amount of fish habitat and the size of fish populations. Flows go lower sooner and thermally stressful summers last longer for temperature sensitive cold-water species like trout and salmon. When extreme drought years coincide with anomalously high summer air temperatures, then that's the worst possible outcome and it's not uncommon for dramatic fish kills to occur and fishing seasons to be curtailed to minimize stresses that anglers cause fish by catching them.



Warm snow drought also has its downsides. Precipitation falling as rain and running off in the winter where it used to be stored as snow until the spring creates a very different hydrograph for fish to deal with. Many fish species spawn in the fall and their eggs incubate in the gravel until late winter when the young fish hatch and begin to swim freely. If those normally quiescent winter periods instead become high flow periods during warm snow years, it may cause streambeds to shift and smother or destroy fish eggs before the young fish hatch. Later in the year as summer low flows drop, it could create a sort of one-two punch

for populations. So the thing I'd most like better information about regarding the two types of snow drought is specifically which parts of the West are going to evolve towards experiencing more dry snow versus warm snow droughts this century as climate change progresses. Ideally, I'd also like to have that information linked into high resolution stream hydrology models that predict flow volumes throughout the year both now and in the future for the 400,000 kilometers of perennial stream and rivers in the western U.S. Then I'd be able to build more accurate species distribution models to predict how fish populations will be affected by snow and if they'll have to wait an uncomfortably long time before they can swim in it.

Lindsay Bourgoine, Advocacy and Campaigns, Protect Our Winters, Boulder, CO

At Protect Our Winters, we work to engage and mobilize the snow sports industry on climate change. As POW's Advocacy Manager, I'm a self-described policy wonk working to bring the research you conduct to our lawmakers to address the very real impacts of greenhouse gas emissions. At the end of April, the founder of POW—world renowned snowboarder Jeremy Jones—and I traveled to Washington DC at the request of Congress to testify on the impacts climate change is having on the outdoor recreation economy.



Here's what we told Congress:

The snowsports community deeply understands the threat that climate change poses on its future. Snowpack is confined to the highest elevations. What should be falling as snow is in fact falling as rain. Our seasons are noticeably shorter. We understand that if we don't act to reduce greenhouse gas emissions, we will see the end of winter as we know it. (Low winter precipitation and a lack of snow accumulation have drastic impacts on our industry.)

As the climate continues to warm our winters, the snowsports industry is increasingly vulnerable. According to the Outdoor Industry Association's 2017 Outdoor Recreation Economy Report, nationwide, the snowsports industry generates \$72 billion annually and supports 695,000 jobs. That means the snowsports industry is responsible for almost 70,000 more American jobs than our country's extractive industries.

Ski resorts have lost over one billion dollars in revenue and up to 27,000 jobs in low snowfall years in the last decade. In recent seasons, 50% of resorts are both opening late and closing early. By 2010, 88% of resorts report utilizing snowmaking to supplement natural snow cover to stay in business, which adds an additional \$500,000 expense to annual operations.

We know that if it stops snowing, future powder days will be the least of our worries. But, at POW, we use winter as a way to connect with people by discussing the climatic changes they have witnessed as outdoor enthusiasts. It's a strategy to depoliticize the issue and connect over a common passion. We all need winter.

Today, we're advocating for innovative policy solutions—like putting a price on carbon and investing in a clean energy economy—at the state and local level. Our 85+ professional athletes are going into schools and talking to kids about climate change, and the impacts they've seen while traveling the world. We are working with scientists—from Anne Nolin to Jason Box—to communicate the changes climate scientists are seeing in the field to our passionate community. And, we're showing up on Capitol Hill. You can learn more at www.protectourwinters.org or contact me at Lindsay@protectourwinters.org with any questions. Thank you for the work you do—we absolutely rely on your research to make the argument for policy change.

Mike Koontz, Department of Plant and Environmental Sciences, University of California, Davis, CA

I'm a recent California transplant and it has been fascinating to learn about how critical snow is for Sierra Nevada forests throughout the year. Much of my dissertation is spent thinking about the spatial arrangement of forest features: how big are clumps of trees? How big are the openings between those clumps? What is the mosaic of microclimates that plants experience? How do we expect disturbances to react to and form



this forest structure? We think answering these questions can tell us about the resilience of forests—whether they may persist or not in the long-run-- and so when I think about different kinds of snow drought, I think about how their effect might vary across space at different spatial scales. For instance, a combination of record snowfall and warm temperatures in the northern Sierra Nevada in 2016-2017 created a late-season snowpack that was above-average at higher elevations and below-average at lower

elevations. We may see spatial signatures of snow drought at smaller extents, too. A large opening between trees (e.g., from a megafire) collects more snow, but that snow melts faster. In a dry snow drought, large forest gaps that better collect a limited snowfall might be the wettest patches on the landscape in that year. In a warm snow drought, the rapid melting of a normal snowfall in a large canopy gap might make them the driest patches on the landscape. How might either of these scenarios affect tree recruitment and future disturbance? The answer is unclear, which speaks to the importance of learning more about these drought phenomena.

Knowing where we expect to see impacts of different kinds of snow droughts will tell us whether they might exacerbate or dampen the feedback loops between forests and disturbances. As we come to appreciate how the spatial arrangement of forest features can affect forests in the long-run, it will be useful to also learn how the spatial arrangement of snow drought effects might inform our understanding of the Sierra Nevada forest social-ecological system.

