

MOUNTAIN VIEWS

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



Informing the Mountain Research Community

**Vol. 5, No. 2
Autumn 2011**

Summer 2011: Started as A Cool, Wet Season in the Mountains of Western North America

Sky Pilots

Either tomorrow
or the day after
they'll bloom
so I'll wait here
on Forester Pass

*Norman Schaefer, From "The Sunny Top of California",
La Alameda Press, 2010 (with permission from the author)*



Sky Pilots

Wally Woolfenden, August 2011

Mountain Views

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

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

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Cover Photos: Jeremy Littell, Research Scientist, University of Washington, Seattle, WA. Front: North Face of Mount Jefferson, OR Cascades. 26 Sep. 2009. Back: West Oval Lake and subalpine larches (*Larix lyallii*), Lake Chelan Sawtooth Wilderness, North Cascades, WA. 11 Oct. 2007.

The Mountain Views Newsletter (*MVN*)

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Welcome to *Mountain Views*, the biannual newsletter of the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT, www.fs.fed.us/psw/cirmount/). With this autumn issue, we complete our fourth year producing *MVN* and reporting news about climate research and climate adaptation relevant to mountains of western North America. Thanks to former lead editor, Henry Diaz, for his help in producing this issue. CIRMOUNT is an informal consortium comprising scientists, managers, policy makers, and others interested in climate science and ecosystem responses in our region. CIRMOUNT provides a forum to integrate and communicate research from diverse disciplines, and seeks to promote awareness of, and solutions to, societal issues arising from anthropogenic impacts on the climate and biophysical systems in mountain regions of the West.

As a grass-roots consortium, CIRMOUNT has been informally advanced by coordinators who promote our community's goals whenever possible given our unfunded status. In 2004, we launched CIRMOUNT following our first major conference, which took place at Lake Tahoe, California. Biennial meetings, now known as the MtnClim Conferences (archives at: www.fs.fed.us/psw/cirmount/meetings/), have become CIRMOUNT's flagship event. *MtnClim 2012* will convene October 1-4, 2012 in Estes Park, Colorado. Find information, register, and submit abstracts for *MtnClim 2012* at www.fs.fed.us/psw/mtnclim/.

The MtnClim Conferences alternate with our sister event, the Pacific Climate Workshops, which convened this year in Pacific Grove, CA on March 6-9, 2011 (see page 37). The next PACLIM Workshop will be March 3-6, 2013 at the Asilomar Conference Center, Pacific Grove, CA.

CIRMOUNT also sponsors mountain-climate sessions at the annual Fall Meeting of the American Geophysical Union (AGU) in San Francisco. At the December 2012 AGU meeting, we are convening a session entitled, *Climatic Water Deficit and Water Balance in Mountain Systems: Biophysics, Ecohydrology, and Impacts* (Dec 7), CIRMOUNT's eighth year contributing to AGU. Information is on the CIRMOUNT meeting page; after the meeting, presentations can be found on the archive page. Join us also for CIRMOUNT's annual AGU evening banquet gathering.

On behalf of the CIRMOUNT coordinators, we send our best for a productive 2011 autumn.

— Connie and Jeremy



What's on the Wind? Musings from a Mountain Top

Jeremy Littell

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In an alpine meadow in Olympic National Park, I'm looking down, then up the soon-to-be dam-free Elwha River valley. I heard from Jerry Freilich, research coordinator at Olympic, that National Park visits are declining every year now - in most parks, not just Olympic. How is it that salmon could run in stretches of this river for the first time in a century and fewer and fewer people would be there to see it, much less care about it? The Lower Elwha Klallam Tribe welcomed representatives from distant Tribes to witness the symbolic beginning of the dams' removal in September. But the president of the US was undecided. Is this, too, evidence of less connection to landscape? I've been thinking about something related that's on the horizon, not clear enough yet to see. I suspect some in our community may dismiss it as less than objective, but if I'm right, I think there is a connection between that decline and our society's willingness to fund the kind of research that interests us most.

But research and the fate of science aside a minute. After busting our lungs into a wildflower paradise full of mountain goat kids, racing clouds, and glaciers, we sat around a fire - me, 13 college students, three very well read UW honors advisers, and, for some of them, newfound acquaintances like bliss earned by blisters, mind- and lung-expanding views, and the kind of quiet that can come only after throwing yourself up - and back down - a mountain. We discussed, notably, Joseph Sax' book "Mountains Without Handrails" and Kelly Duane's film "Monumental", about David Brower. We argued whether wilderness is a privilege or a right, whether boundaries are forever, what role the Parks do and should have, and whether humans are part of wilderness. This fire witnessed the dimensions of our collective confusion without saying much more than any fire ever has, and we went to sleep stargazing no more enlightened than before we sat down. Perhaps less.

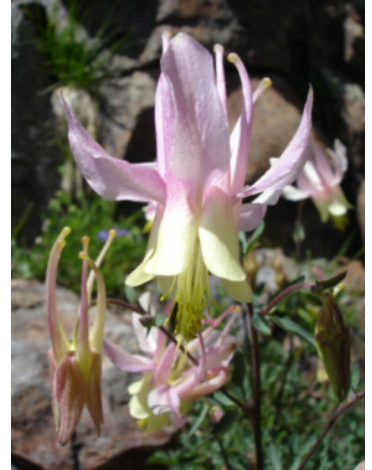
So it got me wondering...tomorrow, next year, a decade or century from now, the importance of understanding these places - not just the metrics of their biophysical function and their ecosystem services, but why they are important to us as a people - that importance may be lost. And that has consequences for the CIRMOUNT community - a loss of connection to landscape by the populace may well be equivalent to a step further from acquaintance with the necessity of funding research, or maybe better put, one degree less tolerance for the use of public money

to understand mountains.

"Monumental" reminded me that people who could vote and write letters might have been fewer generations distant from a direct relationship with landscape in 1964....we could not have a 73-18 vote on a wilderness bill today because as a society, we vote differently, for different people, with different objectives in mind. If we can't expect that kind of connection, can we expect to easily communicate WHY it's important to study such places? Compared to communicating

science in the last 20 years, it may well get a whole lot more difficult, both to find the resources to continue doing the science we know is important and to make it relevant to a broader community. It is already hard enough.

This issue of *Mountain Views* has some pieces that show a human connection more directly - Tague's, for instance. Not all research is so few degrees removed from decision making, but all of it is relevant to people in some way, if only that our efforts at understanding the nature of the universe can inspire others to do things (travel, vote, read), to care about where water comes from, to have sufficient connection with the idea that mountains are important to more than just climbers. I'd like to know how our CIRMOUNT group thinks the long-term prognosis for research is. Are we merely looking at a long-term decline in funding for basic science, and even applied research? Or is it more that that? Are we seeing an even further uncoupling of the empirical and direct observation from the foundations of research? Certainly the incentives are there to focus much more on already harvested fruit, our existing data and models. Remote sensing and automation help greatly, but in mountains the important questions often as not come only once the researcher is removed from the lab. Just ask the field of taxonomy. With everything sequenced, will anyone know how to identify a sedge?



Columbine hybrids, *Aquilegia formosa* x *pungens*, along the Sierra Nevada crest, CA. Photo: Wangdowa Sherpa

Climate Records from Ice Cores Drilled in Papua, New Guinea

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Records of past climate and environmental conditions such as temperature, precipitation and chemistry of the air are preserved in the seasonal layers of ice caps and ice fields. Cores drilled in these frozen archives around the world enable us to examine past climatic variations and understand the mechanisms that control these changes. For the past three decades the Ice Core Paleoclimate Research Group (ICPRG) at the Byrd Polar Research Center has dedicated itself to retrieving climate records from ice fields and glaciers around the world. Our latest project involves the recovery, analysis and interpretation of ice cores from opposite sides of the tropical Pacific Basin. In 2009 we drilled two cores (189 meters and 195 meters to bedrock) on Nevado Hualcán in the Cordillera Blanca of southern Peru. We anticipate that they will provide high resolution climate records extending over 500 years. In May and June of 2010 our team succeeded in drilling through glaciers perched on the edge of a 4884 meter (16,020 ft) high mountain near Puncak Jaya on the tropical island of Papua, New Guinea (Figs. 1 and 2), the only ice fields between the Himalayas and the Andes of Peru. We were able to recover three cores measuring 26 meters, 30 meters and 32 meters (to bedrock) in length. The glaciers in this area are rapidly melting, so this expedition could also be considered to be a “salvage” operation.

Climate variability in the tropical Pacific is dominated on interannual time scales by the phenomenon known as El Niño-Southern

Oscillation (ENSO), or simply El Niño as it is popularly called. The glaciers near Puncak Jaya lie in a climatically sensitive region, the so called ‘center of action’ on the western side of the Pacific Warm Pool which is critically affected by ENSO. Here they are ideally situated to record unique and hitherto unavailable information about past ENSO variability that is sorely needed from this data sparse region. The paleoclimate histories recovered from these glaciers will be integrated with complementary records from glaciers in the South American Andes, including Hualcán, on the eastern side of the Pacific Basin. This new compilation will provide a rare opportunity to examine the nature of tropical climate variability, especially ENSO variability, in space and time. In addition, information from these ice cores will shed new light on the variability of the Austral-Asian monsoon system that brings life sustaining rains to several billion people.

The ice fields near Puncak Jaya are small, and taken together they cover barely 1.7 square kilometers, which is comparable to the current 1.8 square kilometers on the summit of Kilimanjaro in East Africa. The New Guinea cores are relatively short, especially when compared with some of those retrieved during a few of our previous 57 expeditions. However, we have discovered that short cores, such as those taken from Kilimanjaro in 2000 and from Coropuna in southern Peru in 2003, contain climate records of several thousand years in duration. Nevertheless, due to the much



Figure 1. Summit glacier on Puncak Jaya, Papua, New Guinea. Photo: Lonnie Thompson



Figure 2. Drilling tent atop glacier in tropical Papua, New Guinea. Photo: Lonnie Thompson.



Figure 3. Drilling equipment and ice cores were transported to and from the glacier by helicopter. Photo: Lonnie Thompson.

warmer climate and the high precipitation, we expect that the ice core records from Papua will be much younger.

The analyses of the longest Hualcán and the longest New Guinea cores are nearly complete. Measurements include mineral dust concentrations, stable isotopes of oxygen and hydrogen (proxies for temperature), major cations and anions (including sodium, potassium, nitrate, sulfate, and chloride), and trace and rare-earth elements for identifying major

volcanic eruptions. Radioactive tritium from atomic bomb tests in the 1950s and 1960s may be useful for establishing chronology, assuming that the glaciers have not melted below the levels of these time horizons. The isotope analysis of rainwater samples that were collected from the New Guinea shoreline to the top of the mountain should provide information that will help clarify the climate history locked in these ice cores.

Our research in Peru and New Guinea is supported by a paleoclimate program grant from the National Science Foundation. In New Guinea PT Freeport Indonesia and the Freeport-McMoRan mining company, in collaboration with the Meteorological, Climatological and Geophysical Agency (BMKG) of Indonesia, generously provided essential logistical support. Drilling equipment and personnel were transported to and from the Papua ice-coring sites by helicopter (Fig. 3), and freezer storage facilities were provided for the cores in Tembagapura (meaning “copper town”), a city of over 19,000 people which is maintained by Freeport McMoRan for workers employed in mining the largest gold and copper deposits in the world. Tembagapura is also described by travel writers as the “city in the clouds”. Cold storage facilities were also arranged in Timika on the coast and in the capital Jakarta. The company runs a commercial airline from Jakarta to Timika through which they provided transportation for our research team and for our 6 tons of equipment. They also generously provided, at no charge, lodging, food and base camp support for the ICPRG members and for the Indonesian scientists, along with the Indonesian military personnel that accompanied the expedition.

Because of our long experience working in the Peruvian Andes, the field program on Hualcán was relatively straightforward. Our number one goal on all expeditions is to be invited back not only by the governments we work with but also by the local people. Working in New Guinea was a completely new endeavor, and we found ourselves faced with many novel challenges. The drilling operation was delayed for a month after our arrival because the drills were misplaced in Indonesian customs in Jakarta. Moving around the drill site itself was hazardous as the surface was riddled with numerous crevasses (Figs. 4 and 5) and the lack of substantial snowfall to provide traction meant that the team members had to wear crampons to maneuver on the ice. Daily rainstorms in the area, accompanied by lightning, increased the risk. Further, work with the local cultures in New Guinea proved most challenging in that four tribes in the region claim the ice fields and are at war with each other and they still kill each other with bows and arrows. We held public lectures in each town we passed through on our way to the ice fields to explain what we were doing and why. We had color brochures printed in advance in both English and Indonesian that explained the Papua project. However, there are over 2,000 languages in New Guinea alone so communications can be a real problem.



Figure 4. Crevasses and other hazards challenged the ice-core drilling team in Papua, New Guinea. Photo: Lonnie Thompson.



Figure 5. View of the glacier summit, drilling camp, and crevasse-ridden surface. Photo: Lonnie Thompson.



Figure 6. Tribal members and representatives of the government listen at a public forum where Lonnie Thompson explained the values of the Papua, New Guinea ice cores to understanding climate. Photo: Lonnie Thompson.

Our challenge was that it was impossible to make friends with one tribe without making enemies of three others. Near the end, the project came close to catastrophe, ending when members of a local native tribe, after failing in their attempt to reach the ice core drilling site (we were shrouded in clouds as it rained everyday during our stay), broke into the freezer facility where the cores were stored, intent on destroying them. Officials of the Freeport-McMoRan Mining Company (which provided logistical support for the expedition), fearing the worst, had transported the ice to another facility for safekeeping only a few hours earlier.

Several days later, at a public forum arranged by Freeport-McMoRan, I addressed over 100 tribal members and Freeport employees to explain the importance of the project to understanding local to global climate changes. After 4.5 hours of discussion, we were able to secure an agreement with the local people and government that allowed us to finish the drilling and take the cores out of Papua (Fig. 6). So all ended well and we hope to go back

in the near future to present what we have found. The ice core records from Papua will indeed go down as our most difficult as far as transforming that climate history into temporal context.

The OSU team comprised: Lonnie G. Thompson (Glaciologist/Project Leader), Broxton Bird (Post Doctoral Fellow), Paolo Gabrielli (Research Scientist), Victor Zagorodnov, (Glaciologist/Engineer), Vladimir Mikhalevko (Glaciologist/Engineer, Institute of Geography, Moscow), Keith Mountain (Professor, University of Louisville), and Donald Permana (Graduate Student). The results from this research will form the basis of Donald's Masters Thesis.

See also:

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., and Brecher, H.H. 2011. Tropical glaciers, recorders and indicators of climate change, are disappearing globally. *Annals of Glaciology* 52 (59): 23-34.

