

MOUNTAIN VIEWS

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



Informing the Mountain Research Community

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Limber pine (*Pinus flexilis*), 1544 yrs-old, Sheep Mountain, Colorado. Photo: Jeff Mitton

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Front Cover: California white oak savanna in the foothills of the western Sierra Nevada, April 2014. Photo: Kelly Redmond

Back Cover: Moon over bristlecone pine (*Pinus longaeva*), White Mountains, California. Photo: Stu Weiss

Read about the contributing artists on page 46.

Mountain Views

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

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Whitebark pine (*Pinus albicaulis*) krummholz, Mt. Dunderberg, California. Photo: Colin Maher

The Mountain Views Newsletter

Connie Millar, *Editor*

Welcome to *Mountain Views*, the biannual newsletter of the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT, www.fs.fed.us/psw/cirmount/). Gathered in these pages are reports on current mountain-climate and climate-response studies, *Brevia* of recently published articles, book reviews, mountain climate news and announcements, and our seasonal round-up of mountain artwork and poetry.

Two events involving CIRMOUNT are upcoming, and I hope you can attend one or both. The international Mountain Research Initiative is convening a major international conference, *Global Fair and Workshop on Long-Term Observatories of Mountain Social-Ecological Systems*, July 16-19, 2014 in Reno, NV with field trips before, during, and after the conference. Read about this event on page 32.

CIRMOUNT celebrates its 10th anniversary with our flagship conference, *MtnClim 2014*, September 15-18, 2014 at the Homestead Resort in Midway, UT in the high Wasatch Range near Salt Lake City. This event includes a pre-conference field trip to the Uinta Mountains and a post-conference workshop for managers, focused on forest health and climate in the eastern Great Basin. Find more information on the program and venue on page 31.

In this issue I am pleased to share from South American colleagues a summary of research on high-elevation vegetation development in the tropical Andean mountains of the Sierra Nevada de Mérida (Llambí). Also featured is an introduction to WyCEHG (Wyoming Center for Environmental Hydrology and Geophysics), an innovative new project for understanding near-surface hydrology in mountain environments (Hyde). A preliminary report on the diatom flora of the Ruby and East

Humboldt Ranges of Nevada, and the value for deciphering Holocene paleoclimates of these little known ranges is also included (Starratt).

Five recent or soon-to-be published articles or books are featured in the *Brevia* section. These include reports on burn severity patterns in the North Cascades of Washington (Cansler and McKenzie); a global synthesis and conclusion on carbon accumulation relative to tree size (Das and Stephenson); an analysis of complex interactions between forest greenhouse gas sequestration and mountain stream chemistry (Baron and Hartman); development of a new approach for dendrochronology to assess effects of climate change on tree growth (Peterson); and a new volume reporting forest-sector analysis from the National Climate Assessment (Peterson).

Despite drought in California this winter (“Did You See It?”), my intrepid young scientist colleagues in the Mono Basin found adequate snow to complete another award-winning school science project, this year entitled, “Freezing Warm: Thermopoles in the Snow” (McQuilkin and Harper). Read about their application of iButtons to study thermal patterns of subnivean animal habitat on page 42.

This issue’s imagery theme is trees. Thanks to those who responded to my plea for arboreal photos and artwork. Bob Coats’ poetry and Valerie Cohen’s artwork again conclude the issue with their Mountain Visions.

I hope you enjoy these and other articles, news, and art contributions in the spring 2014 issue. On behalf of the CIRMOUNT coordinators, I send best wishes for summer and a productive field season.

Lunar eclipse, April 15, 2014.
Photo: Kelly Redmond



Vegetation Patterns and Processes in the Tropical Andean Treeline: Insights from Research in the Sierra Nevada de Mérida

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During their famous trip through South America, one of the patterns that most impressed Humboldt and Bonpland was the remarkable progression of vegetation belts along the flanks of the tropical Andes, particularly the transition from mountain forests to the alpine vegetation of the páramos (Humboldt and Bonpland 1807). However, more than two hundred years later, there are still many open questions regarding both the patterns of vegetation change and the processes that drive the dynamics of this conspicuous ecotone.

Here we synthesize recent research carried out in the Cordillera de Mérida (Venezuela, Fig. 1), mainly in the context of the LEAF cooperative network, which studied the dynamics of forest-grassland ecotones in environmental change scenarios along the Americas (with support from the Inter-American Institute for Global Change Research, IAI). We explore three questions: What are the patterns of vegetation change along the tropical mountain treeline in areas with little human disturbance? Are there differences in vegetation's successional response to disturbance along the treeline ecotone? Could similar factors modulate tree establishment in old-fields within forests and in undisturbed areas above the treeline?



Figure 1. View of the Sierra de La Culata from the Sierra Nevada de Mérida, in the Venezuelan Andes. Photo: Samantha Ruíz

Vegetation Change along the Treeline: Patterns in Areas with Low Disturbance

Most of the research available on vegetation structure in the tropical Andean treeline comes from areas severely affected by past and present human intervention, especially fires associated with grazing. Hence, it has been argued that in large regions of the northern Andes the treeline is anthropogenic and below its climatic potential altitude, resulting in a relatively abrupt transition between forests and secondary grasslands (Bader et al. 2007a).

However, in most of the Venezuelan páramos fires are not a practice associated with cattle management. This provides an opportunity to study the tropical treeline in scenarios where land-use change drivers have probably not been so determinant. Hence, we focused on a well-protected but accessible sector of the Sierra Nevada National Park (created in 1952) near “La Aguada” station of the Mérida cablecar system, the longest and highest in the world (going from 1640 m to 4765 m). In the area there is extensive cattle grazing with very low animal loads, but aerial photographs from 1952 - 1998 showed no vegetation cover change due to cultivation or the establishment of secondary pastures (Santaella 2007).

In this region the treeline ecotone corresponds to a complex transition zone (from c. 3200 to 3550 m), between continuous montane forests and open páramos dominated by tussock grasses, sclerophyllous shrubs and the spectacular giant stem rosettes emblematic of tropical alpine ecosystems (e.g. *Espeletia schultzei*). Along the transition zone there are forest tongues and islands that penetrate into open páramos, with relatively abrupt local contact borders (Fig. 2). Average annual temperatures along the ecotone vary between 7.9 and 7.0 °C (Ataroff and Soto, unpublished results); this is within the range reported by Körner and Paulsen (2004) for the global position of the growing season isotherm at the treeline (5 and 9 °C).

Species richness is very high: Yáñez (1998) reported 287 vascular plant species along a continuous transect between the upper cloud forest (2895 m) and the páramo (3600 m). While he studied the



Figure 2. Different views from the Sierra Nevada de Mérida National Park, near “La Aguada” station of the cable car system: a) The treeline ecotone zone with forest tongues and islands immersed in the páramo matrix; b) The forest-páramo contact border at 3310 m; c) Grassland-rosette páramo just above the treeline (3500 m) dominated by the tussock grass *Calamagrostis effusa* and the giant stem rosette *Espeletia schultzei*. Photos: Luis D. Llambí and Samantha Ruíz

ecotone as a continuum, we decided to explicitly compare community structure between the different situations that make up this landscape mosaic, determining plant species abundances in replicate plots established in: a) continuous forests, forest tongues and forest islands; b) their contact borders with the páramos; and c) the páramos at different elevations (Ramírez et al. 2009).