Isabella Oleksy, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO

I study mountain lakes in the Colorado Rockies and why primary production is increasing in historically oligotrophic waters. In my study system, I can imagine dry and warm snow drought bringing negative change to lakes, with some key differences between the two types of defined drought. In this snowmelt-dominated lake, dry snow drought could result in decreased flushing and a subdued snowmelt pulse. This would eliminate the “reset” that these relatively small lakes typically experience in the spring. In the high Rockies of Colorado, sublimation of the snowpack may play a proportionally greater role in snowpack loss than melt during dry snow droughts, with implications for stream flow and lake levels in the spring and summer.

Under a wet snow drought scenario, we could expect more export of water from lakes and streams before the typical snowmelt pulse. We would expect accelerating lake ice-melt due to rain-on-snow and generally higher temperatures. More rain than snow would increase delivery of solutes, nutrients, and dissolved



carbon into lakes from the watershed. In both warm and dry snow droughts, this would likely result in early ice-off, which would extend the “growing season” of lake algae. Due to an alteration in timing and magnitude of snowpack, we would expect decreased lake levels in summer, as we reach baseflow conditions earlier. This would result in warmer water temperatures, potentially more stable water columns, and higher likelihood of stratification. For my research, it would be helpful to know how mountain lakes with different types of land cover and surface area of volume respond to different types of drought. Shallow lakes in particular may be more vulnerable to droughts due to critical benthic habitat loss from lake level fluctuations and more intense heat exchange with the atmosphere, leading to more rapid temperature increases. Terrestrial-aquatic linkages and potential decoupling as a result of these two different types of snow droughts are particularly interesting.

Matt Shinderman, Department of Fisheries and Wildlife Science, Oregon State University-Cascades, Bend, OR

Much of my work revolves around species and ecosystems found in the Mazama Ecological Province, characterized by semi-arid to arid climate conditions, basin-and-range topography, and soils influenced by Aeolian deposits of pumice-ash from the eruption of Mt. Mazama (now Crater Lake). Precipitation in the Province occurs primarily during the winter months, more than half of which falls as snow. Keystone structures governing ecosystem processes within the Province include highly porous soils and underlying parent material, substantial groundwater aquifers (shallow and deep), and high connectivity between surface and groundwater hydrology.



As in other semi-arid regions, species (both flora and fauna) in the Province are highly adapted to infrequent and variable precipitation, including drought conditions. SNOTEL and other precipitation data for the region confirm a pattern of high inter and intra-annual variability. As defined for this discussion, snow droughts (both dry and warm) are common as short-term phenomena. It is not clear that longer-term (3+ years) snow drought conditions have been occurring with greater frequency or intensity over the period for which reliable climate data are available. As a result, the current influence of changing snow drought frequency or intensity on ecosystem structure or function in the region is debatable, especially when compared to other,

more immediate drivers of change (e.g. land-use, disruption of disturbance regimes, diversion of surface water sources for irrigation).

Increasing frequency and/or intensity of snow drought in the region will likely influence patterns of vegetation species composition and dominance. Winter precipitation as snow currently favors deep-rooted species in many areas, with shallow-rooted species (grasses and forbs) reliant on ephemeral and sporadic rainfall events in spring, summer and fall. A shift in the form of precipitation to more rain, particularly during the winter months, may result in greater dominance by cool-season, deep-rooted species (e.g. chaparral ecosystems), with important implications for system structure and function. Disturbance regimes (primarily fire) may also be influenced via a reduction of live-fuels moisture, exacerbating the longer-term effects of fire suppression and forest management in the region.

Eryn Schneider, W.A. Franke College of Forestry and Conservation, University of Montana, Missoula, MT

My primary study system is dry mixed conifer forests. Over the last five years we have recorded both above and below average snow years in the forests of western Montana. This location is unique in terms of winter precipitation as it is in a transition zone between warmer, wetter maritime and colder, drier continental snow regimes, blurring the line between what may be natural variability in intra and/or interannual snow regime dominance and the impacts of snow drought.



However, low or warm snow droughts may have important structural and functional consequences for dry mixed conifer forest. Isotope analysis in dry mixed conifer is beginning to show that especially late season water acquired by lower elevation trees is coming from deeper, snow derived sources. With little snow or a greater proportion of rain, the pools of available water will shift testing the plasticity of the rooting structure and adaptability of existing trees or causing a shift in the species distribution. The lack of an insulating snowpack due to snow drought will have consequences for the wildlife composition that rely on the subnivean environment over the winter and altering the microbial communities due to greater fluctuations in temperatures. As with any drought in a forest, the risk of fire increases, but snow

droughts will have a greater influence on when the fire season begins and ends.

Further research examining the historical occurrence and periodicity of snow droughts through the climate record are needed to examine how systems have previously responded to, how they are currently responding to, and to predict how they may respond in the future to snow drought. A greater understanding of the causes and prevalence of the two types of snow drought will help water resources and forest managers identify, design, and implement specific forest management strategies to maximize snow accumulation and retention especially during snow droughts.