Changes in the Vertical Profiles of Mean Temperature and Humidity in the Hawaiian Islands

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Abstract

Recent drought and warmer than normal temperatures affecting the Hawaiian Islands have raised concern among natural resource managers that impacts associated with global warming are becoming manifest in the region. A number of studies published over the past few decades have documented changes in the climate of Hawai'i that are generally consistent with expectations from climate change projections, such as those found in the latest (2007) Intergovernmental Panel on Climate Change Fourth Assessment Report. We examined a suite of climate variables that are important from the point of view of ecosystem impacts, but that also relate to societal concerns such as Island water resources. Our results are consistent with previous studies in showing a significant warming trend, especially evident at higher elevations. In particular, we document a decrease in the frequency of occurrence of freezing temperatures in the upper slopes of the higher terrain (which exceeds 13,000 ft/4,000 m) in Maui and the Big Island and a concomitant rise in the freezing level surface in the region that is in agreement with analogous studies done for other mountainous areas of the world.¹

Introduction

Previous studies have documented secular changes in mean temperature (Giambelluca et al., 2008; hereafter referenced as GDL) and precipitation (Chu and Chen, 2005; Kruk and Levinson, 2008) in the Hawaiian Islands. A study by Cao et al. (2007) of changes in Trade Wind Inversion (TWI) characteristics for the two long-term radiosonde stations in Hawai'i (Hilo and Līhu'e) showed increases in TWI frequency of occurrence for both sites in most months. However, the study, which focused on the period 1979–2003, did not detect any significant changes in inversion base height at Hilo, and only a weakly significant ($p < 0.15$) lowering of inversion base height at Līhu'e. The TWI is a highly persistent feature of Hawai'i's climate occurring in over 80% of the twice-daily soundings analyzed by Cao et al. (2007; also see Cao, 2007). A recent study of projected changes in

precipitation for Hawai'i based on IPCC AR4 model simulation at the end of the 21st century under a mid-range SRES emission scenario (Timm and Diaz, 2009) showed possible declines in winter season precipitation and marginally higher summer season rainfall. In this study we focus on the vertical profiles of climate variables related to both surface temperature and precipitation changes in the Hawaiian Islands. We're interested primarily in net changes occurring for approximately the last 50 years. Evidence for changes on interannual time scales, such as ENSO, and lower frequency variations have been discussed elsewhere (e.g., Chu and Chen, 2005).

Here we illustrate the changes in the vertical profiles of annual mean temperature, and specific and relative humidity at standard pressure levels from 1000 to 300 hPa using the NCEP Reanalysis data set (Kistler et al., 2001) for the period 1958 through 2009 and averaged over a box extending 19°–23°N, 161°–154°W. Linear trends were fitted to annual values of these quantities from twice-daily averages, and the total change for each variable at each standard level plotted. Statistical significance of the linear trends was assessed following the method described in Santer et al. (2000). For illustrative purposes, we calculated the changes for a particularly important climate surface—the freezing level height—from the NCEP Reanalysis data over Hawai'i to show how that piece of information agrees with the results of the surface temperature trend analyses for Hawai'i reported by GDL. Additional data sets examined include radiosonde data for Hilo and Līhu'e—the only operating radiosonde stations available for the State, and data from one of the HaleNet sites located on Haleakalā Volcano on Maui, as described in Loope and Giambelluca (1998). HaleNet is a network of climate monitoring stations, located along transects spanning 1645–2460 m elevation on the windward slope and 965–2990 m elevation on the leeward slope of Haleakalā Volcano, on the island of Maui². The first three stations were installed along the leeward transect in 1988. While the periods of observation are not yet long enough to identify secular trends in temperature, the data can be used to assess how variations in surface temperature relate to free-atmosphere values. The

¹ Excerpted from Diaz, H. F., T. W. Giambelluca, and J. K. Eischeid, 2011: Global & Planetary Change, 77, 21–25.

² <http://climate.socialsciences.hawaii.edu/HaleNet/HaleNet.htm>

data from the highest elevation site, near the Haleakalā summit, are used for comparison with the lower troposphere values derived from Reanalysis data.

Analysis

Figure 1 gives the total linear trend change over the 1958–2009 period at each standard pressure level for mean temperature. For a more complete set of figures and a summary table of the trends, see Diaz et al. (2011). While the free-atmosphere temperature trends are only weakly ($p > 0.15$) significant, this result suggests temperature increases throughout much of the troposphere over the Islands, with a maximum warming of nearly 1°C at the 850 hPa level. Greater warming at the higher elevations agrees well with the findings of GDL, who found that surface warming was enhanced at the higher elevation stations. A number of studies have examined relative changes in surface and free air temperature, with an eye toward elucidating *inter alia* possible differences between the long-term records at surface sites and the shorter upper air record (Seidel and Free, 2003; Pepin and Norris, 2005; Pepin and Seidel, 2005). While in many instances temperature changes at higher surface elevations are consistent with those derived from those at nearby upper air stations, in other instances this agreement was lacking.

We note that surface temperature data from two long-term high elevation NOAA COOP stations on the islands of Maui and Hawai‘i (at Haleakalā National Park Headquarters and near Mauna Loa Observatory) were included in the study of GDL, and both exhibited strong warming trends for the last several decades. The apparent peak warming rate at 850 mb, may reflect the observed increase in the frequency of occurrence of the trade wind inversion (Cao, 2007; Cao et al., 2007), which would tend to result in greater warming for the elevations where the inversion typically occurs. We note that lowering of the inversion would also enhance warming for the zone between the new inversion base height and the original inversion top height.

Studies of changes in freezing level height in the tropics (Diaz and Graham, 1996; Bradley et al., 2009) are in line with expectations that warming in most of the tropical regions will be amplified with elevation as a result of greenhouse warming (IPCC, 2007). Figure 2 shows that the freezing level surface over the Hawaiian Islands has also risen over the past ~50 years. The change in the height of the annual mean freezing level during this time amounts to ~80 m, which compares favorably with the estimate obtained by Diaz et al. (2003) for the band 20°N – 20°S (~55 m for the period 1958–2000). Increases in the height of the

Hawaii Annual Temperature Trend 19°N–23°N; 161°W–154°W

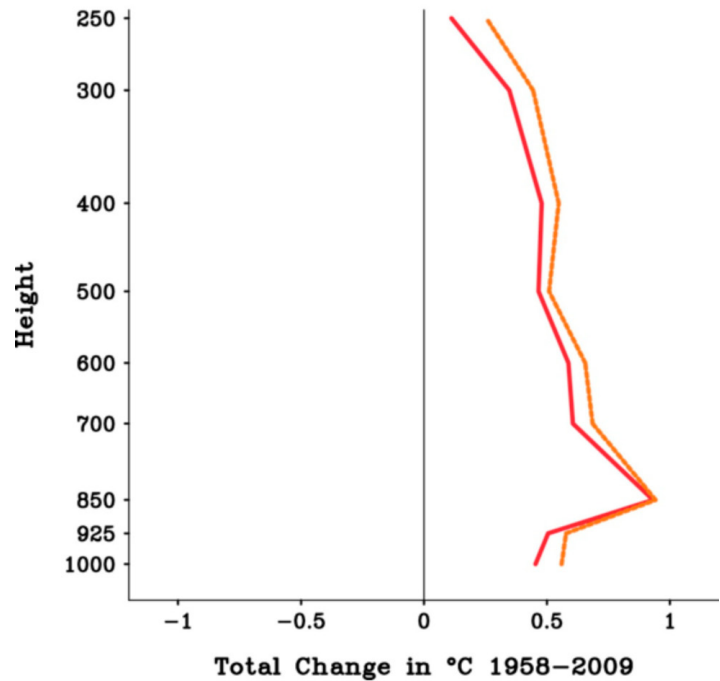


Figure 1. Total linear trend change for the period 1958–2009 in mean annual temperature. Values were calculated in two ways: one using the time series of annual values at each level (red lines), and second using pentad averages to smooth the variability and extract a more robust estimate (orange curves). Data from NCEP Reanalysis.

freezing level for the three nominal winter months of December through February (not shown) were substantially higher (on the order of ~150–200 m for the same period). Since the occurrence of freezing temperatures on the higher slopes of Maui and the Big Island is ecologically significant, we compared the frequency of occurrence of daily freezing values at the 700 mb (~3150 m) level from radiosonde measurements at Hilo on the Big Island with a shorter *in situ* record taken near the summit of Haleakalā Volcano at an elevation of 2990 m. The results, shown in Figure 3 indicate general agreement between the two records in the period of overlap, although because of the relatively short record of the HaleNet site, the frequency of occurrence of freezing temperatures at the Maui site does not exhibit a significant trend. The radiosonde data from Hilo indicate a significant decrease in the number of freezing days from an average of ~4–5 days/year at the beginning of the record to an average ~1 day/year in recent years.

The increase in sea surface temperature (SST) in the Tropics, and the subsequent enhancement of some features of the tropical hydrological cycle related to an increase in lower-tropospheric water vapor content (Held and Soden, 2006) may provide a link

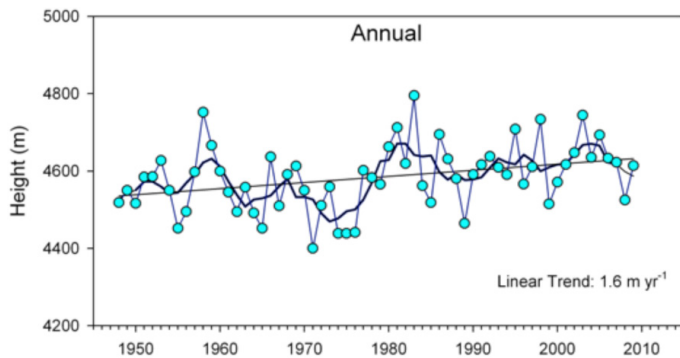


Figure 2. Trend in annual mean height (meters) of the freezing level isotherm over Hawai'i based on NCEP Reanalysis data. The graph illustrates the warming of the lower atmosphere around the Islands and the upward shift of temperature surfaces for the past several decades. Thick line gives the 5-year running mean.

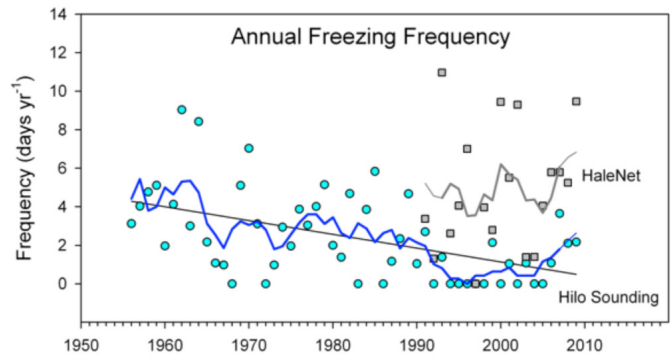


Figure 3. A comparison of the annual frequency of freezing temperatures based on daily Hilo, HI radiosonde observations at 700 mb and surface air temperature measurements from the Haleakalā, Maui summit station (2990 m) of the HaleNet climate network. Thick line gives the 5-year running means.

to the climatic changes discussed above. Sea surface temperature in the vicinity of Hawai'i has also risen in the past ~50 years as illustrated in Figure 4 (see Jokiel and Brown, 2004). The near-shore waters have warmed over the past ~55 years at a rate of $\sim 0.2^\circ\text{C}/\text{decade}$. The base of the TWI varies seasonally with an average inversion base height of 2100–2400 m, or between the 850 and 700 hPa standard pressure levels plotted in Figure 1. The inversion top—the level at which the temperature resumes decreasing with height—is generally below the 700 hPa level (Cao, 2007; Cao et al., 2007). In Diaz et al. (2011) we document a decrease in relative humidity (RH) of $\sim 2\%$ below 700 hPa increasing in magnitude to $\sim 10\%$ of its average value in the 400–300 hPa layer. The temporal changes are dominated by ENSO variability and the secular trend, which is also conflated with decadal changes associated with the PDO (Giambelluca et al. 2008).

We note that long-term measurements of near-shore SST (illustrated in Fig. 4) indicate that warming of near-shore waters exceeds that of the open ocean waters in the region, being closer in magnitude to the values reported by GDL for surface temperature in the Islands.

The thermodynamic changes indicated in Figures 1 and 6 of Diaz et al. (2011) may reflect a possible strengthening of the regional Hadley Circulation (Mitas and Clement, 2005; 2006; Quan et al., 2004). In the Mitas and Clement studies discrepancies were examined between the strength of the Hadley Circulation obtained from the suite of available Reanalysis products and results derived from the 20th century coupled simulations forced with historical changes in greenhouse gases, and in some cases with additional external forcings such as sulfate aerosols, volcanic and solar forcings. We note that possible global-warming-related secular changes in the strength of the Hadley Circulation remain

an open question (Diaz and Bradley, 2004; Lu et al., 2007).

Summary

In this study we examined a suite of climate variables that are important from the point of view of ecosystem impacts, but that may also influence societal concerns such as those related to water resources. Our results are consistent with previous studies in showing a significant warming trend, especially evident at higher elevations. In particular, we document a decrease in the frequency of occurrence of freezing temperatures in the upper slopes of the higher terrain in Maui and the Big Island and a concomitant rise in the freezing level surface in the region that is in good agreement with analogous studies done for other mountainous areas of the world. A ~50-year record of near-shore SST exhibits a strong warming trend that exceeds that recorded over open ocean areas away from the Islands (not shown).

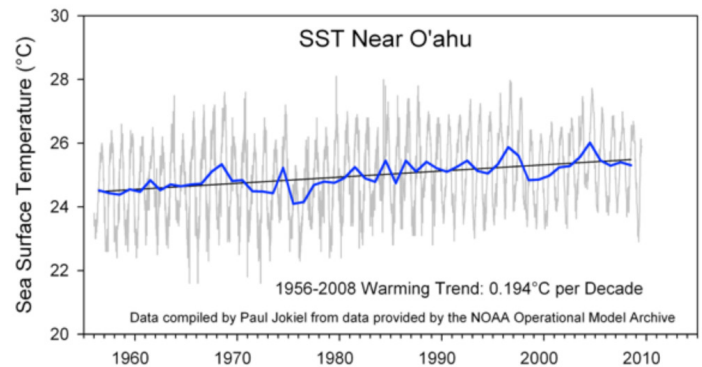


Figure 4. Sea surface temperature series from near shore measurements taken near Honolulu, Oahu, Hawai'i at an approximately weekly interval (light grey line). Mean annual values shown by thick line. Data courtesy of Paul Jokiel. Reference source: Jokiel and Brown 2004.

To provide a quasi-independent assessment of changes in a suite of regional thermodynamic variables, we also examined the radiosonde record at Hilo and Līhu‘e. Our goal was to reproduce the vertical changes in temperature, RH, and SHUM field using vertical profile data from these two sites. However, we concluded that while the temperature records appeared homogeneous, the humidity fields exhibited suspect changes and contained some breaks in the records. Therefore, we are unable to present an analysis of changes in the vertical humidity profile based on the sounding data. Nevertheless, our overall findings are strongly suggestive of warming throughout the lower troposphere in the region of the Hawaiian Islands leading to lower frequency of freezing temperatures at the higher elevations during the Northern Hemisphere winter months, and an upward shift in the freezing level surface over the Islands. The changes are contemporaneous with increasing sea surface temperature around Hawai‘i, and while the thermodynamic changes, such as changes in lower tropospheric relative humidity, a downward shift in the trade wind inversion height, and a recent rise in the local lifting condensation level are not as statistically significant as is the case for the temperature field, they are also consistent with the general warming trend and a possible enhancement of the regional meridional (Hadley) circulation.