We found marked differences in species composition and abundance in both the herb and woody strata between continuous forests, forest tongues, and the islands higher up in the elevation gradient, suggesting that these islands do not constitute remnant forest patches generated by disturbance (Fig. 3, see also Wille et al. 2002 in Ecuador). The islands were dominated by woody species that were also abundant along the edge of forest tongues and in the sparse woody stratum of the páramos adjacent to the continuous forest-line (*Diplostegium venezuelense*, *Hesperomeles ferruginea* and *Cybianthus marginatus*). This suggests as a hypothesis that these species could act as pioneers in scenarios of forest expansion induced by climate change. However, adult *D. venezuelense* individuals established in the low-elevation páramos were not found to facilitate the establishment of other forest trees under their canopies (Llambí et al. 2013).

Differential Successional Responses in Old Fields along the Treeline

But what happens when vegetation is disturbed at different altitudes along the treeline ecotone? To answer this question we switched our attention to another sector of the Sierra Nevada (“La Arenosa”) where semi-traditional potato farming was practiced in small plots all along the transition between forests and páramos, and was subsequently abandoned during the 1960s. Hence, we were able to compare community structure between undisturbed areas and old-fields with more than 50 years of succession in replicate plots along two altitudinal transects (González et al. 2011).

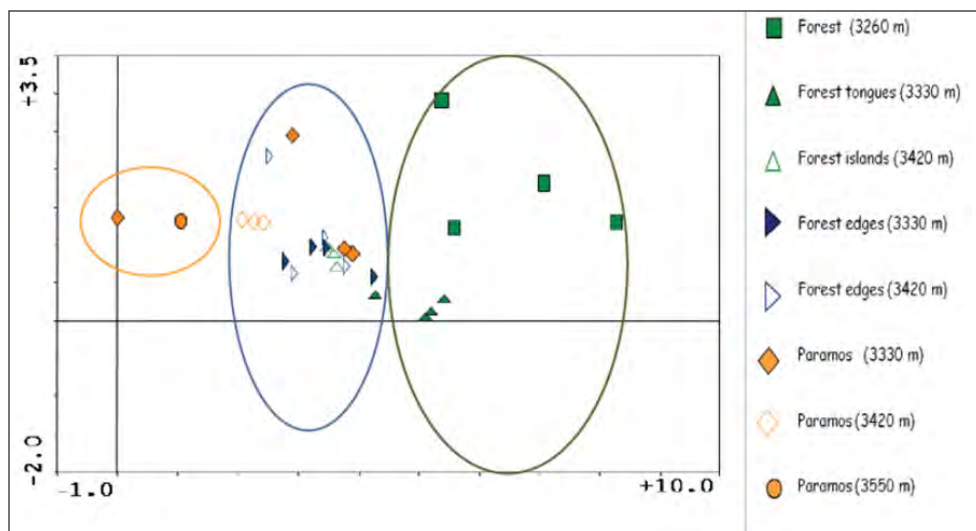


Figure 3. Ordination diagram (Detrended Correspondence Analysis) based on data of plant density in the upper stratum within sampling plots in different physiognomic situations along the treeline ecotone near “La Aguada”, Sierra Nevada de Mérida National Park, Venezuela.

The results indicate that forests have a much lower resilience after agricultural disturbance than páramos; most woody species showed a very limited capacity to establish in the abandoned plots, with significantly lower densities of both saplings and adults than in the non-cultivated forests (with the exception of a few species also abundant in the páramos near the forest-line such as *H. ferruginea*). This indicates that most forest trees face severe limitations to establish in the open environments generated when the closed forest canopy is removed. In addition, many dominant páramo species (e.g. the giant rosette *E. schultzei* and sclerophyllous shrubs such as *Hypericum laricifolium*) were not only very effective in colonizing páramo old-fields, but also those within the forest matrix, produced secondary alpine vegetation patches within forests (Fig. 4). This process, which has been termed “forest paramization”, has also been reported in Colombia and Ecuador (e.g. Kok et al. 1995).

Insights into Factors Modulating Tree Establishment Outside Closed Forests

What factors could limit tree establishment in old-fields along the treeline ecotone? Could they be similar to those that modulate tree colonization above the forest line? In our view, answering these questions could provide key insights both for predicting treeline dynamics in climate change scenarios and for the design of ecological restoration strategies.



Figure 4. Plots in secondary succession after agricultural disturbance (10 years fallow) in the upper forest-line, Sierra Nevada de Mérida, Venezuela. Dominant plants from the páramo (alpine belt) such as the giant stem rosettes of *Espeletia schultzei* are also dominant in these old-fields, while there is very limited establishment of forest trees. Photo: Luis D. Llambí.

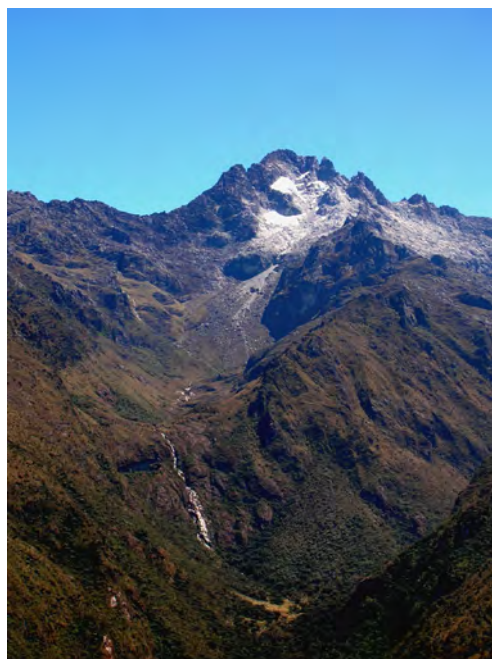
Regarding climatic factors, the experimental and ecophysiological research carried out so far in the Sierra Nevada de Mérida and in Ecuador suggests that the high radiation levels characteristic of highland tropics could be important in limiting tree establishment in open areas (e.g. Bader et al. 2007b; Puentes 2010). This research has shown that woody species that are good in colonizing the páramo above the forest line (e.g. *Diplostephium* spp.) show higher survival and resistance to high radiation (i.e. dynamic, but no chronic photoinhibition of photosynthesis) when transplanted from forests to páramos and/or when plant cover is removed from their neighborhood, compared with other dominant forest species. Resistance to low temperatures in itself does not seem to be so critical: many abundant tree species along the treeline ecotone (including dominant trees within continuous forests) show leaf tissue damage temperatures, for saplings and adults, several degrees C below the minimum temperatures registered near the forest line (Dulhoste 2010; Puentes 2010). However, the role of low temperatures in processes such as photoinhibition of photosynthesis at and above the treeline, remains to be explored.

Interestingly, significantly higher soil base concentration and base saturation were found when comparing continuous forests with adjacent undisturbed páramos and with old-fields at the upper forest-line, suggesting this as a possible limiting factor for tree establishment outside closed forests (Jiménez 2013; Acevedo and Sarmiento, unpublished results).

Finally, remarkably consistent results were found in two sites in the Sierra Nevada when characterizing local safe-sites for the establishment of dominant tree species which are good colonizers of: a) páramos just above the forest-line (*Diplostephium venezuelense*); and b) old-fields within the upper forests (*Berberis discolor*). For this Llambí et al. (2013) and Jiménez (2013) compared local community structure and rock cover inside circular micro-plots centered on tree saplings with randomly located microplots. In both scenarios, they found that a sclerophyllous shrub which is abundant both in mature páramos and old-fields (*H. laricifolium*) was significantly overrepresented in the neighborhoods of saplings of both tree species, suggesting it could play a facilitation effect on their establishment. Superficial rocks were also significantly more abundant in the sapling neighborhoods, while mosses were notoriously underrepresented, suggesting an inhibitory effect. These results support the idea that autogenic, local plant-plant interactions could be important in modulating vegetation dynamics in the tropical treeline both in disturbed areas and above the upper forest-line.