Jeff Dozier, Bren School of Environmental Science & Management, University of California, Santa Barbara, CA

The distinction between a “dry snow drought” and “warm snow drought” is insightful. Whether a future climate in the Sierra Nevada is wetter or drier is hard to forecast because the climate models disagree (Duffy et al. 2006), although with equivalent precipitation, a warmer climate would have higher evaporative demands. The hypothesis that a warmer climate would lead to an elevation of the rain-snow transition, and therefore some snow storms would produce rain instead, seems likely, hence the greater frequency of warm snow droughts. Earlier runoff and more rain-on-snow floods in the early part of the winter are changes that we ought to anticipate, whereas snowmelt floods in the spring might be less likely because earlier snowmelt would probably be slower as it occurs when daylight periods are shorter and sun elevations are lower (Musselman et al. 2017).



The question I get asked is less subtle, “Is the drought over?” The observation by Harpold et al. (2017) that most of the reservoirs in the Sierra Nevada foothills will fill, or have already filled, is correct, but during the 2013-2015 drought, California’s agricultural economy suffered less than we might have expected because of groundwater withdrawals, as evidenced by inelastic subsidence especially in the San Joaquin drainage (Smith et al. 2017). The recent paper by Margulis et al. (2016) approaches this question through an interesting perspective. To augment the traditional metrics for characterizing drought, they define a “standardized SWE (snow water equivalent) index” and use it

to characterize the lack of availability of surface water supplies to support evapotranspiration, and therefore the deficit built up as groundwater is pumped. Their analysis indicates that about four years of normal or greater snowfall would be necessary to replenish the groundwater extracted from 2013 to 2015. The 2016-2017 winter produced about 1.5 to 1.7 year equivalents of normal snowfall, depending on location, hence the time to recover from the drought remains at between two and three years of normal or greater snowfall.

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FIRST PERSON

Naming the Beast: Overcoming Obstacles to Women in Science

Toni Lyn Morelli

*DOI Northeast Climate Science Center and
Department of Environmental Conservation, University of Massachusetts
Amherst, Massachusetts*

Monica recently defended her dissertation in the Department of Environmental Conservation at the University of Massachusetts, where I'm an Adjunct Assistant Professor. She told of her experience, typical of a graduate student in our field of science: long hours, lots of tedious work in unpleasant field conditions, failed methods, eventual victorious revelations. But this particular dissertation stood out in that it was efficient (she got her degree in less than 4 years), impactful (she was able to identify clear recommendations to deal with a tree pest), and scientifically noteworthy. In fact, she had an insect species named after her—not bad for a 20-something student. Monica shared the story of how eminent entomologists—yes, older males, at the risk of supporting your confirmation bias (Science Daily 2017) repeatedly disregarded her assertion that she had evidence of a new species. Instead of giving up, Monica redoubled her efforts until she had so much evidence—ecological, morphological, and genomic—that she could no longer be denied. And so, in the end, the species was named after her.

What I love about this story, aside from its victory for the scientific process, is how so many of the obstacles that are put between young women and long-term science careers were met, and conquered, by Monica. In the beginning of her life, and mine I guess, though I certainly have no memory of it, we were subtly steered away from math and science (not to mention tools and physical activities). Social science research from Nilanjana Dasgupta shows that girls are just as or even more likely to do well in math until puberty, when grades start to diverge. A large latitudinal study found that teachers consistently rate girls'

mathematical proficiency lower than that of boys with similar achievement and learning behaviors (Cimpian et al. 2016). Once they get to college, the increasing lack of mentors and peers increasingly undermines confidence. How did a young woman like Monica have the gall to stand up against the scientific establishment, against older male professionals, given all of the subtle, and not so subtle, cues she had undoubtedly picked up in her life? How did she even manage to make it to that stage in the first place?

I have to admit, I don't want the answer to be that Monica is remarkable. I hope the reason is that things are changing, that a woman coming up in science won't face the consistent bias that has kept our numbers so low for so long. Certainly the proportion of women in science at the undergraduate level is increasing and, in some fields, is outpacing men.

But I have a nagging worry. Because I look back at myself in my 20s and I was Monica. Well, perhaps not as brilliant, but certainly as driven, and totally unaware of breaking or beating convention by pursuing a graduate degree, and then a postdoctoral fellowship, in STEM. I look back and see that nearly all of my peers in the science college I attended at Michigan State University were male; that my most problematic supervisors were male. Part of that could be chalked up to my



The author, Toni Lyn Morelli, in earlier years



Kay Holekamp (Michigan State University) leads one of the world's longest-running field behavioral research studies. The opportunity that Kay gave me as an undergraduate to study spotted hyenas in the Maasai Mara of Kenya changed the trajectory of my career.



Ph.D. advisor, Patricia Wright, (Stony Brook University), studies lemur behavior and conservation and helped establish one of Madagascar's first national parks.

personality, since I tend to be fairly unaware of others' opinions. But we know from recent research that identical resumes will be considered less impressive just by replacing the name John with Jennifer—or John with Jamaal, for that matter (Moss-Racusin et al. 2012, Bertrand and Mullainathan 2004). And that women still get promoted less (Women in the Workplace 2016). And none of this gets into the more serious threats that women face in the workplace, including sexual harassment (Cain Miller 2017).

I'm the youngest of my parents' three kids, all daughters. My parents thought I was going to be a boy, and already had the name Tony picked out for me when, surprise, I wasn't. With 3 girls to deal with, my fairly traditional dad had no choice but to play sports with us, and I grew up chasing rabbits in the backyard instead of taking dance class. I also went to an all-girls high school, and I often wonder how that might have affected my trajectory; at that key developmental time, there were fewer opportunities for me to be told that boys were better in math and science. Perhaps most importantly, I had key female mentors all throughout my education, strong women who believed in me and showed me by example that women could accomplish great things as professionals in science, something that Dasgupta and others have shown is key to retention of women in science.