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Climate Change in the Tahoe Basin: Impacts and Implications

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Introduction and Background

Lake Tahoe, astride the California-Nevada boarder, is world renowned for its natural beauty and cobalt-blue color (Fig. 1). However, long-term monitoring shows that 1) Secchi depth transparency has declined by 10 m since 1968, 2) the rate of ¹⁴C primary productivity continues to increase at about 5 percent per year, and 3) thick growths of attached algae cover portions of the once-pristine shoreline (Goldman et al., 1993; Tahoe Environmental Research Center, 2010). Additionally, like many lakes world-wide, Lake Tahoe has been affected by non-native species that were either intentionally introduced or were part of a large pattern of regional invasion (Kamarath et al., 2008; Wittmann et al., 2008). Figure 2 lists some additional basic facts about the Lake.

The clarity of Lake Tahoe is driven by the influx of phosphorus, nitrogen and fine sediment particles <16 µm in diameter (LR-WQCB and NDEP 2010a; Sahoo et al. 2010). These pollutants come from land disturbance, urbanization (including roadways and road maintenance) and direct atmospheric deposition. Their transport to the lake is accelerated by the loss of a natural landscape capable of treating runoff (Coats et al., 2008).

A complete understanding of the historic and likely future conditions of Lake Tahoe requires consideration of the input of water, nutrients, sediment and energy from the lake's watershed and from the atmosphere. Previous work on the historic trends in the Basin's hydroclimatology in the 20th Century indicated strong upward trends in air temperature (especially minimum daily temperature), a shift from snow to rain, a shift in snowmelt timing to earlier dates, increased rainfall intensity, increased interannual variability, and increase in the temperature and thermal stability of Lake Tahoe (Coats et al., 2006; Coats, 2010). The latter finding was especially ominous, since it suggested the possibility that



Figure 1. Lake Tahoe, from the Blackwood Creek Delta

- | | |
|---|----------------------|
| • Volume = | 156km ³ |
| • Average Depth = | 313 m |
| • Surface Area = | 498 km ² |
| • Max. Depth = | 505 m |
| • Basin Area = | 1310 km ² |
| • Elevation = | 1898 m |
| • Mean WATER Res. Time = | 650 yr |
| • Mixes below 450 m about 1 yr in 4 | |
| • Well-oxygenated to bottom | |
| • Decline in clarity related to both fine sediment and increasing Primary Productivity (PP) | |
| • PP now controlled by available phsophorus | |

Figure 2. Environmental statistics about Lake Tahoe.

continued warming could shut down the deep-water ventilation, leading to anoxia and release of phosphorus from the sediment as well as loss of oxygenated habitat for salmonids.

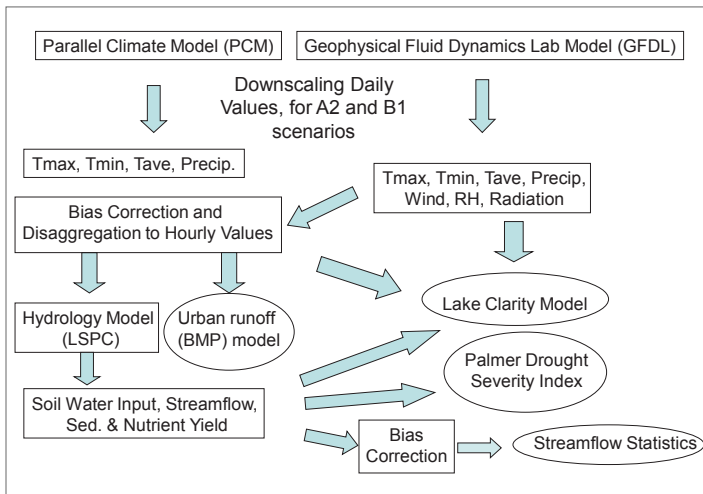


Figure 3. Information flow in the Tahoe Basin Climate Change Project

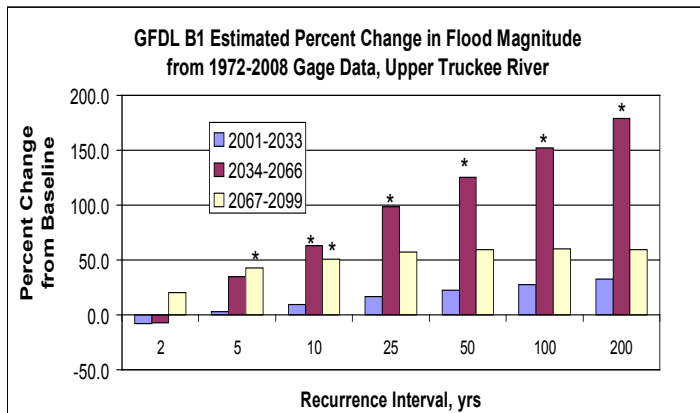


Figure 4. Estimated changes in flood frequency for the Upper Truckee River for three periods in the 21st Century. An asterisk (*) indicates that the increase is significant at the 90% level or greater.

In most years, Lake Tahoe drains into the Truckee River, supplying water to municipal and agricultural users downstream and helping to maintain Pyramid Lake at the river's terminus. From 1910 to 2010, the Tahoe basin contributed on average 23 percent (ranging from 0-40 percent) of the annual yield of the Truckee River at Farad, near the CA-NV border. In 20 out of the last 110 years, however, the lake level has fallen below the natural rim. If climate change increases the frequency or persistence of levels below the rim, the consequences for water supply in the Truckee River basin could be severe.

Study Approach and Methods

In response to concerns about the possible impacts of climate change on Lake Tahoe, we obtained funding in 2009 under the Southern Nevada Public Land Management Act (SNPLMA) for a detailed investigation. We used the 21st Century down-scaled temperature and precipitation daily output from two General

Circulation Models (the Geophysical Fluid Dynamics Laboratory, or GFDL CM2.1, and the Parallel Climate Model, or PCM1) and two emissions scenarios (A2 and B1), and corrected the precipitation data for bias by quantile mapping. For the GFDL, we also had wind (bias corrected), radiation and relative humidity data. The daily data were disaggregated to hourly values and used to drive a distributed hydrologic/water quality model for streams in the Tahoe basin. The output from that model, along with the meteorological data, was then used as input to a 1-dimensional hydrodynamic/clarity model of the lake, and to calculate streamflow statistics for the Upper Truckee River (UTR) and trends in the Palmer Drought Severity Index (PDSI) for selected sites. The hydrology data were also used in a stormwater routing and water quality model to investigate the implications of climate change for design of Best Management Practices (BMPs) in the Tahoe basin. Figure 3 shows the information flow in the study design.

Some Results and Discussion

The results indicate a likelihood that 1) recent trends in basin climate and hydrology will continue, with a possible 5° C increase in average annual air temperature by 2100; 2) precipitation will continue to shift from snow to rain, and annual amounts will remain largely unchanged or may decrease in the latter half of this century; 3) the magnitude of the estimated 100-yr flood of the UTR will increase up to 2.5-fold for the middle third of this century, and decrease thereafter as the snowpack and frequency of rain-on-snow events decline (Fig. 4); 4) the timing of snowmelt and the hydrograph centroid will shift toward earlier dates; 5) summer low-flow will decrease; 6) drought, as measured by the PDSI, will increase, especially toward latter third of this century, and most strongly on the eastern (drier) side of the basin (Fig.5);

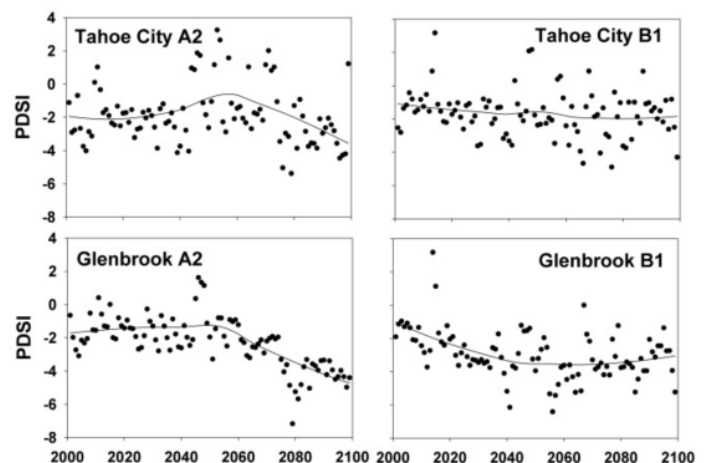


Figure 5. Modeled annual minimum Palmer Drought Severity Index at two stations for two scenarios in the Tahoe Basin.

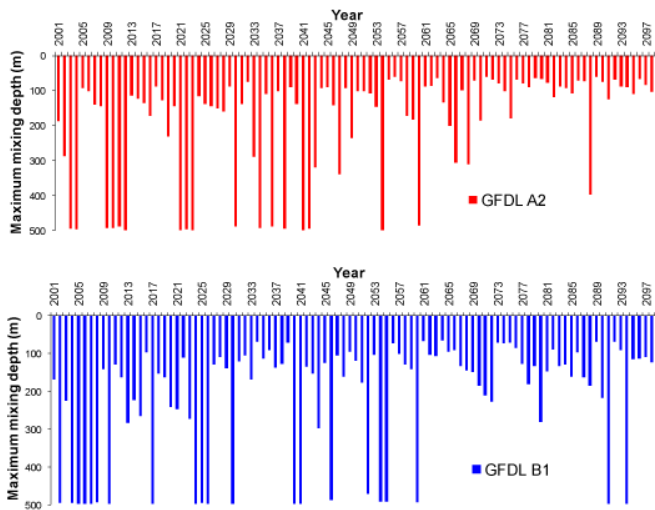


Figure 6. Annual maximum mixing depth of Lake Tahoe, over the 21st Century, for two emissions scenarios, based on results of the GFDL climate model, and the Lake Clarity Model.

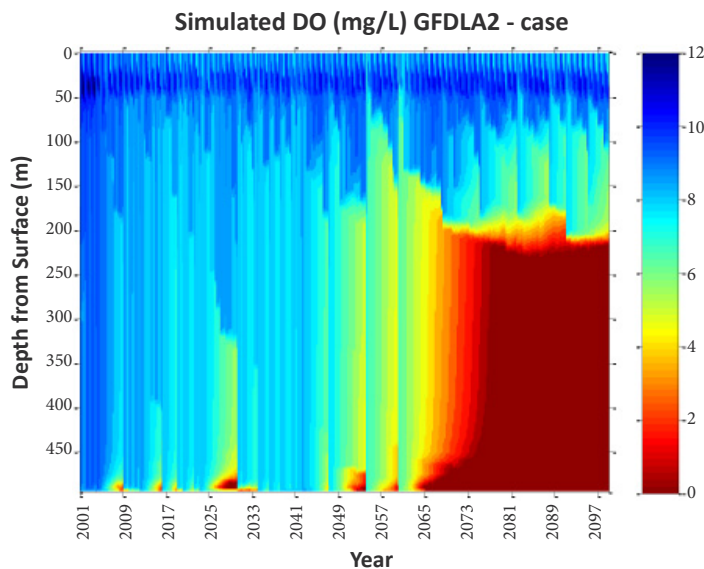


Figure 7. Simulated dissolved oxygen (DO) concentration in Lake Tahoe over the 21st Century, for the A2 emission scenario with the GFDL climate model.

7) the lake will continue to warm, and its increasing thermal stability may inhibit deep mixing and deep ventilation for periods as long as several decades. Without complete ventilation, dissolved oxygen will be lost from the mid-deep water column with the release of nutrients from the anoxic bottom sediments (Figs. 6 - 8); 8) the annual frequency of no lake outflow will increase, especially toward the end of this century (Fig. 9); 9) changes in the precipitation regime will require some increase in the size of stormwater detention basins to achieve water quality goals, but the impacts of climate change on nutrient and sediment loading from urban runoff can be offset by aggressive implementation of BMPs.

The environmental and economic impacts of these climate trends in the Tahoe basin will likely include 1) increased tree mortality, and increased fuel loads; 2) increased wildfire frequency and intensity; 3) increased channel and bank erosion in basin streams; 4) increased infrastructure damage from flooding; 5) reduced stream habitat due to a decrease in summer low-flow; 6) a decrease in available water supply for users in the Truckee River Basin; 7) release of available phosphorus and nitrogen from the anoxic bottom of Lake Tahoe, and their subsequent transport into the photic zone, where they will stimulate algae growth; 8) changes in the theoretical climax vegetation; and 9) economic damage to the basin's ski industry. The management response to these climate change impacts may include aggressive fuel

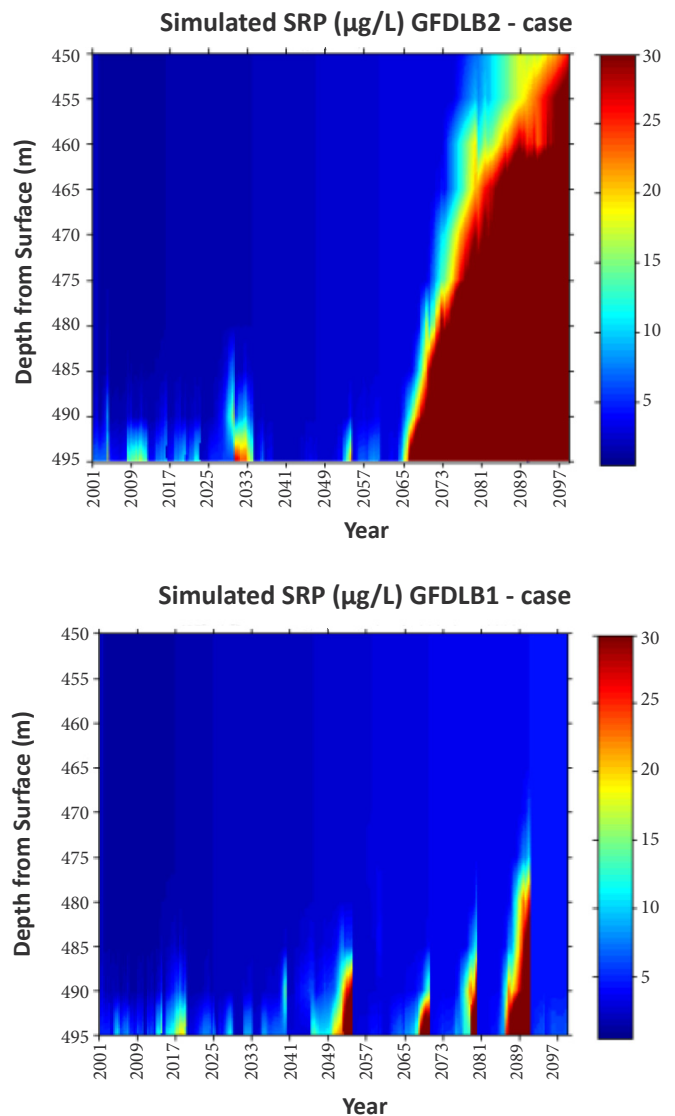


Figure 8. Release of soluble reactive phosphorus from the bed of Lake Tahoe for two emission scenarios, based on results from GFDL climate model and the Lake Clarity Model.