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Bolivar Peak, Sierra Nevada de Mérida, Venezuela

Meeting the Challenge of Water in the West with Integrated Research Solutions

Kevin Hyde

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Imagine... You study the contribution of snowmelt water to vegetation recovery following wildfire. You strap on snowshoes and carry a simple electronic device that continuously records snow depth and measures SWE, snow water equivalent. After an hour of walking you collect 2 kilometers of detailed snow data. You come away with a spatially distributed understanding of snow levels in your recovery area. During the same hour you might have collected only a dozen or so point measurements using snow tube survey and be left with much greater uncertainty about snow-water distribution.

Welcome to the world of WyCEHG (pronounced “Y-keg”), the Wyoming Center for Environmental Hydrology and Geophysics. Using ground penetrating radar (GPR) to estimate SWE is just one of the experimental applications of geophysical tools and techniques being tested to advance understanding of near surface hydrology in mountain environments (Fig. 1). The work of WyCEHG extends beyond geophysics. Based out of

the University of Wyoming in Laramie and funded by a five year NSF EPSCoR grant, integrated teams of scientists and students explore mountain front hydrology, merging science across many disciplines – biogeophysics, critical zone processes, isotope tracers, forest disturbance processes, hydrogeology, and ecohydrology, to name a few (Fig. 2).

Biophysical techniques are employed to study the effects of mortality by insects and disease evapotranspiration and snowmelt processes. Tracing snowmelt through the critical zone provides new insights into subsurface flow and the contributions of snowmelt to groundwater recharge and streamflow. Isotope tracer studies using small bore wells promise to improve understanding of bedrock weathering and geochemical interaction during near surface flow. Electrical resistivity measurements reveal patterns of impaired flow in trees stressed by beetle kill. Airborne electromagnetic surveys across the western slope of the Snowy Mountains indicate potentially critical locations for surface water – groundwater interaction and deep flow pathways (Fig.3).

Funded research opportunities are available at the Masters and PhD level. To learn more about these programs or WyCEHG in general, check out our website at: <http://www.uwyo.edu/epscor/wycehg/>.

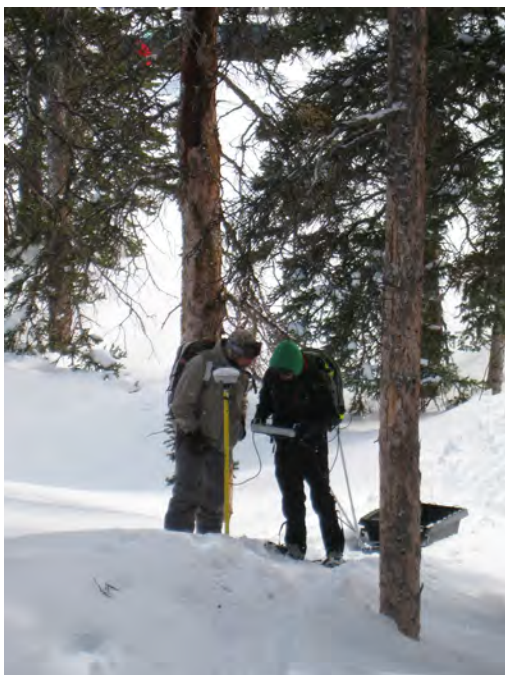


Figure 1. The geophysics team adjusts GPR settings during a snow survey in the Snowy Mountains of Wyoming. Similar surveys were conducted this winter over large areas by mounting a GPR and GPS equipment to a snowmobile. Photo: Kevin Hyde



Figure 2. Scott Peckham (left) and Kevin Hyde (right) rig a sub-canopy eddy-covariance tower in Chimney Park, Snowy Mountains, Wyoming. The experiments monitor evapotranspiration response to the pine bark beetle outbreak. Photo: Elise Pendell



Figure 3. Brad Carr monitors subsurface changes in electrical conductivity as a salt tracer moves through the hyporheic zone of a small mountain stream. Photo: Kevin Hyde



Douglas fir (*Pseudotsuga menziesii*) in the Grove of the Patriarchs, Mt. Rainier National Park, with Hicke youngsters, Laurel (R) and Ava (L), for scale. Photo: Jeff Hicke

Preliminary Analysis of the Role of Lake Basin Morphology on the Modern Diatom Flora in the Ruby Mountains and East Humboldt Range, Nevada, USA

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As paleolimnologists, we often look at the world through a 5-cm-diameter hole in the bottom of a lake, and although a number of studies have shown that a single core in the deepest part of a lake does not necessarily reflect the entire diatom flora, time and money often limit our ability to collect more than one core from a given site. This preliminary study is part of a multidisciplinary research project to understand Holocene climate variability in alpine regions of the Great Basin, and ultimately, to compare these high elevation records to the better studied pluvial records from adjacent valleys, in this case, the Ruby Valley.

The Ruby Mountains and smaller East Humboldt Range (RM-EHR; Fig. 1) to the north are often referred to as America's Swiss Alps. The Ruby Mountains are the most prominent mountain range in northeastern Nevada. From Secret Pass, they run south-southwest for about 130 km; at the widest point they extend 18 km. Ruby Dome, the highest point at 3471 masl lies to the north-northwest of the study lakes. The East Humboldt Range trends north about 48 km from Secret Pass; at 3446 masl, Hole in the Mountain Peak is the highest point in the range.

Two episodes of Pleistocene glaciation have been identified in the RM-EHR. Osborn and Bevis (2001) have estimated that the Lamoille-age (=Illinoian) glacier extended about 19 km down U-shaped Lamoille Canyon, making it the longest glacier in the Great Basin; Angel Lake (=Wisconsin) glacier formed later and was about half as long. Cirques are found at the heads of many of the valleys in both ranges. Wayne (1984) identified about 50 cirques in the central part of the Ruby Mountains. Some valleys contain cirque moraines located several kilometers above the Angel Lake terminal moraines, some of which are considered to be of Neoglacial age (Osborn and Bevis 2001). The study lakes are located in cirques, bounded to some extent by morainal deposits. The depth of the cirque carved in bedrock and the thickness of the overlying till and morainal deposits affects the hydrology of these lakes.

The climate of northeastern Nevada is dominated by winter moisture delivered by Pacific frontal storms (Houghton 1975). Even in years that exhibit strong Southwest Monsoon Index (Mock 1996) convective summer precipitation contributes <10% of annual moisture (Knapp 1997).

In an analysis of potential and actual precipitation, Shinker (2010) and Shinker and Bartlein (2010) showed that there is some variability in the magnitude and timing of precipitation in the RM-EHR when compared to the surrounding region. Ellis and Barton (2012) have shown that the position of the winter jet stream is a more significant factor in the amount of precipitation than its strength. They also showed that the El Niño-Southern Oscillation has little impact on the amount of precipitation that falls in the region. The RM-EHR lie near the fulcrum of a precipitation dipole (Wise 2010), which can bring great variations in the abundance of winter precipitation, sometimes 25% of normal in one year and 400% the next. The 30-year normal PRISM data (www.prism.oregonstate.edu; accessed 4/1/14; Fig. 2) show that owing to their size and location, the RM-EHR receive more moisture per year than most of the mountain ranges in the Great Basin, which is a significant factor in the abundance and longevity of lacustrine records in the ranges.