I'd like to think that I would still be a scientist even if I had a brother. But I wonder...

The latest investigations into the "leaky pipeline" of female attrition out of the sciences, of which there are many (Early Career Climate Forum 2017), indicate that something is happening between graduate school and tenure (or permanent research scientist positions). One of these things, for many of us, is motherhood. The unrelenting time pressures of professional science careers can be especially challenging for parents, and mothers in particular. Even beyond the time to get through potentially debilitating pregnancy and childbirth and time-consuming lactation (which for me involved pumping in a random unlockable conference room, hoping each time that students wouldn't burst through the door), women are often responsible for more of the work at home. According to 2011-2015 averaged data from the Bureau of Labor Statistics, in American households where both spouses work full time and have children under age 18, women spend 46% more time with childcare, eldercare, and housework while men work 18% longer hours (Bureau of Labor Statistics 2016). Studies show that married women with children are 35% less likely to enter tenure track positions after receiving a Ph.D. in science than men of the same circumstances (Mason et al. 2010). Women with children are 27% less likely to achieve tenure than men with children. Moreover, women with children are 28% less likely to achieve tenure than women without children.

Personally, I was oblivious to the experience of most of these statistics in my 20s. But as I got farther along as a scientist, undergrad to grad school to postdoc to 2nd postdoc (2nd postdoc is the new PhD, ha ha!), more of my friends were dropping out.



Toni Lyn's current supervisor, USGS Biologist and Northeast Climate Science Center Director, Mary Ratnaswamy, pictured here at Biosphere 2 at the base of the Santa Catalina Mountains in Arizona.

And most of my female friends did. One day I woke up and I had a 2-year-old and a great science career but nearly all of my career scientist peers were male. Even more striking is that among parents I know, with few exceptions, the dads are the tenure track professors and research scientists.

There are names for all of the terms that chip away at the proportion of women in STEM along the career path. Confirmation bias affects all minorities, causing us to include and exclude people based on stereotypes. Another is stereotype threat – the idea that if you are a rare “token” example of something you feel a lot of pressure to do things well (American Psychological Association 2006). The feeling can be so overwhelming that it can cause a person not to even try. I heard a joke recently that perhaps we can all relate to this on some level, but in this case I’ll relate it in terms of gender dynamics: a man and a woman, sitting around bored, each throw a pebble into a can. The woman misses and is immediately embarrassed, thinking stupid her, what was she thinking, why even try, what will everyone think of her, and, by extension, all women’s throwing ability. Her male companion takes a shot at the can, and his pebble misses too. He just thinks, Stupid rock.

Establishing a career in science is extremely difficult, and seems to be getting more competitive each year. It takes an incredible combination of motivation, intelligence, creativity, humility, and luck. On top of that, if we are causing certain groups of people—women, people of color, LGBTQ persons—to have to overcome extra obstacles, achieve more accomplishments, and overcome additional skepticism, we will continue to be less diverse in the sciences than in society, something research shows will hurt our productivity, outcomes, and achievements (Phillips 2014). On top of that, many women in the critical point in their career have to fight societal expectations of how they should be choosing to spend more time as mothers than at work.

In the end, I circle back to Monica, her accomplishments and her tenacity. I’m not sure if she is a sign of a better, more equal future on our horizon, or a shining exception to the rule. I just know we’ll all be better off with more scientists like her.

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Morelli and our very own Connie Millar in Washington D.C.
Connie catalyzed my work on climate adaptation.

FIELD NOTES



Searching for Pikas in the Himalaya: Different Cultures, Common Landscapes

Nifer Wilkening

U.S. Fish and Wildlife Service, Southern Nevada Field Office, Las Vegas, Nevada

As we stop for yet another herder and his group of baby goats to pass by us on the road, my sleeping daughter stirs in my lap. It is early morning in the Indian Himalaya and we are driving on a steep mountain track to the village of Taluka. We had arrived in the small town of Sankri the night before, exhausted after a 12-hour car ride from our home in Dehra Dun. The pavement ended in Sankri and we loaded ourselves and gear into a jeep this morning to take us to Taluka, the last village accessible by road before we start trekking. It is only 12 km from Sankri to Taluka yet the drive takes almost an hour. The road, a thin ribbon carved into the side of the mountain, winds through boulder fields and across streams and is barely wide enough for one car in most places. Our driver dutifully honks the horn around every blind corner, standard operating procedure for mountain driving in this part of the world. Although I have been on similar mountain roads numerous times in the past, I'm still a little nervous. There are no seat belts and this time I don't insist that we need one. Seatbelts are not a standard feature in Indian vehicles. Back in Dehra Dun, we have wasted hours driving around to the homes of friends and family members of our drivers, in search of a seatbelt for my daughter. Faced with drop-offs of a thousand feet, a prolonged hunt for a seat belt seems futile in this case.