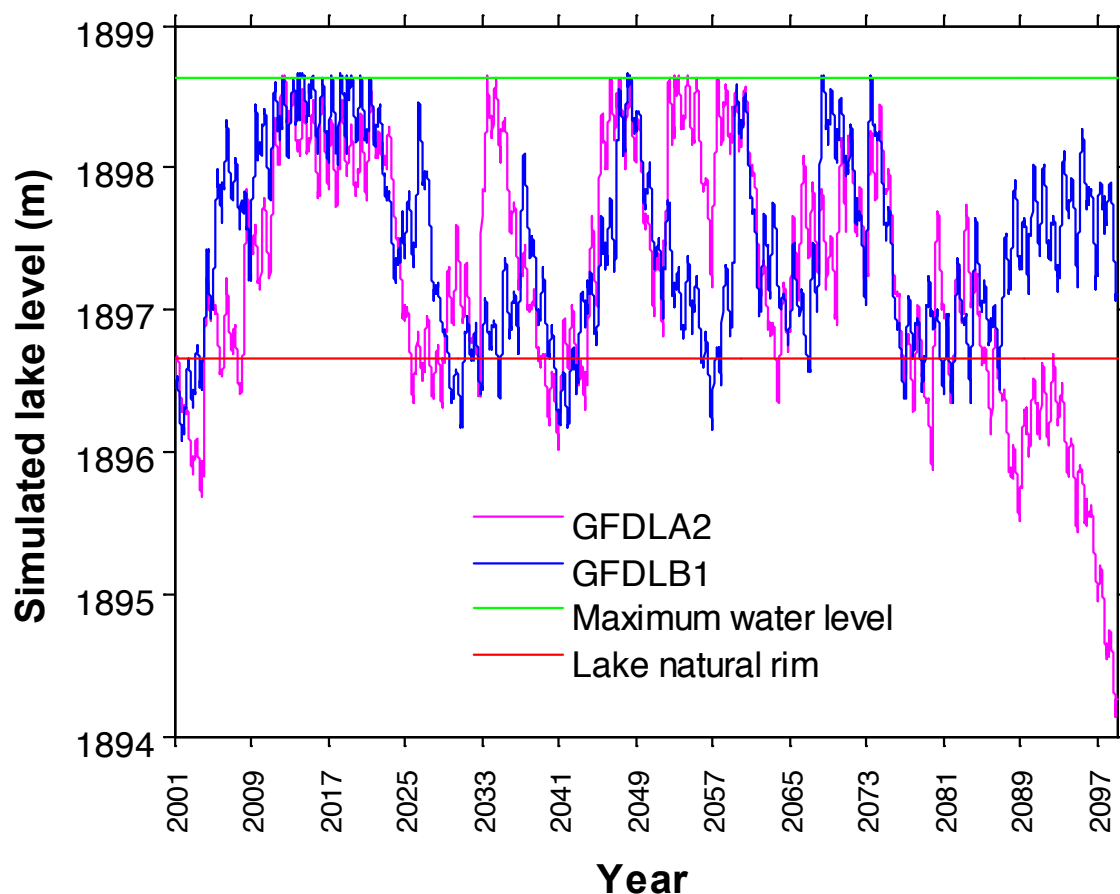


Figure 9. Simulated level of Lake Tahoe over the 21st Century, for two emission scenarios.

load reduction, establishment of plant communities and species adapted to lower elevations, continued efforts to control nutrient and sediment flux to the lake (including BMP implementation and erosion control), and increased water conservation efforts in the Truckee River basin.

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BREVIA

Groundwater Dynamics in Snow-Dominated Alpine Regions; Vulnerability to Changing Climate

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Farley, K. A, C. Tague, and G. E Grant. 2011. *Vulnerability of water supply from the Oregon Cascades to changing climate: Linking science to users and policy. Global Environmental Change, 21: 110-122.*

In the past decade, empirical observations and hydrologic models have shown that one of the primary climate warming impacts on streamflow is through changes in the spatial and temporal patterns of snow accumulation and melt (Bales et al. 2006; Adam, Hamlet, and Lettenmaier 2009; Barnett, Adam, and Lettenmaier 2005). In the mountains of western USA, where the majority of annual precipitation typically falls during winter months, spring snowmelt is a significant source of water for drier summer months. Reduced snow accumulation and earlier melt have been shown to decrease summer water availability for human water users and both aquatic and terrestrial ecosystems (Rood et al. 2008; Stewart, Cayan, and Dettinger 2005; Maurer 2007; Clow 2010). At the same time changes in precipitation patterns, including increases in intensity and frequency of drought, have the potential to compound these effects (Luce and Holden 2009). As the climate continues to warm, resource managers need accurate predictions of these effects across a range of scales. While the general relationships among warming, snowmelt and streamflow are understood, a key challenge is providing assessments at local watershed scales relevant to resource decisions.

Spatial patterns of sensitivity of snow accumulation and melt reflect topographic complexity of mountain environments. Snow at risk areas are typically those elevations where current winter temperatures are frequently near 0°C (Kapnick and Hall 2011; Nolin and Daly 2006). In Tague and Grant (2009), we showed that spatial patterns of streamflow response to warming reflect not only sensitivity to changes in snow accumulation and melt but also watershed properties, particularly the geologically determined drainage efficiency that controls how quickly recharge (either as precipitation or snowmelt) is translated into discharge. Our

paper demonstrates that for basins across the Western Cordillera of the US, spatial differences in drainage rates and groundwater response times associated with geologic and geomorphic settings are a first order control on streamflow responses to warming.

In Tague and Grant (2009) we used a conceptual mathematical model to develop a general relationship among changes in water inputs either as snowmelt or precipitation, subsurface drainage efficiency, and summer streamflow responses. Application of this conceptual model for watersheds within the Western Cordillera demonstrated that geologic-based differences in drainage characteristics are as important as spatial differences in the timing/magnitude of snowmelt in determining spatial patterns of late summer water availability. The timing of snowmelt controls when

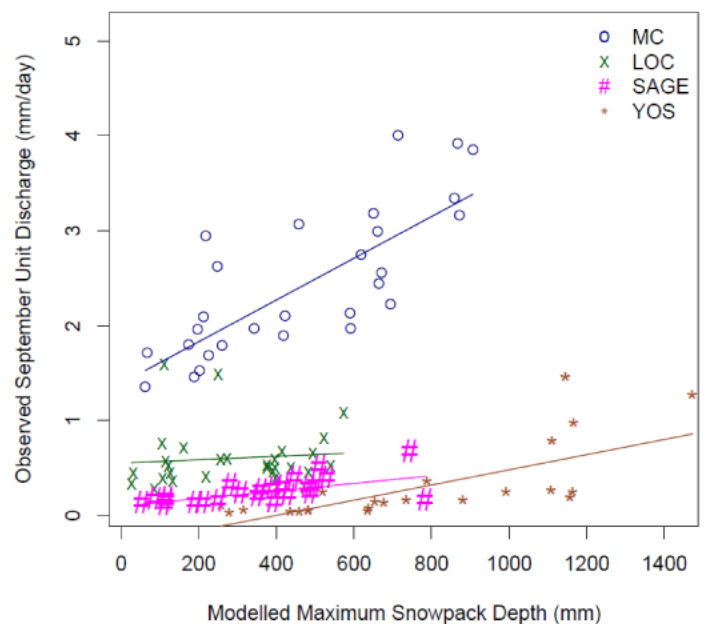


Figure 1. Mean daily discharge for September against annual maximum 15-day running average of mean watershed snow water equivalent depth (SWE). SWE is estimate using RHESys hydrologic model. Slopes of the relationship between annual maximum SWE and streamflow are all statistically significant ($p < 0.01$) in linear regression model. From Tague and Grant 2009.

Site Name		Lookout Creek (LOC)	McKenzie River at Clear Lake (MC)	Sagehen Creek (SAGE)	Upper Merced River at Happy Isles (YOS)
Location		Oregon	Oregon	California	California
USGS Gage Number		14161500	14158500	10343500	11264500
Geology		Western Cascade basalt	High Cascade basalt	Sierra granite, with Miocene andesite cap	Sierra granite
Elevation Range (m)		410–1630	920–2035	1928–2653	1200–3997
Drainage Area (km ²)		64	239	2.6	465
Mean Annual Streamflow (cm/year)		176	169	45	67
Estimated k		0.028	0.01	0.027	0.038
Average Peak SWE (mm)	Historic	254	430	311	703
	1.5 C	85	172	176	616
Average day of Peak SWE (yearday)	Historic	73	83	90	88
	1.5 C	63	64	62	77
Average day of 50% of Peak SWE (yearday)	Historic	135	139	137	153
	1.5 C	116	124	122	144
Change in Peak SWE (mm) with 1.5 C Warming		-169	-257	-134	-87
Change in Day of Peak SWE (days) with 1.5 C Warming		-10	-19	-28	-11
Change in Day of 50% Peak SWE (days) with 1.5 C Warming		19	15	15	9

Table 1. Environmental characteristics of the study regions.

in the season most of the water inputs occur while drainage rates control how these inputs and changes in the timing and magnitude of inputs are distributed over the seasonal hydrograph. We then applied a spatially distributed hydrology model, RHESSys (Regional hydro-ecologic simulation system), to four watersheds that differ in terms of both geologic characteristics and snowmelt patterns (Table 1). We used the model to compare changes in September streamflow as a function of annual peak snow-water equivalent (SWE), spatially averaged across the watershed (Fig. 1). As expected, all watersheds showed increases in late summer streamflow for years with greater peak SWE. Fast-draining watersheds, such as those underlain by granite in the California Sierras or deeply dissected volcanics in the western Cascades of Oregon, however, showed less sensitivity to inter-annual variation in peak SWE relative to slower draining, deeper groundwater dominated systems such as the Oregon High Cascades. Greater sensitivity also occurs in high-elevation watersheds where snow melts later in the spring such as in Yosemite's Merced River. Our results show that it is the combination of the timing of snowmelt and the

geologically mediated drainage characteristics that determines local watershed sensitivity to warming.

The implication of these differences can be seen by applying a similar 1.5°C warming scenario to the four watersheds. Paradoxically, our results show that slower draining, deep groundwater dominated watersheds are likely to have more water in summer but subject to the greatest absolute summer water losses under a 1.5°C warming scenario (Fig. 2). A slow draining watershed located in the Oregon High Cascades shows on average 4 times the summer streamflow reduction with a 1.5° C increase in temperature, when compared with faster draining watersheds with similar timing of peak snowmelt. The faster draining watersheds, in contrast, have greater reductions in spring flow. Our results highlight the importance of geological factors in interpreting hydrologic response to climate change, and argue for a geo-climatic framework to guide both climate scenario development and the design of monitoring networks that will become the basis for assessing climate change impacts in mountain regions throughout the globe.

A logical next question is, “What are the implications of these spatial differences for water resource managers?” To begin to answer this question, we focused on two contrasting sub-watersheds of the McKenzie River in Oregon, where we found strong differences in climate warming response between the slower draining, deeper groundwater-dominated High Cascades and more responsive, shallow subsurface flow-dominated Western Cascades. We conducted in-depth, semi-structured interviews with water users and other stakeholders representing specific water uses in the McKenzie River watershed, seeking to understand vulnerability to changing streamflow regimes. We presented users with modeling results, and asked respondents to assess how changing water availability would impact their activities. We found that vulnerabilities were determined in part by the spatial scale and timing of water use and the flexibility of those users in time and space (Fig. 3). For example, in the case of fish habitat for endangered species, bull trout currently rely on the colder refugia of the High Cascade system, which is commonly perceived by some fisheries managers as more stable and less sensitive to climate change. Our hydrologic modeling results, however, suggest that summer streamflow in these systems will actually show greater losses than neighboring, but shallower and warmer, Western Cascade reaches. The strategic importance of the High Cascade region

for bull trout combined with its differential sensitivity to warming demonstrates the importance of spatially explicit streamflow predictions for longer-term conservation planning.

At the same time, institutional vulnerability was influenced by each sector’s adaptability. Institutions within some sectors were found to be better positioned to effectively respond to changes in water resources, while others had substantial barriers to being able to flexibly adapt to changing conditions. For example, the adaptability of Oregon chub is enhanced by the spatial flexibility associated with its ability to establish and relocate new populations within and outside the watershed. From an institutional perspective, listing as part of Endangered Species Act has supported spatially detailed analysis and thus fisheries managers have ability to integrate spatial distinctions in streamflow into recovery plans. Further the regulatory framework in which fisheries conservation occurs supports periodic review and facilitates the integration of new scenarios as they become available.

This flexibility is in contrast to the institutional constraints that the U.S. Army Corps of Engineers, which manages the two main reservoirs in the McKenzie watershed, operate under. Filling and releasing water are guided by “rule curves” that are based on estimates of flood risk that were developed 50-60 years ago

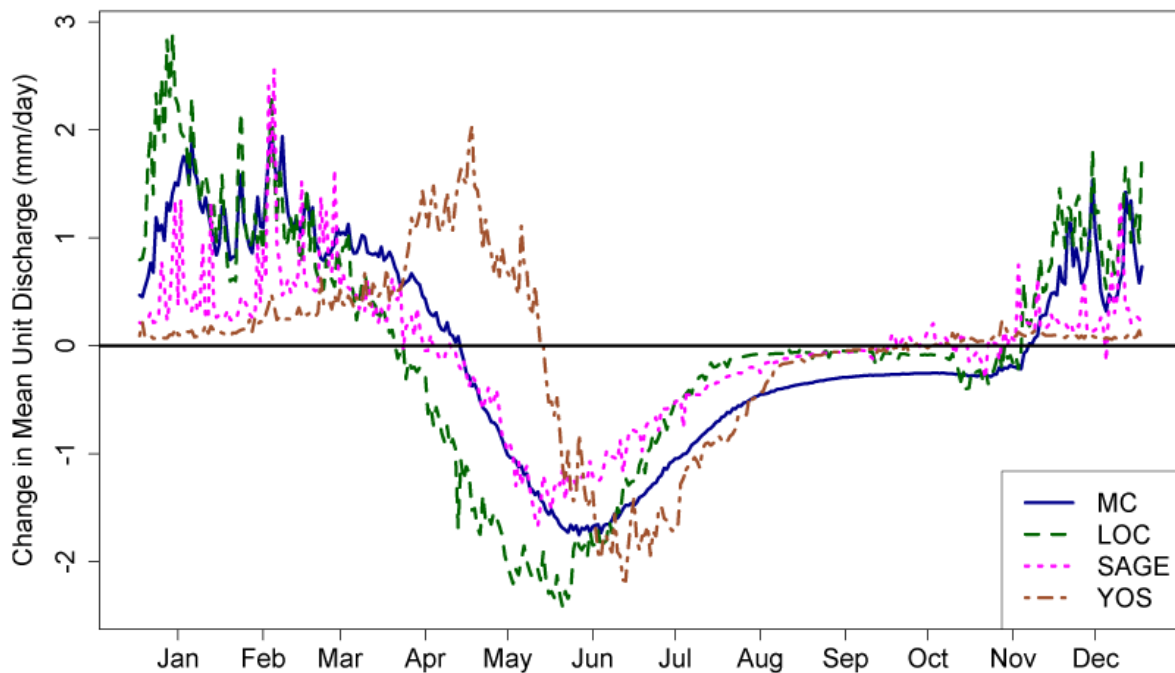


Figure 2. RHESSys estimates of change in average day of year flow between baseline and 1.5°C warming scenario for 4 study catchments. Mean unit discharge is computed by averaging RHESSys estimates of daily streamflow (normalized by drainage area) for each day of year for 30 year climate record. From Tague and Grant 2009.