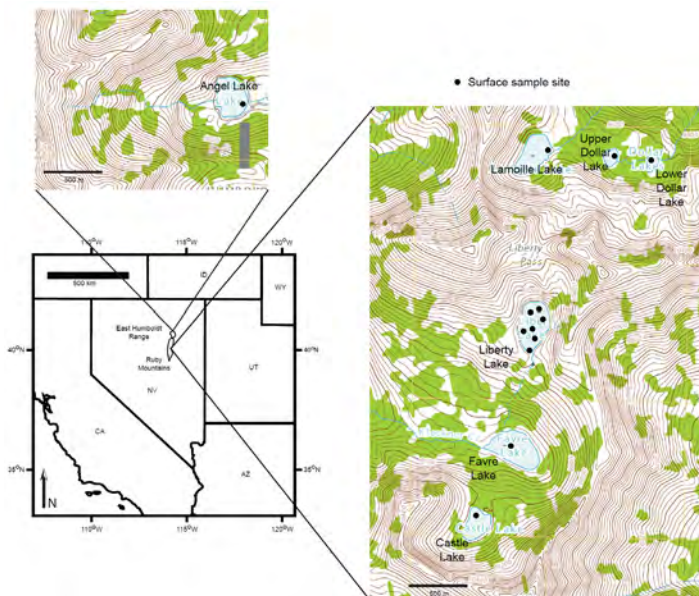


Figure 1. Location of Ruby Mountains and East Humboldt Range in NE Nevada, and the location of the study lakes and surface sampling sites.

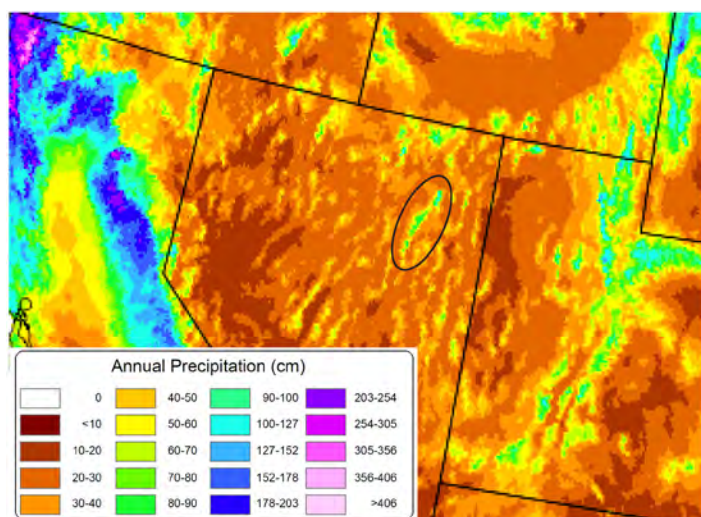


Figure 2. Annual precipitation (30-year normal [1981-2010], 4 km resolution) showing that northeastern Nevada receives greater amounts of annual precipitation than much of the Great Basin. (www.prism.oregonstate.edu ; accessed 4/1/14)

Diatoms (Division Bacillariophyta) are one of the most useful tools for characterizing modern aquatic conditions in alpine lacustrine systems, and the preservation potential of the siliceous frustule (shell) makes diatoms a useful proxy for paleoclimate reconstructions. They are sensitive to conditions affected directly by climate including water and air temperature, which affect photosynthesis and growth rates, lake level, and ice cover. Chemical variables are indirectly affected by climate change such as nutrient load, pH, and ionic concentration.

The lake levels and water chemistry in the RM-EHR are controlled by a number of factors other than the precipitation and evaporation rates. Significant among these are the shape of the lake basin and ice cover. The lakes sampled in this study (2555-3060 masl) have a number of basin forms. These vary from uniformly shallow (~1 m; Lower and Upper Dollar Lakes) through a deep depocenter (~12 m) surrounded by a wide shallow shelf (Favre Lake) to those with a deep depocenter (~28 m) and a relatively small shallow shelf (Liberty Lake; Fig. 3).

The bathymetry of a lake is important for two reasons, both of which are related to the amount of habitat available for colonization by benthic diatoms. The first is the response to seasonal variations in lake level. Under conditions common across the Great Basin, shallow lakes without a consistent source of moisture will become desiccated, sometimes on an annual basis, resulting in an incomplete record. Lakes with a wide, shallow shelf may, during periods of decreased moisture, only have water in the deepest part of the lake, resulting in a diatom flora that under-represents the littoral component of the flora. The

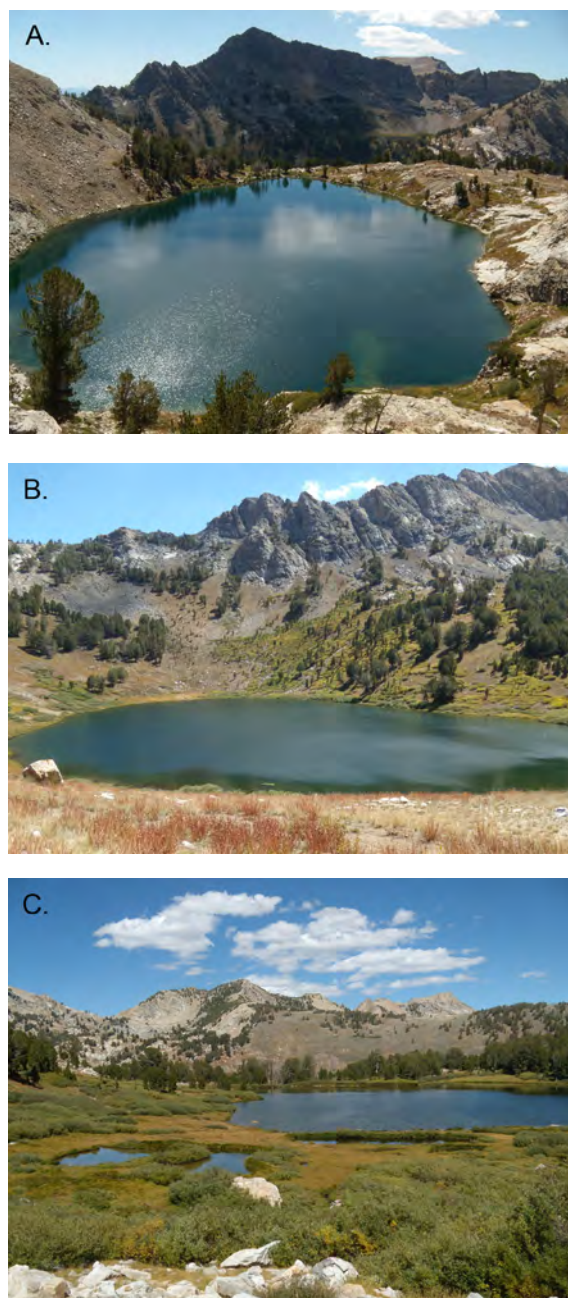


Figure 3. Lakes cored in the Ruby Mountains, A) Liberty Lake, B) Favre Lake, C) Castle Lake. Photos: Connie Millar

diatom assemblage in a deep lake with only a limited shallow margin may show little change in response to the lower lake level.