We arrive in Taluka without incident, which consists of one main street lined with houses and a few small stores and restaurants. The village is still waking up and the smoke from cooking fires fills the air. My daughter claims she is hungry and we head to

a small restaurant for a breakfast of chai and stuffed parathas. While we are waiting, our field assistant Raju sets out to find more assistants. Raju is currently a student at the Wildlife Institute of India in Dehra Dun but is from Osla village, further up the valley. He has repeatedly assured me that it will be no problem to locate and hire two more people in Taluka on such short notice. He is right of course, and soon returns with his cousin and another young man from his village, both just arrived



Village of Taluka



At the beginning of the trail- Surrender, RD, Sabuj, Raju, Avi



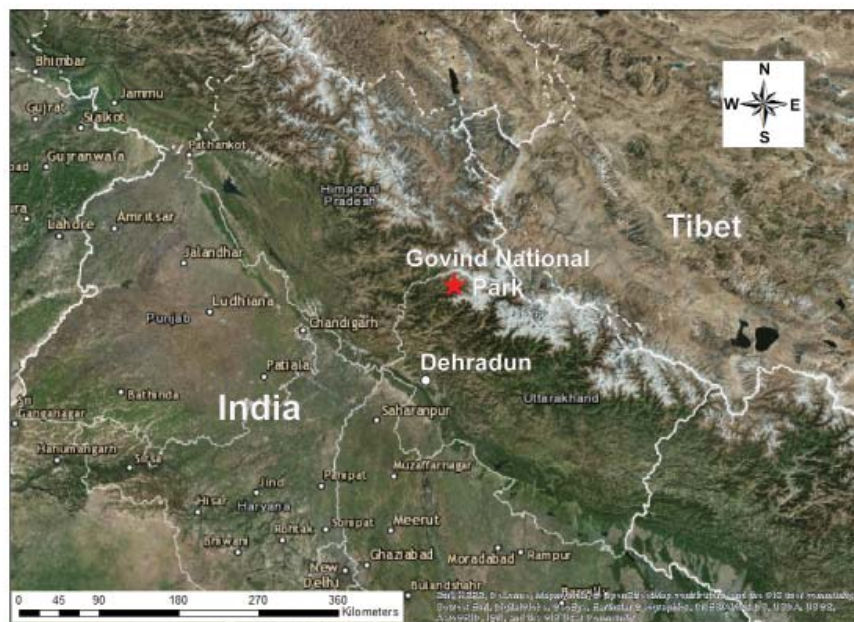
Royle's pika (*Ochotona roylei*)

in Taluka from the trail up the valley. Surrender is very tall while Ram Dass (or RD) is smaller and looks like his cousin Raju. This team of three will be invaluable to us over the next few weeks, acting as guides, cooks, porters, research assistants, translators, and local facilitators for the region. In addition to these three, our group consists of myself, my 5-year-old daughter and my good friend and colleague, Sabuj Bhattacharyya.

We are here in this remote, mountainous part of northern India to collect data on a lesser known alpine mammal, Royle's pika (*Ochotona roylei*). Pikas are cold adapted members of the rabbit order that typically occur in high elevation habitats in Asia and North America. In the western United States, American pikas

inhabit cool microclimates and have been identified as a sentinel species for detecting ecological impacts of climate change due to their narrow thermal tolerance and limited dispersal ability. Royle's pika, which inhabits parts of China, India, Pakistan and Nepal, may occupy a similar role as a potential indicator species for the Himalaya region. In order to investigate how climate change may be impacting this pika species, I am working with collaborators at the Wildlife Institute of India in Dehra Dun as part of a Fulbright scholarship. We have chosen the Har ki Doon valley in Govind National Park as one of our study areas and will be conducting our final round of field work for the season. Our plan is to follow the trail up the valley until it ends near Jaundhar glacier, approximately 35 km and 1600 meters higher. We will

Field work was conducted in Govind National Park as indicated by the star. The Wildlife Institute of India is located in Dehra Dun. Also shown are states, major cities, and the Himalayan Range.



stop in rocky areas along the way to conduct occupancy surveys, collect data related to habitat characteristics (slope, aspect, dominant vegetation, etc.), and place data loggers (ibuttons) to record temperatures.

The genesis of our work here stems from American pika research in the Rocky Mountains. Several years earlier, Sabuj had spent a year in my lab at the University of Colorado, Boulder as a Fulbright researcher. We became friends and working in his part of the world to study an Asian pika species was an opportunity I couldn't pass by. The amount of effort required by my family to make it happen has been monumental. My husband has had to juggle work responsibilities in the US and will not be coming back to India until December. It is already November, late in the season for Himalayan field work. In addition to the usual delays associated with visas and research permits, we have been further postponed by colossal flooding, both back home in Colorado and throughout the state of Uttarakhand in northern India. Our initial research sites had to be changed due to roads being washed out and we arrived in India much later in the summer than planned. We have been lucky with weather and this part of the Indian Himalaya is still accessible this late in the year. We know this could change quickly though and are prepared to turn around at any point in the next few weeks.

After a final round of last minute shopping at the small stores in Taluka, we set out along the trail. Following my American instinct to be prepared and gear up, I had purchased a child carrier for my daughter from an online company in Dehra Dun. Sabuj had warned me that it was probably unnecessary, as the locals have their own way of carrying children. Almost

immediately the carrier is put inside one of the packs and my daughter is up on the shoulders of Surrender. This birds-eye view delights her and her frequent laughter drifts down from above. The trail is crowded with mule trains wearing brightly colored blankets and tinkling bells and we stop often to let them pass by. The mules are carrying winter food stores to the villages further up the valley, sacks of rice, lentils and flour. These 3,000 year old villages are populated by pastoralist families that grow vegetables and graze their livestock in the verdant pastures of the Himalaya. It is said that one day the Indian government will extend the road all the way to the last village, 16 km up the valley. For now the trail provides the only access and all supplies are carried in by animals or humans. Once the snow arrives the trail becomes too icy and treacherous and the mule trains will stop for the season, further isolating villagers up the valley.