Feature of water use	Range of characteristics	
Spatial scale and flexibility of use/activity	Full watershed to reach-specific and Highly flexible to minimal flexibility	↓ Sensitivity and adaptability to climate change effects on streamflow
Temporal flexibility of use/activity	Highly flexible to minimal flexibility	
Institutions that enable response	Existing frameworks able to adjust practices to non-existing frameworks and/or unable to adjust practices	↓ Response capacity in the human system
Access to information on streamflow and climate change	Readily accessible to minimal access	

Figure 3. Assessing sensitivity and adaptability, including factors related to response capacity of water users with respect to climate change effects on streamflow in the McKenzie River watershed. From Farley et al., 2011.

based on climate and streamflow conditions over the previous 30 years. Because the rule curves are Congressionally authorized, any change in these rules requires a detailed evaluation of the hydrologic, economic, and environmental tradeoffs of any proposed change, followed by reauthorization through Congress. Decisions for any particular reservoir in the system are further influenced by the reservoir's role in the overall larger Willamette water supply system that includes 13 major reservoirs and multiple demands and rule curves. While the Corps recognizes the need to adapt to both changes in climate and demand, the larger scales and more complex regulatory system mean that implementation is likely to be a slow process. Even for smaller-scale water managers, such as the Eugene Water and Electric Board, who have more institutional flexibility, the time and costs associated with infrastructural changes can limit adaptation and the degree to which strategies are tailored to spatial differences in streamflow responses to warming.

In summary, we are learning that a combination of both geological factors and climate controls on snowmelt set the stage for evaluating watershed sensitivity to streamflow changes at scales relevant for water resource managers. Geologically-mediated drainage efficiency is a first-order control on spatial patterns of summer streamflow sensitivity to warming. One of the key challenges to incorporating this insight into water resource planning is that drainage efficiencies are difficult to measure directly, and must be inferred from analysis of recession rates of measured streamflows. This is a problem because many watersheds of interest to water and fisheries managers are ungaged or have short or discontinued flow records. In these cases, strategies to infer drainage efficiency directly from mapped geology are needed; we are working on this now. We've also learned that institutional flexibility and the nature of the resource managed strongly shape

adaptive response. Our interviews with managers underscore a broad need across many water resource sectors for spatially explicit information and prediction across a range of scales on how streamflow regimes are likely to change in the future.

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BREVIA

Changing Distribution of a Montane Forest Carnivore, the American Marten (*Martes americana*), in the Sierra Nevada and Southern Cascades of Northern California

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Moriarty, K. M., W. J. Zielinski, and E. Forsman. 2011. Decline in American marten (*Martes americana*) occupancy rates at Sagehen Experimental Forest, California. *Journal of Wildlife Management*, 75: 1774-1787.

The Important Role of Predators in Ecosystems

Predators have important effects on the structure of biological communities, not only because the act of killing and eating other species transfers energy and nutrients but also because their consumption of prey, and their simple presence, affect the distribution of herbivores which, in turn, affect the abundance and distribution of plants. These “trophic cascades” have been most clearly demonstrated by research on the effects of the return of wolves to the Yellowstone ecosystem (Ripple and Beschta 2004). In addition, when these larger predators are absent, intermediate-sized (meso) predators can increase to the point that they have destabilizing effects on their prey, a phenomenon referred to as “meso-predator release” (Crooks and Soulé 1999, Roemer et al. 2009). The “top down” control of community structure by predators, which has been demonstrated on every continent and ocean, is primarily why we work to understand the ecology of montane mammalian predators and to collect information that will help assure their persistence in the face of environmental change. California has already lost some key mammalian predators (i.e., grizzly bear [*Ursus arctos*], gray wolf [*Canis lupus*]) and some species are so rare that they no longer play effective ecological roles (i.e., wolverine [*Gulo gulo*], Sierra Nevada red fox [*Vulpes vulpes nescator*]). Thus, the disproportionately important functional roles of mammalian predators are already reduced in montane forest ecosystems in California, and elsewhere in North America (Laliberte and Ripple 2004). We focus our research on projects that will help guarantee that additional predators, in particular two species of forest mesocarnivores, the fisher (*Martes pennanti*) and the American marten (*M. americana*), are not lost



Figure 1. An American marten (*Martes americana*) photographed at a baited (chicken) and remotely triggered camera station in the Sierra Nevada of California.

from our forest ecosystems and continue their important roles throughout their geographic ranges.

The Marten and its Recent Contraction in Distribution

Some of our recent work has focused on the distributional dynamics of the marten (Fig. 1) in the Sierra Nevada and Cascades. The marten occurs in high-elevation, late-seral forests and is most abundant where dense forests include large live and dead trees, and large downed logs, which martens use for daily resting

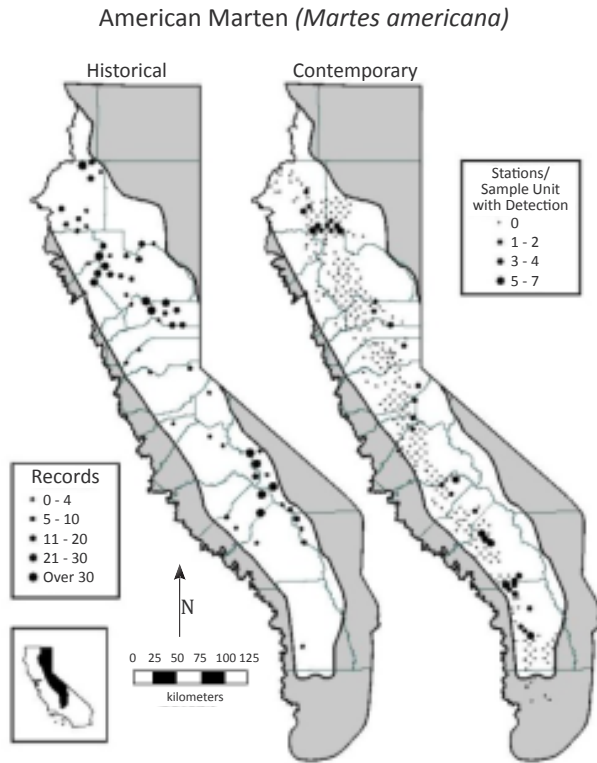


Figure 2. Distribution of historical records (Grinnell et al. 1937) and contemporary survey data for the American marten. Bold lines represent the boundaries of the historical distribution as represented in Grinnell et al. (1937) and shading identifies portions of the study area that were outside the historical range. Black dots in the historical map represent one or more records (depending on size). Black dots in the contemporary map represent one or more track plate or camera stations per sample unit (depending on size) where a marten was detected (1996 – 2002); open circles represent sample units with no detections.

sites, foraging substrates and for reproductive dens (Buskirk and Ruggiero 1994). Concern about the decreasing distribution of martens in some regions of the Pacific states has been voiced for decades (Dixon 1925, Kucera et al. 1995, Zielinski et al. 2001). Historical and contemporary distributions were formally compared in the Sierra and Cascades of California by contrasting the locations of animals trapped for their fur in the early 1900s (Grinnell et al. 1937) with surveys we recently conducted (Zielinski et al. 2005) using non-invasive methods (track stations and remotely triggered cameras; Long et al. 2008). These surveys revealed changes in the distributions of a number of carnivore species, including the marten, fisher, wolverine and Sierra Nevada red fox. Historically, the marten was reported to occur throughout the higher elevations of this region but our survey results indicated that populations are now reduced in size and fragmented (Fig. 2).

We used the results of our surveys to build regional landscape habitat suitability models, by contrasting the environmental features at places where martens were detected with those at places

where they were not, and confirmed that the available habitat for martens did indeed appear isolated and reduced in area (Kirk and Zielinski 2009; Fig 3). The model that best fit the data suggested that remaining marten populations were associated with sites with the largest amount of reproductive habitat (dense, old forest), the greatest number of nearby habitat patches, and with nearby reserved land (land protected from timber harvest). The highest density of detections was located in the largest protected area in the region, Lassen Volcanic National Park. This is in stark contrast to the historical distribution, which found that martens were evenly distributed in the region during the early 1900s, including at lower elevation sites (Fig. 4).

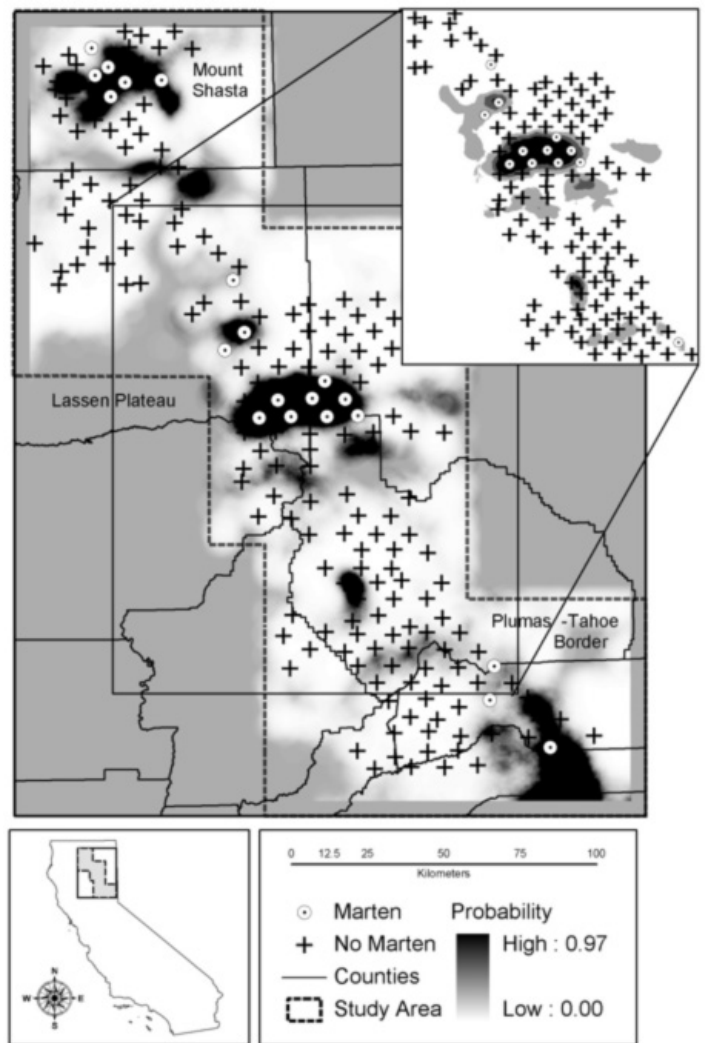


Figure 3. Predicted probability surface of top performing model with detection results for American martens in northeastern California. Sample unit locations with marten detections (white circles) and without (plus signs) at track plates and/or cameras. Inset depicts the region where independent test data were available.

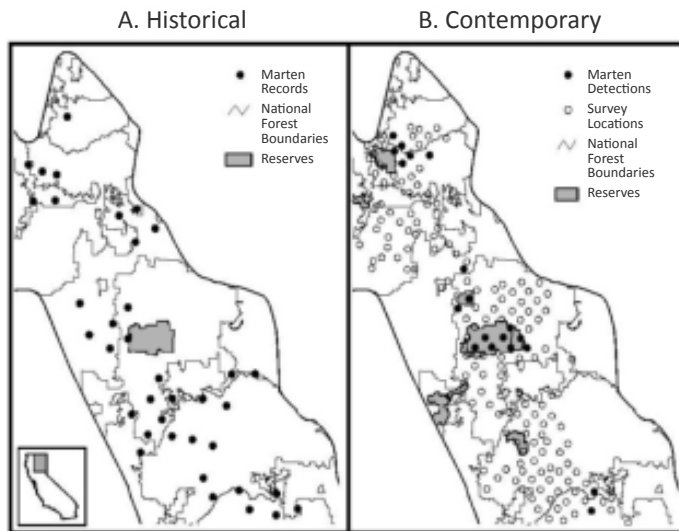


Figure 4. Northeastern California, primarily the Cascades mountains in California, depicting (a) the historical distribution of marten records (Grinnell et al. 1937), national forest boundaries (thin lines) and the reserves as of 1937 (i.e. national parks), and (b): the contemporary survey data with black dots representing track plate/camera survey sample units with at least one marten detection, open circles representing sample units with no detections, and shared polygons representing reserves (i.e., national parks, wildernesses). The bold lines indicate the boundaries of the historical distribution of martens (Grinnell et al. 1937).

The Cause?

The loss of marten distribution seems clear, but what is less clear is the cause. This is difficult to ascertain with data from such a large region; what is necessary instead is a more focused look at a smaller area that may have experienced a loss of martens over this same period and to ask what may have caused the loss there. This is where our recent work in the Sagehen Experimental Forest (SEF), near Truckee California, comes into play (Moriarty et al. *in press*). SEF has hosted a number of seminal studies on marten ecology in California, but the unique element of this body of work is that most of these studies also included a systematic survey of marten occurrence throughout much of the forested portion of the ~ 40 km² area. Martens were assumed to be very common in the SEF in the 1970s and 1980s but anecdotal observations suggested that they had become quite rare at SEF. This concern led to new surveys, which, unfortunately, verified this conclusion: no martens were detected during summer surveys, despite the fact that martens were regularly detected during the summer in earlier surveys (Moriarty et al. *in press*, Fig. 5). A few marten detections occurred in the winter, but these were in a small, western portion of the SEF. Marten detections in 2007–2008 were approximately 60% fewer than in surveys in the 1980s.

Thus, at the small scale of the SEF we had reported the same phenomenon that was apparent for the northern Sierra/southern

Cascades as a whole. Perhaps, we thought, the type of changes that occurred at SEF, when aggregated over the larger region, accounted for the larger changes seen in the earlier regional work? The cause of the decrease in marten numbers at SEF is uncertain. However, GIS analysis comparing older vegetation maps from 1978 with maps from 2007 revealed a loss and fragmentation of important marten habitat (Moriarty et al. *in press*). This included a decrease in predicted habitat patch size, core area, and total amount of marten habitat in the study area, as well as an increase in distance between important habitat patches. Much of this was a result of change in landscape vegetation between 1983 – 1990 when 39% of the forest habitat in SEF experienced some form of timber harvest. The sensitivity of martens to forest fragmentation is well established (e.g., Bissonette et al. 1989, Hargis et al. 1999, Potvin et al. 2000), thus loss and fragmentation of habitat is the most likely explanation for the decline at SEF. As a result of this work we recommended that future management of forests in the SEF focus on restoring and connecting residual marten habitat to improve habitat quality for martens and that this same approach be applied elsewhere within the range where marten populations have decreased.