The thickness and extent, as well opacity of the ice, affects the transmission of light, and therefore the amount of light available to planktonic and benthic diatom communities. The thickness and duration of ice cover are controlled by a number of factors including the depth and extent of the shallow margin of the

lake. The fall timing of ice formation is partially controlled by thermal feedback from underlying sediments and the resulting convectional transport of water. The presence of a shallow shelf enhances the thermal feedback and delays the development of an ice cover. Melting in the spring is first driven by insolation, snow cover, and ice color. Once the ice around the margin begins to melt, thermal feedback from the shallow margin increases the rate of melting. Depending on the local conditions (warm cloudless spring vs. cool cloudy spring) the ice may completely melt, partially melt, leaving the deeper part of the lake covered, or melt only enough to leave a small ring around the lake ice free. The result is that lakes that are only tens of meters apart can have ice cover that differs in duration by days or weeks.

Ultimately, the extent and duration of ice cover affects the abundance of diatoms and the environments in which they grow (Smol 1988). With a warmer summer and a longer ice-free growing season, productivity is higher and a more diverse community develops. Substrates (aquatic macrophytes) that are unavailable during colder periods develop secondary and tertiary attached diatom floras, including those that can be attached to other diatoms. Warmer temperatures tend to produce higher influxes of snowmelt-derived nutrients early in the season rather than slowly release nutrients into the lake over an extended period. During colder periods, those nutrients may only reach the open water along the margin of the lake.

The diatom flora that characterizes the study lakes is typical of shallow, cool, slightly alkaline, oligotrophic, seasonally ice-covered lakes (Fig. 4; Table 1). This is supported by measurements made in Favre and Liberty Lakes at the time of sediment collection. Small fragilarioid diatoms (*Pseudostaurosira*, *Staurosira*, and *Staurosirella*) and *Fragilaria* dominate the assemblage in all the lakes. This group forms mats in the shallow littoral zone which break apart and float into deeper water. The abundance of this group is controlled by the extent of the littoral zone. Although there is a connection between the size of the littoral zone and the abundance of

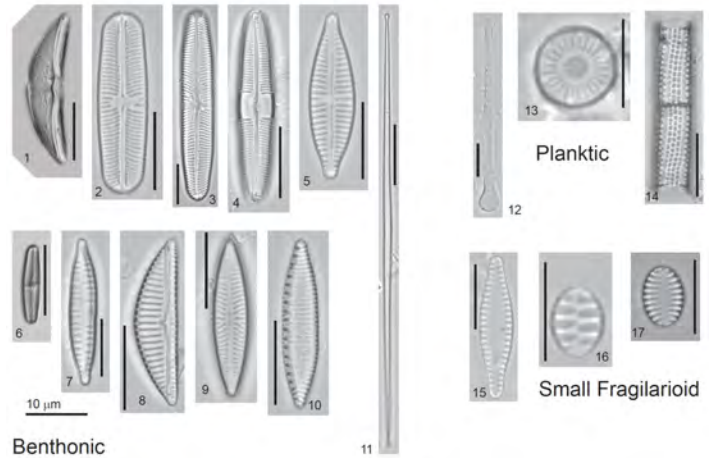


Figure 4. Examples of diatoms commonly found in the surface sediments collected from the seven study lakes. Benthonic: 1) *Amphora libyca*, 2) *Sellaphora pupula*, 3) *Pinnularia microstauron*, 4) *Caloneis bacillum*, 5) *Gomphonema parvulum*, 6) *Achnanthisidium minutissimum*, 7) *Fragilaria vaucheriae*, 8) *Encyonema minutum*, 9) *Navicula cryptotella* var. *veneta*, 10) *Nitzschia amphibia*, and 11) *Fragilaria tenera*; planktic: 12) *Asterionella formosa*, 13) *Discostella pseudostelligera*, and 14) *Aulacoseira granulata*; small fragilarioid: 15) *Pseudostaurosira brevistriata*, 16) *Staurosirella pinnata*, and 17) *Staurosira consturens* var. *venter*. Scale bars are 10 µm.

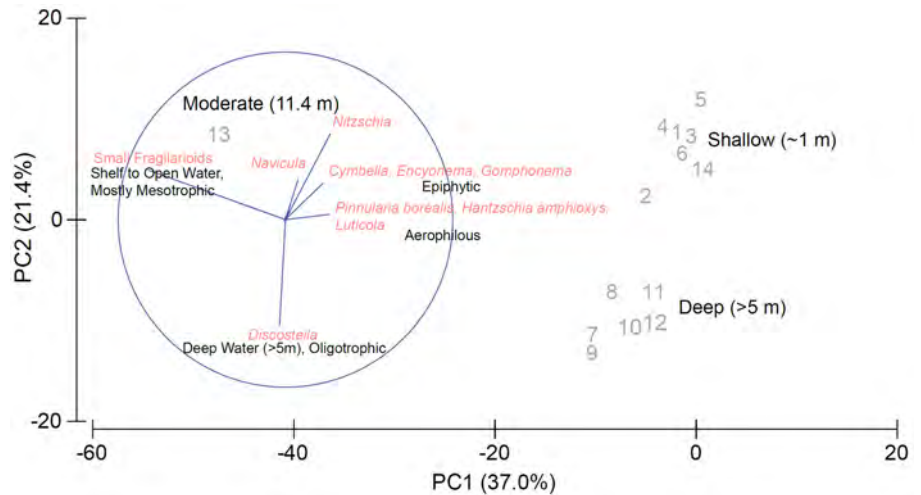
small fragilarioids, even a small littoral zone can produce fragilarioids that will appear in sediments that collect in deeper parts of the lake. In general, the planktic and other benthonic taxa comprise a smaller part of the flora.

Principal Components Analysis (PCA; Fig. 5) was used to identify the most significant environmental factor(s) controlling the distribution of diatom taxa in the Ruby Mountain lakes and which genera and species were most strongly affected by those factors. The first two principal components account for 58.4 percent of the variability in the flora. The 14 samples cluster into three groups, each representing a bathymetric range or form. All

	ach-tot	amp-tot	ast-for	cyc-tot	cym-tot	enc-tot	fra-tot	gom-tot	nav-tot	nit-tot	pin-tot	pse-tot	stu-tot	str-tot
Upper Dollar	7.8	0.4	0.0	0.4	6.2	2.4	4.2	1.6	6.4	5.2	17.8	2.4	15.0	8.6
Lower Dollar	4.0	0.4	0.0	0.0	1.8	1.6	2.8	2.4	4.6	4.0	3.4	3.6	52.0	13.2
Lamoille Lake 2-X-07	20.2	1.6	0.0	0.0	0.2	4.8	7.6	0.4	13.0	12.8	0.4	13.6	13.0	7.0
Lamoille Lake 6-VIII-08	12.0	0.8	0.0	1.2	3.8	4.6	5.0	3.0	19.0	9.0	8.0	12.8	2.0	1.0
Castle Lake	6.4	0.6	0.0	0.0	4.6	10.6	1.8	1.8	8.6	15.0	3.6	0.2	28.6	9.0
Liberty Lake shore	5.2	0.0	0.0	14.8	7.2	10.8	5.8	0.6	9.0	24.4	2.4	5.2	3.0	1.0
Liberty Lake LL1	3.4	1.6	0.2	15.0	0.2	0.8	8.0	0.2	2.2	0.8	0.2	2.2	23.6	34.8
Liberty Lake LL2	5.6	2.8	0.0	7.8	0.2	0.2	9.0	0.0	4.8	0.6	0.2	17.4	15.4	26.2
Liberty Lake LL3	3.0	1.2	0.0	17.0	0.0	0.8	11.2	0.0	2.6	0.6	0.4	7.8	20.4	28.8
Liberty Lake LL4	11.0	5.8	0.8	17.0	1.0	1.0	6.4	1.6	5.8	2.4	0.0	3.4	9.0	24.6
Liberty Lake LL5	19.2	3.2	0.0	11.6	0.6	4.0	4.6	0.2	5.8	0.4	0.0	3.2	10.6	25.0
Liberty Lake LL6	15.2	4.0	1.0	15.8	0.2	1.4	10.0	0.2	9.8	0.8	0.2	5.2	7.4	18.2
Favre Lake	1.2	1.2	1.0	4.6	3.4	2.8	11.0	0.0	0.8	0.0	0.2	4.2	15.0	40.2
Angel Lake	20.6	5.8	7.2	0.0	2.6	4.0	17.6	0.2	6.8	11.0	0.0	0.8	16.2	2.8