The other mothers we meet on the trail ask for various types of medicine, which we don't have. The children ask for candy that we do have, and which my daughter dutifully hands out. I have mixed feelings about passing out cavity-inducing sweets but convincing a 5-year-old to lie and claim that we don't have any is yet another moral dilemma. We have struggled with several since moving to India, which have involved very complicated discussions about trash-filled rivers, stray dogs in deplorable physical condition, and children on the streets begging (probably the most difficult). Admitting to having sweets but not distributing them does not appear to be an acceptable option either. Everything is shared in this mountainous part of the world, a communal attitude prevalent among cultures existing in harsh environments.



Mule trains carrying supplies to villages up the valley



Resting along the trail, Raju, Nifer and Avi with local villagers

My daughter's hair is a sun-bleached brown, almost blonde, and the women wind strands around their fingers while murmuring softly. The children stare at my daughter and shyly ask questions. This is not exactly an unvisited part of the Himalaya as the Har ki Doon trek is very popular among Indian and foreign tourists alike. These groups are typically not traveling with children however, and a 5-year-old foreigner is still somewhat of a novelty. I speak very limited Hindi and most of the villagers speak only Garhwali. Our three field assistants (Raju, Surender and RD) speak Garhwali and Hindi (but not much English) while Sabuj speaks Hindi and English (but no Garhwali). So the train of translation begins with the villagers asking Raju questions in Garhwali, Raju translating the questions into Hindi, Sabuj translating the questions into English, and me answering in English and then back again. There are many questions about where we are from and why we are here. Raju explains that I am an American researcher that has traveled with my family all the

way to India to study one of their local animals, Royle's pika. I watch the eyes light up in the faces of the little girls listening, and I have never been more proud to be a woman scientist.

As the days pass by we slip into a comfortable routine. Our daily activities consist mainly of walking along the trail further up the valley or taking side trips into talus areas and surveying for pikas. Our nights are spent in one of the government run Forest Service rest houses, organizing field gear and collected data and planning surveys for the next day. Raju, Surender and RD take turns with various duties—usually one of them comes with Sabuj and I to help collect data, one person watches my daughter, and somebody else goes ahead to prepare the meal at our next stop. My daughter becomes good friends with all three and seems contented and relaxed. We've been in India for several months but these peaceful areas where pikas live feel more like home than our



Sabuj and RD photographing a site in the Har ki Dun area



Royle's pika near Osla



Typical pika habitat found at higher elevation sites in the Har ki Dun area

house in Dehra Dun. India is a land of shocking contrasts, capable of presenting some of the most beautiful and horrifying examples of humanity at the same time. Foreigners claim that one either hates this country or loves it, and this does appear to be true for most people. Although we live in a nice neighborhood in a city considered small by Indian standards (Dehra Dun population ~ 700,000), it is never completely quiet. The nights are filled with the noise of motorcycles, dogs barking, monkeys chattering, wedding parties, and street vendors and ear plugs are necessary for a good night's sleep. We are not accustomed to such a cacophonous environment, and the soft sounds of wind blowing through the trees and the river gurgling below remind us of our mountain home in Colorado. We meet only one other group of foreign travelers in this valley, a team of Italian climbers. They spend a night with us at one of the rest houses and respond to my daughters' charms by giving her high quality European chocolate.

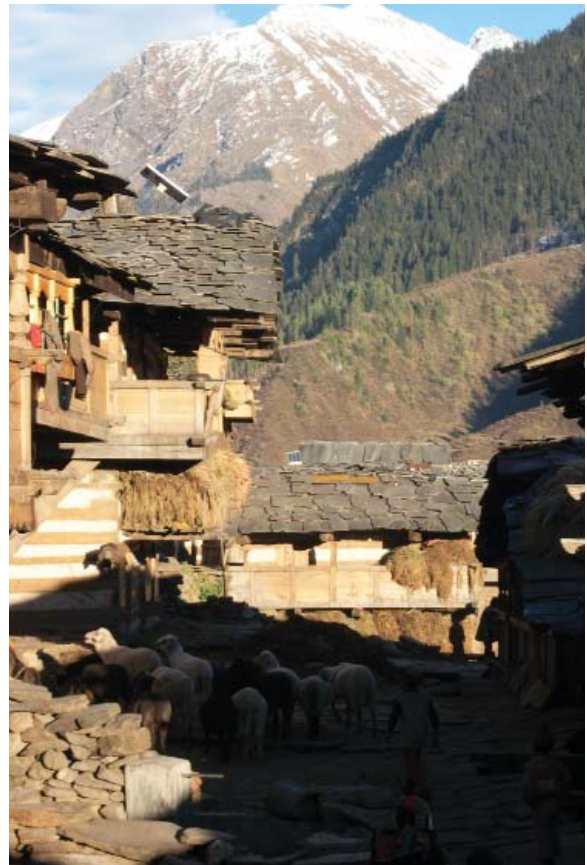
The weather holds and we make it to the final Forest Service rest house at the end of the trail, just before Jaundhar glacier. Several kilometers before the rest house the trail becomes snow packed and for the next few days we will be surveying in snow. As we

are heading up, we cross paths with Raju's uncle heading down. He is the caretaker for the rest house and was on his way back to Osla village after closing up for the season. He agrees to re-open the rest house and will return later with food and supplies. This area is the most beautiful we have seen so far but also the coldest. The Himalaya region of India is located at lower latitudes (approximately the same as the US-Mexico border) and the snowline in these mountains typically begins at higher elevations. We are at 3500 meters, a relatively low elevation for the highest mountain range in the world. However, we are surrounded by 6000 meter peaks and this combined with the recently arrived blanket of winter snow on the ground, intensifies the feeling of cold. The Forest Service rest houses are not heated and the cooking fire does little to provide warmth. My daughter sleeps in her ski pants and coat and at night we huddle together in our sleeping bags to stay warm.