The change in marten distribution at SEF occurred rapidly; more rapidly than changes in the flora and fauna that affect martens might be expected to change due to climate. Yet, marten is a species that may not fare well given the predicted changes in vegetation distribution as a result of warming climates. The true fir (*Abies* sp.) forests that martens require are predicted to diminish in area (Lenihan et al. 2003, Mortenson 2011), resulting in a poor prognosis for martens (Lawler et al. *in press*). Thus, marten populations have experienced rapid changes in their habitat as a result of timber harvest and may experience additional loss of habitat with climate change. We are exploring the genetic implications of further range contraction by comparing diversity from samples collected from the northern Sierra and southern Cascades in the early 1900s with samples we have collected recently. This will help us understand whether the marten genome has simplified as a result of the range contraction that has already occurred and, importantly, what we can expect if the predicted effects on marten habitat from climate change cause additional contraction.

Some Good News for Carnivores in the Sierra Nevada

A number of recent developments provide reason for optimism. First, the Tahoe National Forest (NF) has accepted the results of recent marten studies at SEF and plans to restore forest ecosystem conditions at SEF that are favorable for marten. A collabora-

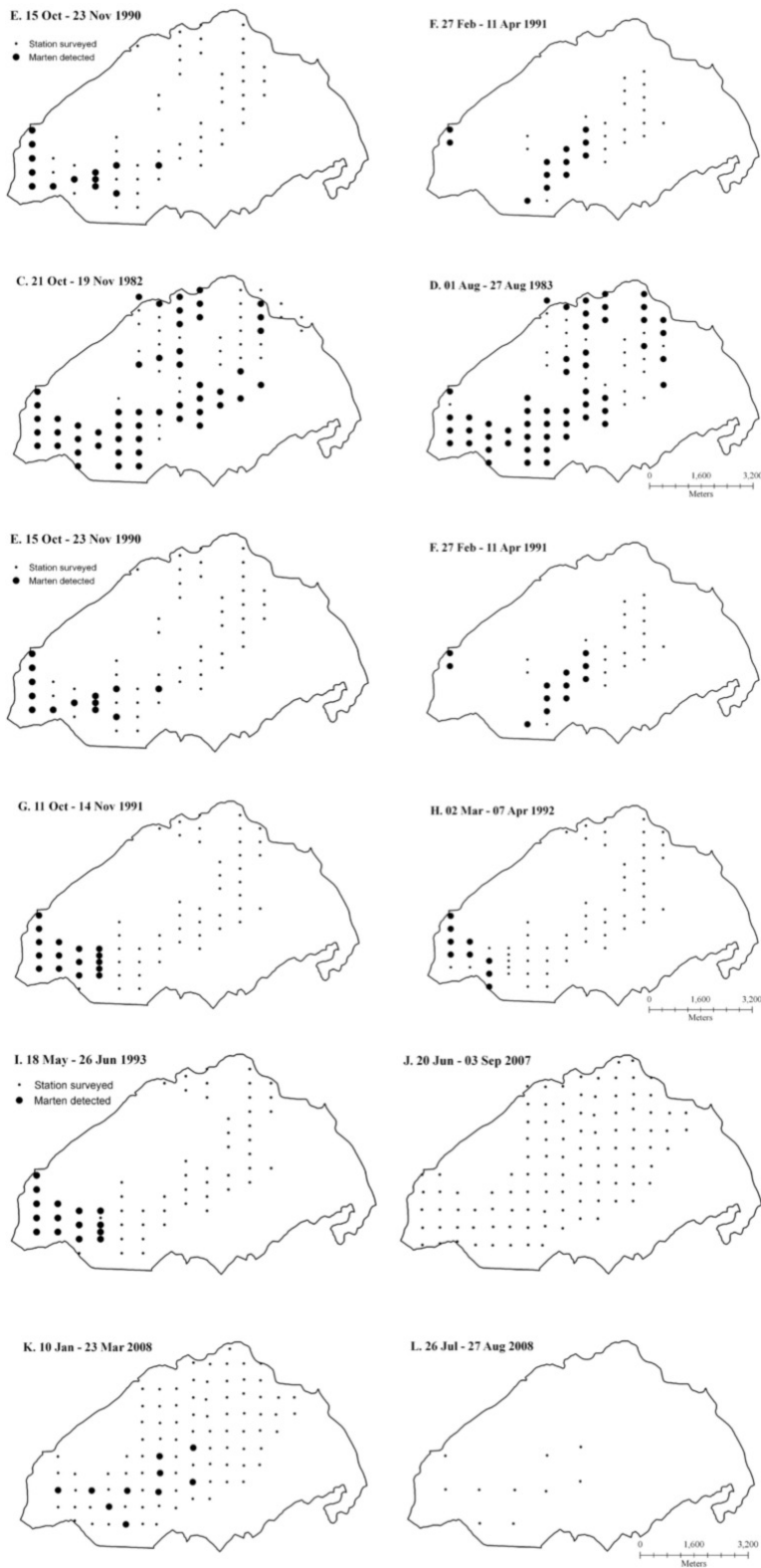


Figure 5. American marten (*Martes americana*) detections in, and immediately north of, the Sagehen Experimental Forest, California during 9 previous surveys (Spencer 1981, Zielinski 1981, Martin 1987, 1995) and during 3 surveys in 2007–2008 (Moriarty et al. in press). Stations with and without marten detections are indicated by large and small solid circles, respectively.

tive effort is underway to implement a fuels treatment and habitat restoration project, which is informed and guided by the science of marten habitat management (<http://sagehenforest.blogspot.com/>). We hope that other public land managers will follow this lead and consider marten habitat in future management plans. Also encouraging is the creation, by the Lassen NF, of a marten habitat connectivity plan (Kirk and Zielinski 2010). Second, in February 2008 a wolverine was verified to occur on the Tahoe NF, the first verified record of this species in California in over 80 years (Fig. 6). Genetic tests indicated that it had a high likelihood of originating from the wolverine population in Idaho (Moriarty et al. 2009) and—as of early 2011—this male was still alive in the general vicinity of the original discovery. Third, until recently there was believed to be a single remnant population of the Sierra Nevada red fox, a genetically distinct subspecies that originally occurred in the montane meadows and mixed forest/alpine environments of the Cascades and Sierra Nevada in California. This small population comprised about 20 individuals and located within or near Lassen Volcanic National Park (LVNP) (Perrine 2005, Sacks et al 2010). Then, in August of 2010, biologists who were conducting camera surveys for another purpose were amazed to have photographed a red fox near Sonora Pass in the central Sierra Nevada, which was later verified from a genetic sample to be a Sierra Nevada red fox (B. Sacks, UC-Davis, unpubl. obs.). Since then at least three additional individual foxes have been photographed by biologists (S. Lisius, Humboldt-Toiyabe National Forest, A. Rich, Stanislaus National Forest, C. Stermer, California Fish and Game, pers. obs.). As exciting as the discovery of a second population of Sierra Nevada red foxes, is the recent news that these individuals are a remnant of a population that originally occurred in the southern Sierra Nevada, genetically distinct from the small population at LVNP (B. Sacks, UC-Davis, unpubl. obs.).

Restoration of populations of the montane carnivores of California will require coordinated effort by managers, conservationists and the public. We will require new science that identifies important habitat and plans for maintaining connections among habitat patches, now and in the uncertain climate future. However, recent events suggest that we can count on a bit of help from



Figure 6. Initial photograph of the male wolverine (*Gulo gulo*) that was photographed at a remote camera station in February 2008 on the Tahoe National Forest in the Sierra Nevada of California. This was the first verifiable evidence of a wolverine in the state of California in > 80 years. The camera was part of a grid of similar cameras set to document the occurrence of American marten (*Martes americana*).

the species themselves as they demonstrate their extraordinary abilities to disperse to suitable habitat or unexpectedly reveal their presence, despite considerable efforts to find them! Our efforts, combined with their characteristics, will help maintain mammalian carnivores and the important functions they contribute to montane ecosystems.

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BREVIA

Climate Change Links Fate of Glaciers and an Endemic Alpine Invertebrate

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Muhlfeld, Clint C., J. Joseph Giersch, F. Richard Hauer, Gregory T. Pederson, Gordon Luikart, Douglas P. Peterson, Christopher C. Downs, and Daniel B. Fagre. 2011. Climate change links fate of glaciers and an endemic alpine invertebrate. *Climatic Change Letters*, 106: 337-345.

Climate warming in the mid- to high-latitudes and high-elevation mountainous regions is occurring more rapidly than anywhere else on Earth, causing extensive loss of glaciers and snowpack (Pederson et al. 2010). Climate warming and associated glacier loss are likely to shift patterns in distribution, abundance, and phenology of many species (Walther et al. 2002; Parmesan and Yohe 2003). This is particularly true for range-restricted mountaintop aquatic species that show strong temperature and flow-related range contractions and thus are potentially the most threatened groups of species due to climate change. Therefore, it is increasingly urgent to assess and monitor the status of aquatic species living in mountainous regions to fully understand their basic ecological requirements and the potential impacts of climate warming across a range of spatial scales from local to global.

Cold-water stenothermic species inhabiting alpine stream environments are especially vulnerable to warming and snow loss and may be useful biological indicators of climate-induced changes in mountain ecosystems. One species that may be particularly vulnerable to climate change is the meltwater stonefly (*Lednia tumana*; Fig. 1), a species endemic to the Waterton-Glacier International Peace Park (WGIPP) area and previously reported to be limited to glacial and snowmelt-driven alpine streams (Baumann and Kondratieff 2010). The loss of glaciers in WGIPP is iconic of the combined impacts of global warming and reduced snowpack; 125 of the estimated 150 glaciers existing in 1850 have disappeared, and the remaining 25 are predicted to be gone by 2030 (Hall and Fagre 2003). Consequently, *L. tumana* is a recent candidate for listing under the U.S. Endangered Species Act (ESA) due to climate-change-induced habitat loss, yet little is known specifically about how climate impacts may threaten this rare species and many other alpine aquatic species worldwide.

We found a strong linkage between regional climate change and the fundamental niche of *L. tumana*. During 14 years of research, we documented that *L. tumana* inhabits a narrow distribution, restricted to short sections (~500 m) of cold, alpine streams directly below glaciers, permanent snowfields, and springs (Fig. 2A). Furthermore, densities sharply declined with increasing distance downstream from these sources (Spearman's $\rho = -0.99$, $P < 0.001$) and with increasing mean (Spearman's $\rho = -0.95$, $P < 0.05$) and maximum stream temperatures (Spearman's $\rho = -0.76$, $P < 0.05$).

We used the maximum entropy method (Maxent) to model the potential geographic distribution of *L. tumana* in WGIPP as a function of environmental variables (snow/ice, elevation, and aspect) at sites of known occurrence (Phillips et al. 2006). The simulated current geographic distribution showed that the highest probabilities of occurrence are associated with perennial snow and ice masses in upper-elevation areas (Fig. 2B). The future distribution of *L. tumana* under a conservative climate warm-



Figure 1. Rare alpine aquatic invertebrates, such as the meltwater stonefly *L. tumana*, are excellent biological indicators of climate change in mountain ecosystems. Photo: J. Giersch.

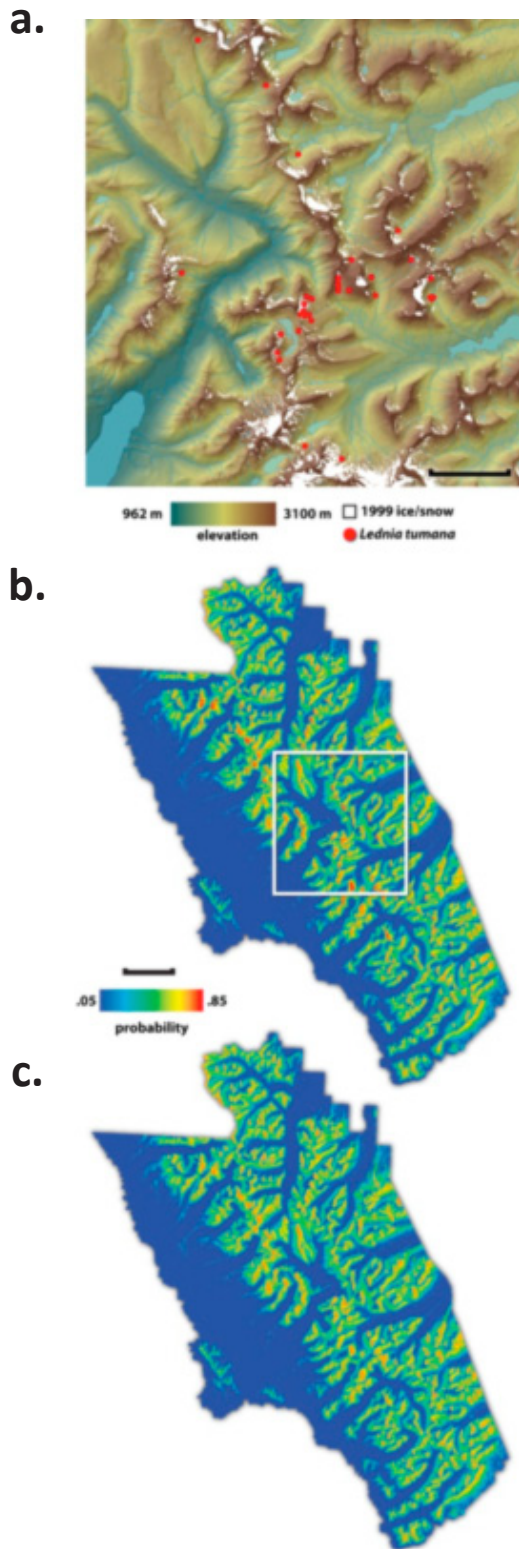


Figure 2. Map of study area, occurrences, and predicted current and future distribution of *L. tumana* in Waterton-Glacier International Peace Park (WGIPP), Canada and USA. (a) *L. tumana* detections in relation to glaciers and permanent snow. (b) Predicted potential distribution (probability of occurrence); (c) Predicted potential distribution with the loss of glaciers and permanent snow (Hall and Fagre 2003). Scale bar is 5 km for Panel A and 10 km for Panel B.