Table 1. Diatom percent abundance of total assemblage tabulated by genera (except *Asterionella formosa*). The cyc-tot includes *Discostella*. Five most abundant genera highlighted.

Figure 5. First two principal components separating lakes by depth of surface sample, dominant diatom genera and environmental preferences. Numbers in gray correspond to sampling sites: 1) Upper Dollar Lake; 2) Lower Dollar Lake; 3) Lamoille Lake 2-X-07; 4) Lamoille Lake 6-VIII-08; 5) Castle Lake; 6) Liberty Lake Shore; 7-12) Liberty Lake LL1-LL2; 13) Favre Lake; and 14) Angel Lake.



samples (Angel, Castle, Favre, Lamoille, Liberty, Lower Dollar, and Upper Dollar Lakes; eight samples) collected in ~1 m deep water cluster together. All the samples collected in more than 15 m of water were collected in Liberty Lake during the bathymetric survey form a second cluster. A core was collected from the deep central basin of Favre Lake (11.4 m) for paleoenvironmental analysis. The sample from the top of the core comprises the third cluster identified by the first and second principal components.

The PCA also identified three diatom assemblages. The deep water assemblage is dominated by *Discostella pseudostelligera* and *D. stelligera*, which are common in deep (>5 m) oligotrophic subalpine, alpine, and boreal lakes (Rühland et al. 2003; Starratt 2012; Starratt and Anderson 2013). A number of genera comprise the shallow assemblage including those that are attached to aquatic macrophytes (epiphytes; *Cymbella*, *Encyonema*, and *Gomphonema*), aerophilous species (*Hantzschia amphioxys*, *Luticola* sp., and *Pinnularia borealis*), and taxa that occupy a number of niches (*Navicula*, *Nitzschia*) (Sickman et al. 2013; Starratt 2012; Starratt and Anderson 2013). The sample collected from the deep center of Favre Lake (11.4 m) is dominated by small fragilarioid species (*Pseudostaurosira brevistriata*, *Staurosira construens* and varieties, *Staurosirella lapponica*, and *S. pinnata*) (Fig. 6). This assemblage is typical of small alpine (Reinemann et al., 2009) and shallow arctic lakes (Finkelstein and Gajewski 2007; 2008).

The simplest measure of diversity is the number species in a lake. In small lakes, species number is greater in shallow lakes with more ecological niche space in the photic zone. Diversity and equitability decrease with increasing nutrient load. The Shannon index quantifies both the number of species present in each lake, as well as how equally those species are distributed. Species diversity in the RM-EHR lakes varies from 53 to 102, the Shannon index (log10) from 1.2380 to 1.7270, and equitability

between 0.688 and 0.866. In general, the shallow lakes (Castle, Lamoille, Liberty (shoreline), and Upper Dollar Lakes) in the Ruby Mountains exhibit greater diversity, higher Shannon index values, and greater equitability. This is probably due to the larger number of ecological niches (rocks, sediment, macrophytes) available for colonization. Most of the deep water sites in Liberty Lake have low values for all three parameters, reflecting the dominance of the assemblage by a few species. The results from Angel and Lower Dollar Lakes are difficult to explain. Angel Lake values are the mean for all three parameters, while Lower Dollar Lake has a number of species similar to that found in deep water samples from Liberty Lake. The low value for the Shannon index and equitability is the result of the dominance of the assemblage by *Staurosira* spp. The abundance of *Staurosira* and *Staurosirella* are responsible for the low values in the Favre Lake sample.



Figure 6. Wrapping sediment cores. Photo: Elmira Wang

Research in British Columbia has shown that changes in subalpine lakes considered to be responses to climate change are not reflected in the regional pollen records (Bennett et al. 2001; Cumming et al. 2002; Karst-Riddoch et al. 2005). This suggests that the record of climate change across the Great Basin derived from pollen records may not provide an accurate indication of alpine lake response to changes in temperature and precipitation. In order to better understand the effect of climate variability on subalpine lakes in the region using diatoms as a proxy, it is necessary to start with an understanding of the variability in diatom assemblages in modern settings. The lack of comparable sites in the Great Basin makes it difficult to determine if the lakes in the RM-EHR are a reflection of local conditions, such as basin geology or bathymetry, or are an indication of regional conditions. The only similar diatom record in the central Great Basin is from Stella Lake (3170 m; 2.05 m deep) in Great Basin National Park in the Snake Range of eastern Nevada (Reinemann et al. 2009). Like the lakes in the RM-EHR, the modern diatom flora at Stella Lake is dominated by small fragilarioid species (*Staurosira*, *Staurosirella*, and *Pseudostaurosira*) indicating similar conditions of temperature, pH, nutrient load, and ice cover. The diatom record, in conjunction with chironomid and loss-on-ignition data, was used to create a ~7000 year record of environmental variability. Diatom diversity suggests warmer conditions prior to about 6250 years ago. Although the mean July air temperature values determined from the chironomid fauna show an increase in this interval, these are not the highest temperatures during the Holocene. The diatom diversity remained relatively stable throughout the remainder of the record.

Diatoms are valuable tools in identifying the effects of climate variability on aquatic ecosystems. Unlike pollen, which provides a regional record of climate variability, diatoms reflect a combination of lacustrine characteristics which are not directly related to changes in climate, or may alter the response to those changes. The RM-EHR lakes analyzed in this study were chosen to test the role of bathymetry on the flora of small alpine lakes. The analyses show that the amount of shallow habitat available for colonization has a significant impact on diversity by controlling the number of niches available for colonization and the impact of ice cover. The results also show that the analysis of multiple cores from each lake provides a more accurate record of the effects of climate variability on alpine ecosystems.

Acknowledgements

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American pikas (*Ochotona princeps*) are residents of the talus slopes surrounding the lakes of the Ruby Mountains. Photo: Scott Starratt

BREVIA

Burn Severity and Severity Patterns in the Northern Cascade Range, Washington

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Cansler, C. A., D. McKenzie. 2014. Climate, fire size and biophysical setting influence severity and spatial pattern of wildfires in the northern Cascade Range, Washington, USA. *Ecological Applications*. In press. DOI: 10.1890/13-1077.1

Changes in disturbance regimes will be an important driver of changes in vegetation under climate change. We know that warm and dry climate is positively correlated with annual area burned (Heyerdahl et al. 2008; Littell et al. 2009; Abatzoglou and Kolden 2013), but we do not know how increased area burned translates to changes in the ecological effects of fire. Increased area burned by wildfires could potentially move vegetation structure and pattern closer to that of pre-Euroamerican settlement, counteracting the undesirable impacts of fire suppression (Larson et al. 2013). If a warmer climate changes the way fires burn—with higher severity and larger more contiguous patches of severity—then the ecological effects of fires and associated ecosystem processes and functions will be altered predictably.