After several chilly days, we finish the surveys, place the last of the data loggers, and head back down the trail. Raju's family invites us to stay with them in their village of Osla and we excitedly accept. Along the trail to the village we are passed by



Approaching final Har ki Dun Forest Rest House (FRH)



Osla village, view from the front porch at Raju's house



Osla village, winter haypiles for the livestock



Osla villager spinning yarn

many people carrying bundles of collected vegetation on their backs. This serves as winter fodder for the goats, sheep, horses, and mules which will spend the winter stabled underneath the homes of the pastoralist families. Heat from the animals rises into the house above and this arrangement is commonly seen among pastoralist communities located in cold mountainous regions. Villagers are bringing in groups of animals for the night accompanied by herding dogs wearing spiked metal collars to provide protection from leopards. Our arrival in Osla village generates a lot of excitement, especially among the children. We visit the village temple and play games with the children and then settle into Raju's family home for the night. His parents have traveled to Dehra Dun to purchase supplies but his favorite sister Nirmala is home. Nirmala and Raju make dal (lentils) and potato curry for dinner which my daughter eyes suspiciously. Although I think the food alone is worth the trip, my daughter is a picky eater and has an entirely different opinion about Indian food. She subsists mainly on rice, chapattis (flat Indian bread), and peanut butter that I brought with us from a special store in Dehra Dun, and milk when available. It is much warmer at this lower elevation and my daughter falls asleep in front of the fire almost immediately after dinner.

We leave Osla village early the next day for the long hike back to Taluka. From there, we will hire a car to take us back to the Wildlife Institute in Dehra Dun, where I will spend my remaining months in India. This last round of field work has been a success and we are leaving the Himalaya very grateful for the data collected. Hindus believe that the Pandavas (mythological

brothers featured in the epic Hindu text, the Mahabharata) ascended to heaven following the trail up the Har ki Doon valley. The name roughly translates to "Valley of the Gods" and many Indians take this pilgrimage to feel closer to their gods. Our purpose in these mountains is more secular in nature but we depart feeling a similar way—physically exhausted but mentally invigorated. Those of us who live and work in mountain environments understand the capricious nature, and the delicate balance, of these systems. Environmental conditions can change in an instant and plans often have to be altered again and again. Regardless of our spiritual beliefs, we are united in our dependence on good weather and good luck. As we head down the trail with the snow-capped peaks receding behind us, I hear others around me giving thanks in different languages.



Temple in Osla



Departing Osla, heading back to Taluka then home to Dehra Dun



Back in Taluka, field research successfully concluded—RD, Raju, Nifer, Sabuj, Avi, Surender

Photos by Nifer Wilkening and Sabuj Bhattacharyya

DID YOU SEE IT?

Winter of 2016-2017 and the Mystery of the Pine-Branch Cast

Connie Millar

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

By now the winter of 2016-2017 has earned its place among record weather years for its recurring atmospheric rivers that yielded epic snow depths in many parts of the West. Having worked in the eastern Sierra Nevada of California for thirty years, I delighted to compare the effects of this winter with those of other big snow years, and to witness the stark contrast to prior drought years.

An early-spring phenomenon in the forests of the region, while deep snow still covered the ground, caught the attention and curiosity of locals and visitors alike. The main north-south highway in the region, US 395, parallels the base of the Sierra escarpment, traversing montane pine forests before it drops into arid, low, Owens Valley. North and south of Deadman Summit (2453 m; about 20 km south of Mono Lake) the highway passes through mature Jeffrey pine forests (*Pinus jeffreyi*). Beginning about March 20, during a sunny-days-respite between storms, travelers on US 395 observed dense carpets of pine-branch tips lying on the surface of the snowpack (then about 1—2 m deep) directly under trees along the highway (Fig. 1). I drove this route several times during March 25-27, and made the following observations (see photos):

- branchlets were mostly all less than 0.5 m;
- branchlets had green foliage and appeared healthy, not abraded or scarred; needles had also, but not all, been detached from the branch.

- branchlets did not show obvious evidence of rodent harvest or chewing;
- break points of the branch were relatively clean, not ripped or shredded.
- branchlets were lying on the surface of the snow as if a one-time event, not melting from the snowbank;
- branchlets formed a dense cover over the snow that did not extend beyond the edge of the canopy of the tree and were symmetrically distributed under the entire crown; branchlets were not in areas between trees where canopies were non-overlapping (Fig. 2);
- Jeffrey pine and lodgepole pine (*Pinus contorta*) showed this effect;
- trees from which the branchlets derived were healthy and not obviously drought (or otherwise) stressed.
- the effect persisted 150 m from the highway edge but didn't seem to extend farther into the forest, although I could only check this visually and in one place where I walked out.
- the effect extended about 15 k along US 395, but there were places where the effect wasn't present despite apparently similar forest and snow conditions.
- snowblowers as well as snow plows were routinely used on US 395 for snow removal (Fig. 3).