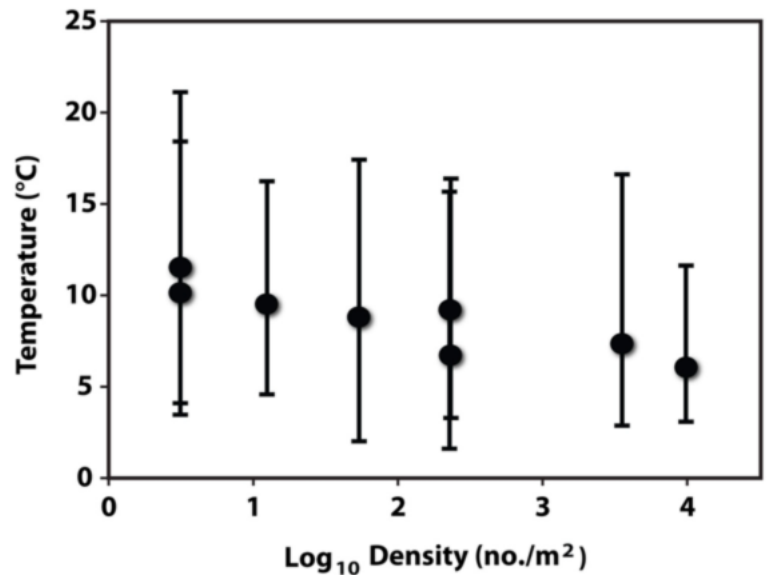


Figure 3. Mean larval densities ($\log_{10} + 0.5$) of *L. tumana* versus mean August (black circles) stream temperatures. Error bars indicate minimum and maximum temperatures.

ing scenario (A1B) was modeled using Maxent by applying the trained model to a new set of environmental conditions that did not include the presence of glaciers and permanent snowfields (Hall and Fagre 2003). Areas with the highest probabilities of occurrence were drastically reduced under the climate change simulation, with an overall 81% potential reduction in distribution (Fig. 2C); the total area potentially supporting *L. tumana* declined from 23.2 km² (current) to 4.5 km² (potential future).

Alpine aquatic species are important to regional biodiversity in mountain ecosystems (Hauer et al. 1997). Understanding how species are likely to respond to climate change is critical for conservation and management strategies designed to enhance resiliency and adaptation. Here we show compelling evidence that climate change links the fate of glaciers and a narrow endemic alpine stonefly. Our results show that *L. tumana* is a range-restricted endemic that may be particularly vulnerable to climate-change-induced snow and ice loss, with the species predicted to lose over 80% of its potential current range under future climate warming. These potential habitat reductions imply a significant range contraction and greatly increased probability of extinction.

Mountaintop aquatic invertebrates exhibit severe climate-related range-restrictions and are ideal early-warning indicators of thermal and hydrological modification that may be associated with climate warming in mountain ecosystems. Because relatively little is known about mountaintop invertebrates, yet they are increasingly threatened by climate change, more research and monitoring is urgently needed to avoid extinctions and to predict effects of extirpation on ecosystem integrity and function worldwide.

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BREVIA

Climate Change Could Rapidly Transform Greater Yellowstone Fire Regimes

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Westerling A.L., M.G. Turner, E.A.H. Smithwick, W.H. Romme, G.M. Ryan. 2011. Continued warming could transform Greater Yellowstone fire regimes by mid-21st century. *Proc. Nat. Acad. Sci. USA*, 108: 13165-13170.

Climate change is likely to alter wildfire regimes, but the magnitude and timing of potential climate-driven changes in regional fire regimes are not well understood. We (Westerling et al 2011) considered how the occurrence, size and spatial location of large fires might respond to climate projections in the Greater Yellowstone Ecosystem (GYE; Wyoming, USA), a large wild-land ecosystem dominated by conifer forests and characterized by infrequent, high-severity fire. We developed a new suite of statistical models that related monthly climate data (1972-1999) to the occurrence and size of fires > 200 ha in the northern Rocky Mountains; these models were cross-validated and then used with downscaled (~12 km x 12 km) climate projections from three global climate models to predict fire occurrence and area burned in the GYE through 2099.

Our statistical models predicted fire and characterized extreme fire years in the Northern Rockies more effectively than has been done previously. Temperature, precipitation and moisture deficit were all important for predicting fire occurrence and number; given that a fire occurred, cumulative water year moisture deficit was key for estimating fire size distributions. The models explained 83% of interannual variation in large fire occurrence and 73% of the variation in burned area for the calibration data set. For the model estimation period in the Northern Rockies, 33% of fires and 66% of burned area occurred during the two largest fire years (1988 and 1994); 30% of fires and 45% of burned area in our simulation also occurred during those two years.

High fire activity always occurred during warmer-than-average years, and this pattern was clear within the GYE (Fig. 1). The relationship between temperature and fire was non-linear, and only about 0.5°C above the 1961-1990 average spring and summer temperature (March-August) distinguished large-fire years from

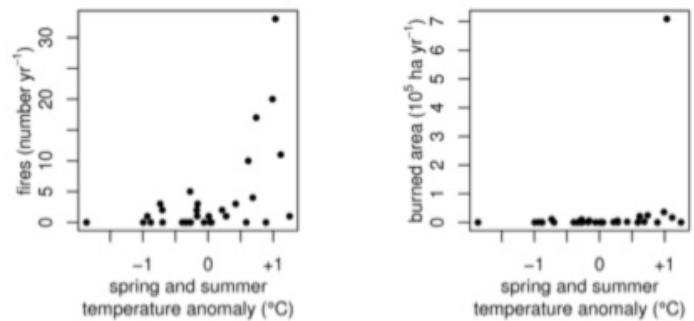


Figure 1. Greater Yellowstone annual large fires (left) and burned area (right) vs spring and summer temperature anomalies for 1972 – 2008.

most other years in the GYE. Warmer-than-average temperatures were a necessary but not sufficient condition for predicting extreme fire years; in addition to temperature, moisture deficit and summer precipitation (July-August) also influenced fire during warm years.

Fire simulations for three downscaled GCM scenarios for the recent historical period (1950-1990) in the GYE produced realistic inter-annual variation in area burned and no directional trends (Fig. 2). Predicted area burned was < 10,000 ha (< 1.25% of the GYE) in most years and agreed well with observed variability; however, no simulated fire years were as extreme as 1988 prior to the first decade of the 21st Century.

Post-1990 simulations projected substantial increases in GYE fire (Fig. 2). Notably, by 2020 projected increases in burned area over a 1951-90 reference period were detectable with 95% confidence over 100% of simulations using one-sided Mann-Whitney tests. Fire seasons comparable to 1988 became more frequent, with between one and five such events occurring between 2011 and 2050. After 2050, all models predicted that annual area burned would exceed 100,000 ha during most years. Years with no large fires—common in the historical record—became extremely rare by 2050 and did not occur in 1000 simulations after 2050 for either the CNRM or GFDL scenarios, and occurred only three times out of the 1000 NCAR simulations. This increase in aver-

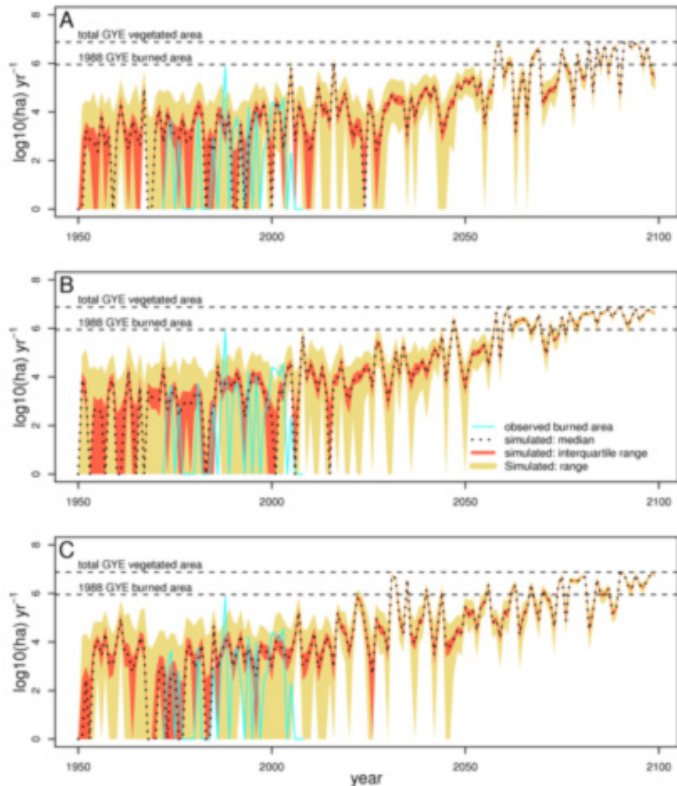


Figure 2. The range (light shading), interquartile range (dark shading) and median (dotted line) of predicted area burned for 1000 gridded monthly simulations, aggregated over the GYE by year, and the observed annual area burned (solid line) for three downscaled GCM SRES A2 climate scenarios: NCAR CCSM 3.0 (A), CNRM CM 3.0 (B), GFDL CM 2.1 (C).

age annual “background” area burned in years without 1988-scale events is also apparent in observed fires for the last two decades. By about 2075, potential annual area burned regularly exceeds the signature 1988 event, often by a large margin. By then, forest ecosystems in the GYE, and the fuels and fire responses they support, would likely have been transformed by changing climate and disturbance and moved outside the bounds of the modeled climate-fire relationship.

Fire rotations (FR, Baker 2009), which exceed 120 yrs throughout most of the GYE before 1990, are in transition to shorter periods across all scenarios by the first decades of the 21st Century (Fig. 3). Downscaled climate predictions from all three GCMs were qualitatively similar but differed somewhat with respect to mid-century timing of fire-regime shifts. For 2005 to 2034, FRs begin to fall below 60 yrs in portions of the landscape for all scenarios, although the rate of change varies; differences in precipitation among scenarios have greater influence on fire early on, whereas effects of high temperatures dominate late in the century. Spatial patterns are similar across scenarios, with FR decreasing sooner and to greater extent in the northwestern

areas of the GYE. By midcentury, FR are < 20 yrs throughout the majority of the GYE, except for small portions to the southeast (Fig. 3). By end of century, climatic conditions associated with large fires are the norm, and FR < 10 yrs are projected across the GYE for all three GCMs (Fig. 3); however, by the time such short fire rotations could be driven by climate, fuel limitations would be expected to constrain fire occurrence and area burned.

Our findings indicate that GYE forests are rapidly approaching a threshold beyond which fire occurrence and extent are likely to change the ecosystem qualitatively. Recent history shows that a shift in spring and summer temperature (March-August) of just over 0.5°C above the 1961-90 average distinguished extreme fire years from most others in the Northern Rockies, and increases in average spring and summer temperatures predicted by 2099 are approximately 4.5 to 5.5°C for the GCM scenarios explored here. The projected changes in temperatures and fire are not consistent with persistence of the suite of conifer species that have dominated the Yellowstone landscape throughout the Holocene. Rather, the projected climate-fire regime is consistent with lower montane woodland or non-forest vegetation and implies a shift from a climate-limited to a fuel-limited system (Littell et al 2009) by mid-century. Climate conditions conducive to large fires in

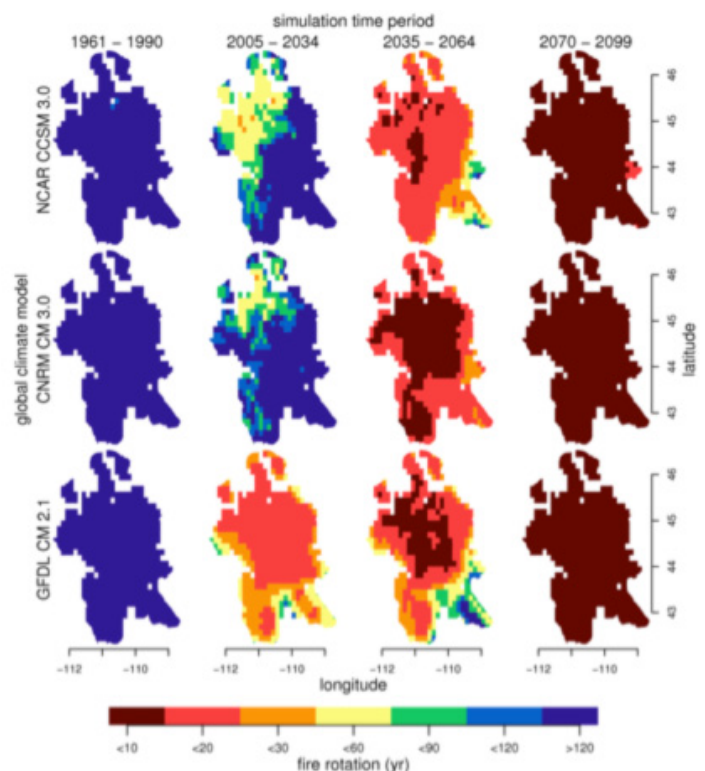


Figure 3. Projected fire rotations calculated for 1000 monthly gridded simulations for four 30-yr periods across three downscaled GCM SRES A2 climate scenarios.

the current system would occur in most years, but less biomass would be available to burn because recovery times between successive fires would be shorter. Thus, we might expect novel fire-climate-vegetation relationships, suggesting that the GYE is approaching a tipping point (i.e., critical change in temperature and moisture deficit) that could be exceeded by mid-21st century.

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CIRMOUNT Meanderings

A round-up of ongoing within the CIRMOUNT community

Stephen Gray, long-time CIRMOUNT contributor of paleoclimate and hydrologic science and work with water managers, has been hired by USGS as the first director of the Department of Interior Alaska Climate Science Center, hosted by the University of Alaska. Steve moved to Anchorage late this summer, and is looking forward to spending his winters in balmy Anchorage instead of Laramie. About his move, Steve says, “There is a tremendous amount of climate change and climate impacts related work being done in the Alaska region. The challenge now is in translating all of this science into products and resources to help guide management. The Alaska Climate Science Center provides an ideal means to link science and management, and it’s this part of the job that most excites me about the new CSC.”

Contributing Artists

Don Erman is professor emeritus from the University of California, Davis, where he was on the faculty in aquatic ecology and Director of the Centers for Water and Wildland Resources. Among his many mountain studies and programs, Don served as Team Leader for the Congressionally-mandated Sierra Nevada Ecosystem Project (SNEP), whose influential reports from the late 1990s served to guide resource management decisions across Sierra Nevada landscapes in subsequent decades. Those of us who served under Don on SNEP know well his verbal skills, but many might not have known he is an accomplished poet as well.

Jeremy Littell (speaking for himself): I view myself mostly as a visual learner, and have seen the power of images to convey to people what words cannot. I’ve also had the good fortune to work and do research in some stunning parts of western North America. In 1996, as an undergraduate, I got a Pentax K1000 camera - kind of the very last gasp of entirely manual SLR cameras. The only thing automatic on it is the light meter, and it runs on a watch battery - to me, it is simple and elegant. For a decade, I conducted a sort of experiment - what could an amateur armed with an off-the shelf 35mm and the stock lens do? It turns out, the answer is that if you shoot enough film in enough wild places, eventually you’ll get some good pictures. In 2006, I began using a digital SLR (still a Pentax, but now more often with a wide angle lens) to document my research and the places I am fortunate enough to walk.

Norman Schaefer is a naturalist and mountaineer who has been observing the effects of climate and weather on Sierra Nevada mountain-scapes for more than forty years. His poetry, most recently collected in a volume entitled, “The Sunny Top of California, Sierra Nevada Poems and a Story” (2010, La Alameda Press), reflects this deep connection of land, earth, and sky. He lives currently in Port Townsend, WA, from where he travels often into western mountains.