Increased availability of satellite data and developments of methods of processing these data have improved our ability to quantify the ecological impacts of fires. Our research uses one remotely sensed index of burn severity, the Relative differenced Normalized Burn Ratio (RdNBR; Miller and Thode 2007), to examine the relationships between climate, fire size, and the spatial pattern of burn severity. We developed a fire atlas of all fires >10 ha that occurred in the northern Cascade Range of Washington State from 1984–2008. With the assistance of experts at the Monitoring Trends in Burn Severity program (Eidenshink et al. 2007), we created burn severity images for all 125 fires in the dataset, and classified those images into four severity class (no change, low, moderate, and high) based on a previous analysis of field data from the study area (Cansler and McKenzie; Fig. 1).

We expected to see a positive relationship between fire size and (1) fire severity, and (2) spatial continuity of the high-severity areas within fires. Long-term drought stress predisposes fuels to burning and causes fuels to be more spatially connected

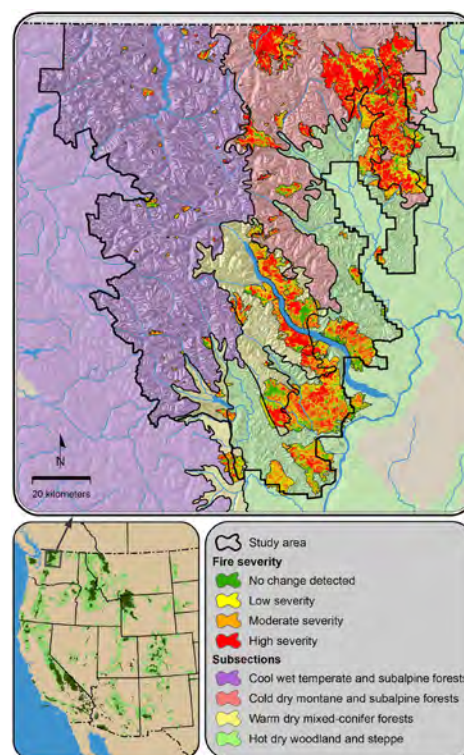


Figure 1. Map shows classified burn severity images for the 125 fires included in the study that burned from 1984–2008 on federally managed land in the northern Cascade Range, overlaying the four ecological subsection used in this study. Subsections had differing climate, vegetation, and topographical complexity, which we used to examine differences in the relationships between climate drivers, fire size distributions, burn severity and the spatial pattern of severity within fires. The climate was cool and wet, and the topography had the highest complexity in the Cool Wet Temperate and Subalpine Forests (“cool wet”); The Cool Dry Montane and Subalpine Forests (“cool dry”) had the coldest temperatures but also a dry summer season, and low topographical complexity. The Warm Dry Mixed-Conifer Forests (“warm dry”) was intermediate in climate, vegetation, and topographic complexity compared to other subsections. The Hot Dry Woodland and Steppe (“hot dry”) had the highest temperatures and lowest precipitation, and a heterogeneous mix of forest, woodlands, and shrub-steppe at lower elevations. The insert reference map shows the location of the study area in northern Washington State, USA, adjacent to the US-Canada border. Federal lands are shown in green, and lands in protected status (national parks, federally designated wilderness areas) are shown in dark green.

across the landscape. Likewise, short-term weather, such as high winds associated with thunderstorms and the passage of cold fronts, causes extreme fire behaviour, allowing high-intensity fire to pre-heat fuels ahead of the main flame front and loft fire brands over barriers to the spread of surface fires. During climate and weather that are conducive to large fire spread, there are weaker relationships between fire severity and local variation in topography and fuels (Turner and Romme 1994; Bessie and Johnson 1995).

The threshold at which fire spread is no longer limited by fuels and topography depends upon the characteristic intensity of the fire regime and the spatial variability of the local topographic and fuels (Kellogg et al. 2008; Kennedy and McKenzie 2010; McKenzie and Kennedy 2012). Thus, in biophysical settings where topography and fuels have lower spatial variability we would expect to find more synchronous fire occurrence across the landscape, larger fires, and larger contiguous patches of high severity (Fig. 2). To examine how the biophysical setting influences the relationships between climate, fire size, burn severity, and burn-severity pattern, we divided our study area up into four ecological “subsections” (Fig. 1, based on ECOMAP 2007). The subsections have differing climate, vegetation, fire regimes, and levels of topographical complexity.

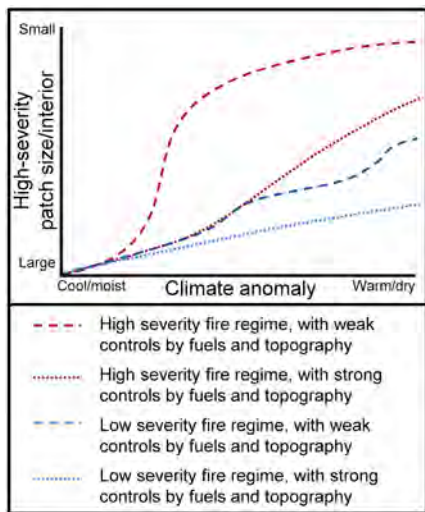


Figure 2. Theorized relationships between climate (x-axis) and the spatial heterogeneity of high severity within fires (here patch size or patch interior (y-axis)). The lines represent the aggregate properties of multiple fires over time, as opposed to individual events, for given combinations of fire regime types (e.g. high-severity or low-severity) and the strength of endogenous controls by fuels and topography. In high-severity fire regimes, this is reflected in sudden and marked increases in high-severity patches, while in lower-severity fire regimes, this may be reflected in simply a faster increase in high-severity patch size. In areas with weak local controls, we hypothesize that non-linear changes in fire regimes attributes are more likely.

We used regression to quantify the strength of the relationship between fire size and the severity and spatial pattern of areas that burned with high severity within each fire. We measured severity using two metrics, the “severity metric” (Lutz et al. 2011), which is highly correlated with the mean RdNBR values within a fire, and the proportion of area within each fire that burned at high severity. To measure the spatial pattern of the severity we quantified patch size, the size inequality of patches, patch interior, and spatial aggregation at the grain of the pixel (30 m) of high-severity areas within each fire using seven spatial pattern metrics (Table 1).

Table 1.

Spatial pattern metric	Pattern attribute it quantifies
Mean patch size	Patch size
Area-weighted mean patch size	Patch size
Gini coefficient	Patch size inequality
Proportion of core area	Patch interior
Total core area	Patch interior
Proportion of like adjacencies	Spatial aggregation at the scale of the pixel
Clumpiness index	Spatial aggregation at the scale of the pixel

Twenty-two percent (or 316,567 ha) of our 1,445,500 ha study area burned during our 25-year study period. We found a positive relationship between July temperature and annual mean fire size and negative relationships between July-August precipitation and annual mean fire size. The severity metric and the proportion of area burned at high severity significantly increased with fire size in our study area ($P \leq 0.001$, $R^2 = 0.23$ and 0.22 , respectively). We also found significant positive relationships between fire size and the size, size inequality, and interior area of high-severity patches ($P \leq 0.001$, R^2 s ranged from 0.09 to 0.61, depending on the spatial pattern metric used). Despite these significant relationships, large fires had both desirable and undesirable ecological effects. Within large fires, there were substantial areas where the effects of the fire likely restored spatial heterogeneity by burning with lower (moderate, low, unburned) severity and creating a heterogeneous pattern of small high-severity patches. Large fires also created very large patches of high severity, however, with a higher proportion of their area at distances >100 m from lower severity classes (Fig. 3).