Figure 1. Pine-branches cast under trees along US 395.



Figure 2. Branches and needles cast below a lodgepole pine.

What Happened Here? A Few Ideas, None Totally Convincing

1. *Drought stress weakened branches such that winter freeze and/or heavy snow caused them to break. Alternately, heavy snow with repeat freeze-thaw events caused breakage whether trees were stressed or not.*

The regularity of branch size and the light weight of the small branches makes this explanation unlikely; snow and ice damage would more likely break large branches, and not so regularly.

2. *Wind blew the branches down, perhaps combined with snow/freeze pre-conditioning.*

The region experienced tremendous winds this winter, with significant damage to forests as well as homes and infrastructure. Wind damage would more likely result in many sizes of broken branches, including large branches and whole stems, and wouldn't occur only along the highway corridor, although some turbulence might develop there. Most importantly, wind effects should be directional, such that broken branches would have an asymmetric distribution downwind of individual trees, rather than forming a neat pattern of downfall directly below, and all around, the crown.

3. *Rodents chewed the branches off.*

Tree squirrels are common in the eastern Sierra and they cut branch tips to obtain pollen and seed cones. Small branches of regular size and about the same length as the mystery branches can often be found in early spring distributed symmetrically around the base of pine and juniper trees in eastern Sierran forests (Fig. 4). Squirrel-harvest trees, however, occur sporadically, and it would take an uncommonly large army of squirrels to produce the volume of branch litter we witnessed.

4. *Snow removal equipment blew the needles off the trees.*

While this might seem to be the most compelling argument, given the nature of the branch-fall event along the highway corridor, it is not clear that snowblowing alone would cause the effect we

saw. The lateral, directional force of the spray of snow should create asymmetric distribution of branches if the force of the snow spray directly broke the branches. In the end, my best guess is a combination of snowblowing, which loaded the branches with snow, and a subsequent freeze-thaw event that served to snap the ice-laden branches. Even here questions remain: Why were branches broken at their tips? Why only in some parts of the forest (the snow removal was continuous)? Why relatively far back into the forest (even though still within the highway corridor)? Why don't we see this more often and in more places, in that CalTrans uses snowblowing equipment routinely?

Any ideas? Send them to me! cmillar@fs.fed.us



Figure 3. Typical CalTrans snowblower.
Photo courtesy of James Young.



Figure 4. Typical squirrel-clipped branches below *Pinus contorta*.

CONTRIBUTING ARTISTS

Valerie Cohen has contributed many mountain paintings for previous issues of *Mountain Views*. She is a landscape and botanical artist with a focus on mountains and trees of the American Southwest, in particular bristlecone pines. She has been painting since the 1980s alongside her mentor, Milford Zornes. Her husband, Michael Cohen was professor of literature and environment at Southern Utah University for twenty-seven years, and visiting professor at University of Nevada, Reno in recent years. In addition to many mountain adventures, Valerie and Michael sojourn to the high White Mountains during the annual GLORIA (alpine plant-monitoring) monitoring week. We feature their recent book, *Tree Lines*, in this issue. See more of Valerie's work at <http://valeriepcohen.com/>

I have known **Jim Blanchard** since 1968 when we worked together at Hoodoo Ski Bowl in the Oregon Cascades as ski patrol (Connie) and ski instructor (Jim). Jim retired from Director of the Outdoor Pursuits Program and Outdoor Leadership

Training Program at the University of Oregon in 2009, and since then has honed his lifelong passion for mountain photography while he continues to forge new tracks into the Oregon wilderness. He has contributed articles and many photographs to *Mountain Views*, and we use images from a winter trip to Crater Lake for the covers of this issue.

Mackenzie Jeffress is a Diversity Biologist with the Nevada Department of Wildlife. Her photo for our inside front cover was taken during the annual goshawk breeding surveys, which usually start with helicopter monitoring, followed by ground confirmation. The day Mackenzie took this picture, she was post-holing through deep snow in the East Humboldt Range, NV, to observe whether the nest was active. Goshawks are very territorial during the breeding season, and this particular bird was showing its protective behavior by dive-bombing Mackenzie.



Wizard Island—Crater Lake, by Jim Blanchard

MOUNTAIN VISIONS



A Steep Laboratory

A GREAT DEAL of beautiful wood embellishes the slopes of Campito Mountain, in remarkable shapes and finishes. How many shapes? How many embellishments, how decorous? How “dressed up” as a fiction? Yes it is a sculpture garden and most pieces are labeled. Was it more than just wood to Valmore La Marche and the researchers who followed?

Trees all the way to the summit, their aluminum labels sometimes waving in the wind like tinsel.

Many people have worked here: these trees and their remains mean many things to many people, who tag them in various ways and with various codes: SHP 241: TRL 64: VLM 40: CAM 27. Researchers continue to replace the tags of their predecessors. The codes change because the interests and institutions of people change. Data disappears too.

Like other places, this is an island with its own biogeography: A great deal of wildlife here, perhaps due to the soil of the Campito Formation. Dark rock, shrubs around the trees. ✦

Michael P. Cohen

Prose and drawing from *Tree Lines* (see page 48 in this issue, New Book Announcement)



11,600 in the Whites, Valerie P. Cohen