Wangdowa Sherpa hails from the high Himalaya Mountains of Nepal, where he grew up in intimate connection with mountains, mountain weather, and climate extremes. Currently Wangdowa lives in the Mono Basin, California, from where he bases his eco-tourism business, Sherpa Travel, Inc. (www.sherpa-travel.com), which specializes in the conservation and exploration of nature and culture. In addition to his artistic talents as photographer, Wangdowa has a remarkable capacity to transform the glacial outwash soils of the Mono Basin into productive gardens, from which he supplies his fortunate neighbors with abundant produce.

Wally Woolfenden has combined a love of mountains, mountain science and art all his life. Majoring in visual arts at City College in San Francisco, Wally works in many media, including watercolors, pen and ink, and acrylics; his content is equally diverse, ranging from landscapes and portraits to cartooning. Wally went on to earn a Ph.D. in Geosciences (paleoecology) at the University of Arizona and to apply his skills in a career as Archeologist with the US Forest Service. As a historical ecologist and mountain wanderer at heart, Wally has a unique capacity to see into deep time and depict mountain environments in their former visages. After retiring from the Forest Service, Wally has been working as a Fulbright Scholar undertaking paleoecology research in Jordan. He lives in the shadow of the Sierra Nevada near Bishop, CA.

From CIRMOUNT authors, a publication of interest to natural-resource managers and climate adaptation:

Peterson, D.L., C.I. Millar, L.A. Joyce, M.J. Furniss, J.E. Halofsky, R.P. Neilson, and T.L. Morelli. 2011. Responding to climate change on national forests: a guidebook for developing

adaptation options. USDA Forest Service General Technical Report GTR-PNW. In press.

Abstract: This guidebook contains science-based principles, processes, and tools necessary to assist with developing adaptation options for national forest lands. The adaptation process is based on partnerships between local resource managers and scientists who work collaboratively to understand potential climate change effects, identify important resource issues, and develop management options that can capitalize on new opportunities and reduce deleterious effects. Because management objectives and sensitivity of resources to climate change differ among national forests, appropriate processes and tools for developing adaptation options may also differ. Regardless of specific processes and tools, the following steps are recommended: (1) become aware of basic climate change science and integrate that understanding with knowledge of local resource conditions and issues (review), (2) evaluate sensitivity of specific natural resources to climate change (rank), (3) develop and implement strategic and tactical options for adapting resources to climate change (resolve), and (4) monitor the effectiveness of adaptation options (observe) and adjust management as needed. Results of recent case studies on adaptation in national forests and national parks can facilitate integration of climate change in resource management and planning and make the adaptation process more efficient. Adaptation to climate change will be successful only if it can be fully implemented in established planning processes and other operational aspects of national forest management.

From CIRMOUNT authors, a new book on dendroclimatology:

Hughes, Malcolm K.; Swetnam, Thomas W.; Diaz, Henry F. (Eds.). 2011. *Dendroclimatology: Progress and Prospects*. Springer Series: [Developments in Paleoenvironmental Research](#), Vol. 1 1st Edition., 2011, XII, 365 p.

Abstract: A top priority in climate research is obtaining broad-extent and long-term data to support analyses of historical patterns and trends, and for model development and evaluation. Along with directly measured climate data from the present and recent past, it is important to obtain estimates of long past climate variations spanning multiple centuries and millennia. These longer time perspectives are needed for assessing the unusualness of recent climate changes, as well as for providing insight on the range, variation and overall dynamics of the climate system over time spans exceeding available records from instruments, such as rain gauges and thermometers.

Tree rings have become increasingly valuable in providing this long-term information because extensive data networks have been developed in temperate and boreal zones of the Earth, and quantitative methods for analyzing these data have advanced. Tree rings are among the most useful paleoclimate information sources available because they provide a high degree of chronological accuracy, high replication, and extensive spatial coverage spanning recent centuries. With the expansion and extension of tree-ring data and analytical capacity new climatic insights from tree rings are being used in a variety of applications, including for interpretation of past changes in ecosystems and human societies.

This volume presents an overview of the current state of dendroclimatology, its contributions over the last 30 years, and its future potential. The material included is useful not only to those who generate tree-ring records of past climate-dendroclimatologists, but also to users of their results, e.g., climatologists, hydrologists, ecologists and archeologists.

Interview: Don Grayson Elected to National Academy of Sciences

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

Donald K. Grayson, a University of Washington (UW) anthropology faculty member since 1975, was elected to the National Academy of Sciences in May 2011. Grayson joined the UW Department of Anthropology in 1975 as an assistant professor and became a full professor in 1983. He received his doctorate in anthropology from the University of Oregon in 1973, and has long focused research on paleoclimates and their influence on vertebrate fauna of the Great Basin, including Great Basin mountains.

In addition to many scientific papers, Grayson has authored four books. The most recent of these is an extensively revised (and re-titled) edition of “The Great Basin; A Natural Prehistory”, which describes the environmental and human history of the American West centering on the mountains of Nevada and adjacent regions.

In early summer, I had the pleasure of Don’s company on a trip to re-survey historic sites of American pika (*Ochotona princeps*) in northern California.

Connie: What key concepts would you like our mountain-climate science community to consider from your research career in Great Basin climate- and related ecological sciences?



Figure 1. In central Utah, Donald Grayson kneels next to a woven model of the western North American diminutive pronghorn, which became extinct about 11,000 years ago. Photo: David B. Madsen

Don: From the beginning of my career, one of my prime concerns has been to provide fine-scale, long-term histories of mammals within local environmental contexts, including both the climates

and the people of those environments. The LTER [Long Term Ecological Research] Network’s 2011 Strategic Plan notes that “many ecological phenomena change at decadal to century and longer time scales, and it is essential to maintain experiments and observations across periods appropriate to these scales”, but LTER sites span decades, not centuries. Archaeological and paleontological data might not be as well-controlled chronologically, but, when properly retrieved and analyzed, they can provide information on mammal and plant species abundances and distributions that span thousands of years; the longest Great Basin sequence I have been fortunate enough to study covers some 11,000 years. No LTER can do that. In addition, there are no LTER sites in either the Great Basin or in southwestern France, where I have also worked, but archaeological and paleontological sequences spanning vast amounts of time are rich in both areas. I wouldn’t have either the nerve or the knowledge to suggest key concepts to mountain-climate scientists, because I am a consumer, not a producer, of the kind of understanding they provide. For mountain biologists, though, I want to stress how rich our understanding of plant and animal histories in the Great Basin has become as a result of the extraction and analysis of archaeological and paleontological data, and to become familiar with that understanding if your interests are in biogeography. Had I been asked to address my thoughts to an archeological community, my answer would have been quite different. While I get frustrated by ecologists who know little in depth about the past, while often pretending they do, I get equally frustrated by archaeologists who pretend they know about ecology but don’t. These archaeologists often complain that their work is not taken into account by ecologists, but if ecologists were to read that work, they would be astonished by the lack of biological sophistication that it shows.

Connie: What do you feel are the most important mountain-climate research questions currently facing scientists who work in the Great Basin ecoregion?

Don: I have to opt out of this one; I am mainly grateful to mountain-climate researchers for generating the knowledge critical for my own work. I would, though, point out that there are very few archaeological faunas known from high elevations in the Great Basin. As a result, should mountain scientists come across potentially important sites (caves and rockshelters are the obvious

candidates), it would be good to carefully note their locations and report them to appropriate members of the archaeological community. Wouldn't it be great, for instance, to have a deep biotic sequence from, say, 3500 m, on any Great Basin mountain range?

Connie: What advice or recommendations can you offer graduate students and young scientists as they embark on careers in mountain-climate sciences of western North America?

Don: Be thoroughly interdisciplinary. Learn everything you can learn about all relevant disciplines; don't pretend to know what you don't know. Devise your own research rather than letting your advisor dictate what your research is to be. Have fun.

Connie: What are you most proud of in your career?

Don: My students.



Figure 2. Don Grayson re-surveying a historic location of American pika, (*Ochotona pinceps*) above Madeline Plain, northern California. *Photo:* Connie Millar

News and Events

Send contributions for posting in this section to cmillar@fs.fed.us

PACCLIM (the Pacific Climate Workshop) 2011

Scott Starratt, U.S. Geological Survey, Menlo Pk, CA

In 1984, a group of scientists interested in the impact of atmospheric and oceanographic conditions in the eastern North Pacific Ocean on western North America met at Asilomar, a stone's throw from the waters of Monterey Bay. Out of what has become known at the Pacific Climate Workshop (PACCLIM) came an improved understanding of ENSO circulation. PACCLIM has continued to provide insight into the complex processes that affect the climate of the west. The 25th PACCLIM (March 6-9, 2011) continued the tradition of bring together oral and poster sessions presenting up-to-date information on the past, present, and future of west coast climate including lacustrine records from the Great Basin, paleoceanography of the Gulf of Alaska, ice core records from British Columbia, future climate change and flood risks in California, and the future of Lake Tahoe. In the PACCLIM tradition, a proceedings volume is in preparation as a special issue of *Quaternary International*.

HEIDI: High Elevation Instrumental Data Inventory

Raymond Bradley, Dept of Geosciences and Climate System Research Center, University of Massachusetts, Amherst, MA

Although high mountains represent only a small geographical area of most countries, they are of vital economic and environmental significance to much larger regions. High mountains provide critical water resources via rivers and streams, which are essential for agriculture, urban drinking water supplies and sanitation, and for hydroelectric power generation. Mountain regions also attract tourists, and many mountain communities rely on the economic benefits of tourism for their survival. Mountain regions provide critical habitat for rare species, and are key regions for the protection of the biodiversity of Europe. For all these reasons, high mountain regions should be considered as among the most important natural resources of all alpine countries.

Meteorological measurements provide the essential scientific basis for all environmental assessments. In the high mountains, such measurements are very difficult, requiring great human effort to ensure the accuracy of the data collected. Remarkably,

in the high mountains of Europe, such efforts have been carried out at a small number of locations for many decades, and in a few cases, for over a century. Observers faced great hardship and danger in making these measurements, under some of the most extreme conditions on the continent. Today, these data provide unique perspectives on long-term climate change, as they represent measurements that were made in pristine environments, far from the confounding effects of urbanization and localized air pollution. As scientists develop sophisticated computer models to assess the changes that have resulted from human activities, the importance of high quality data sets for model validation becomes of increasing significance. Furthermore, many models indicate that future changes in climate may be greater at higher elevations, making it even more important that these measurements in remote high mountain locations be continued, and that all the past records be assembled so that current changes can be placed in a long-term perspective.

We therefore propose an initiative called **HEIDI: High Elevation Instrumental Data Inventory**, in which all long-term high elevation data sets from across Europe would be brought together and digitized, to be made freely available on a web site, for access by scientists and the general public. An example of the possible outcome of HEIDI is provided by the HISTALP project (www.zamg.ac.at/HISTALP/). Data were gathered from diverse sources, digitized when necessary, then checked for quality and homogeneity before being made available on the web. Initially, monthly mean data would be obtained, but daily data sets should not be neglected, as these are essential for many research purposes.

Financial support for digitization, quality control and homogenization, as well as website development, will be required to ensure the success of this project. Funding for such a data management project is quite low when one considers the enormous effort that was already invested in acquiring these data sets, most of which are now collecting dust in archives and libraries across Europe. Support for HEIDI would be a fitting tribute to all those who labored hard, under very difficult conditions over many years, to provide unique high quality measurements of some of the most pristine regions in Europe.

Upcoming Meetings

- Fall Meeting, American Geophysical Sciences Union:** *December 5 - 9, 2011*, San Francisco, CA. The 2011 session, sponsored by CIRMOUNT in the Global Change section of AGU, is entitled, Climatic Water Deficit and Water Balance in Mountain Systems: Biophysics, Ecohydrology, and Impacts, and convened by Jeremy Littell, Andy Bunn, Connie Millar, and Christina Tague. Poster and oral sessions are Wed, Dec 7. See: <http://sites.agu.org/fallmeeting/>. Presentations from the oral and poster sessions will be available on the CIRMOUNT meeting archive website after the conference. Contact Jeremy Littell (jlittell@uw.edu) for information.
- Another session of interest at the **AGU Fall 2011 San Francisco Meeting:** *Atmospheric Processes in Mountainous Terrain: Basic Studies and Applications*, convened by Stephan DeWekker (dewekker@virginia.edu) and Fotini Chow (tinakc@berkeley.edu)
- 2012 IGBP Congress, “Planet Under Pressure”: *March 26-29, 2012*, London, UK, www.planetunderpressure2012.net
- Environmental Restoration in a Changing Climate:** *May 22-24, 2012*. Tahoe Science Conference. Hosted by the Tahoe Science Consortium and Sierra Nevada College with support from the Nevada Water Resources Association. Find information at: www.nvwra.org
- MtnClim 2012:** CIRMOUNT’s biannual conference will convene *October 1 – 4, 2012*, in Estes Park, Colorado, adjacent to Rocky Mountain National Park. Conference website: www.fs.fed.us/psw/mtnclim/. Contact: Connie Millar (cmillar@fs.fed.us).
- Pacific Climate (PACLIM) Workshop:** *March 3-6 2013*, Asilomar Conference Center, Pacific Grove, CA. Contact: Scott Starratt (sstarrat@usgs.gov).

MOUNTAIN VISIONS

From the palettes of our CIRMOUNT community

The Lakes Grow Up with Flowers and Trees After the Water is Gone

Not long ago,
Evolution Meadow was a lake
left by a retreating glacier.
You can see the snowmelt streams
that filled in with sediment
from the slopes above,
making way for grasses and flowers
and finally trees.
A lake might live 10,000 years,
More than a human mind can grasp,
but for Mt Darwin
rising above Evolution Lake,
it's just another moment
in the lives of streams and glaciers.
In a heartbeat of geologic time
an alpine lake
turns to lodgepole pine forest.
Be careful you don't blink your eyes.

Norman Schaefer, from "The Sunny Top of California", La Alameda Press, 2010 (with permission from the author)

Pine Creek Glacier at Last Glacial Maximum, ca 20 ka, Sierra Nevada, CA



Sketch by Wally Woolfenden, August 2011

Sierra lily (*Lilium kellyanum*)



Photo: Wangdowa Sherpa

Despite a Cool and Wet Start to Summer, August Brought Fire and Smoke to Western Mountains...

Sierra Smoke

Only the black-eyed Susans
 have lasted this far into
 another hot, dry Sierra summer.
 Higher, of course, penstemon
 and fragrant, ever present pennyroyal
 still grace the trails and rocky outcrops.
 Do they gasp now that lightning fires
 pump out their clouds
 that mist our days?
 Sun strains to pierce the smoky atmosphere
 while the moon, ripe in its harvest stage,
 glows with a fire like the primordial birth.
 We cry and curse
 this visit from Mars; Nature
 cannot intrude upon our lives
 this way!
 How brief our tolerance
 for forces that shape us.
 Tomorrow must be different from today:
 Change carries with it pleasure
 as well as pain.

Don Erman, 1999

The smoky Sierra Nevada barely visible from the White Mountains, August 2011



Photo: C. Millar