The observed spatial patterns of high severity conformed to our theoretical model presented in Figure 2 (Figs. 4, 5). The cool dry forests in the northeastern part of our study area, which have weak topographical controls and more contiguous fuels, showed the steepest slopes in regression that predicted the proportion of area that burned at high severity, high-severity patch size,

Figure 3. Pictures show burned areas that are indicative of the fire regimes in each of our three subsections. Top left: The 168 ha Mt. Redoubt fire (1997) in the cool wet subsection, where fires were usually small in size, with small patch sizes. Top right: The 70,753 ha Tripod fire (2006) with the Thunder fire (1994) in the background, in the cool dry subsection, where fires were larger in size, high severity patch sizes increase rapidly with fire size. Bottom left: the 2,626 ha Butte Creek fire (1994) in the warm dry subsection, which burned with a patchy mix of severity. Bottom right: the 6,555 ha Fischer fire (2004) in the hot dry subsection; despite the relatively un-complex topography, high-severity patch size and patch interior did not increase as rapidly in this subsection as the others, likely reflecting less connected fuels. Photos: Alina Cansler, between 2009-2012.



and high-severity patch interior based on fire size. Conversely, the cool wet forest on the western side of our study area, where fires were smaller and there are many topographical barriers to fire spread, had the weakest relationships between fire size and high-severity patch size and patch interior. The warm dry forests, with intermediate climate and topography, had stronger relationships than the cold wet forests to the west, and weaker relationships than the cold dry forests to the northeast. The hot dry woodlands on the eastern edge of our study area had relatively uncomplicated topography, but had a relatively weak relationship between fire size and high-severity patch size, likely reflecting fine-scale heterogeneity of fuels.

For the PNW, regional models predict that future climate will be warmer, with increased intensity and duration of the summer dry season (Mote and Salathé 2010). Thus, if the statistical relationships we observed persist under future climates, future landscapes will have more large even-aged patches, created by high-severity fire. We expect that the changes in the landscape pattern with climate change will be most pronounced in regions with high-severity fire regimes, less complex topography, and connected fuel. Regions with barriers to fire spread or heterogeneous fuels may be more resistant to climate-induced increases in fire size, severity, and high-severity patch size.

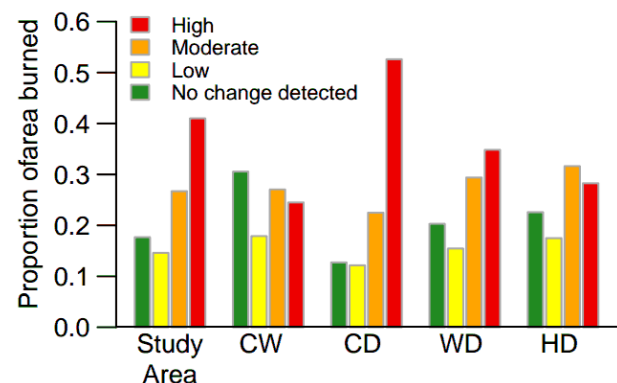


Figure 4. The proportion of area burned within each severity class for our study area as a whole, and within each of the four subsections within our larger study area. The cool wet forests (CW) generally burned with lower severity, and the cool dry (CD) forests with higher severity than the other subsections. The warm dry forests (WD) had less high severity than the similar montane and subalpine forests in the cool dry subsection. The hot dry woodlands (HD), which contain ponderosa pine and Douglas-fir forests though to have had low or mixed-severity fire regimes during the pre-settlement period, burned with the full range of fire severities during our study period.

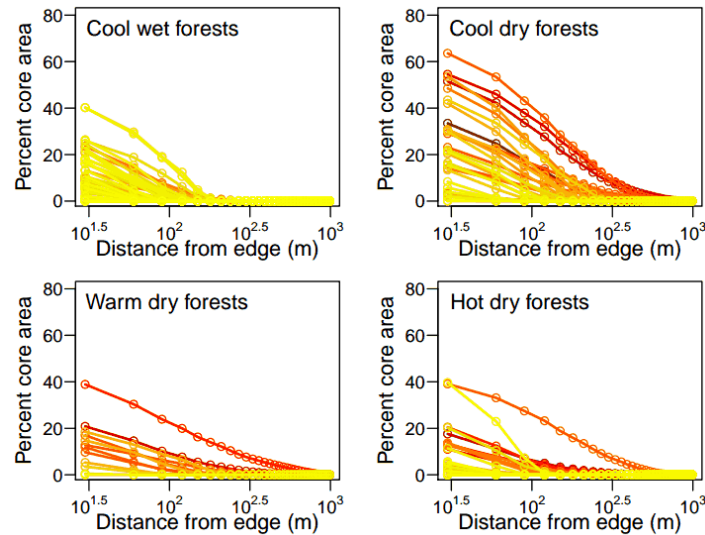


Figure 5. The percent of high-severity core area in each fire, when core area is defined by a specific distance from the edge of the patch (points shown here in 1 pixel/30 m increments). Lines represent individual fires colored according to the size of the fire, ranging from yellow, for fires $<10^2$, to dark red for fires $>10^4$. Separate plots show all fires within each subsection, as labeled.

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BREVIA

Rate of Tree Carbon Accumulation Increases Continuously with Tree Size

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Forests are major components of the global carbon cycle, providing substantial feedback to atmospheric greenhouse gas concentrations (Pan et al. 2011). Our ability to understand and predict changes in the forest carbon cycle—particularly net primary productivity and carbon storage—increasingly relies on models that represent biological processes across several scales of biological organization, from tree leaves to forest stands (Medvigy et al. 2009; Caspersen et al. 2011). Yet, despite advances in our understanding of productivity at the scales of leaves and stands, no consensus exists about the nature of productivity at the scale of the individual tree (Enquist et al. 1999; Kutsch 2009; Sillett et al. 2010; Meinzer et al. 2011), in part because we lack a broad empirical assessment of whether rates of absolute tree mass growth (and thus carbon accumulation) decrease, remain constant, or increase as trees increase in size and age.

A widely held assumption is that after an initial period of increasing growth, the mass growth rate of individual trees declines with increasing tree size (Carey et al. 2001; Weiner and Thomas 2001; Phillips et al. 2008; Kutsch 2009; Meinzer et al. 2011; Piper and Fajardo 2011). Although the results of a few single-species studies have been consistent with this assumption (Piper and Fajardo 2011), the bulk of evidence cited in support of declining growth is not based on measurements of individual tree mass growth. Instead, much of the cited evidence documents either the well-known age-related decline in net primary productivity (hereafter ‘productivity’) of even-aged forest stands (Ryan et al. 1997) or size-related declines in the

rate of mass gain per unit leaf area (or unit leaf mass) (Ryan et al. 1997; Mencuccini et al. 2005; Drake et al. 2010), with the implicit assumption that declines at these scales must also apply at the scale of the individual tree. Declining tree growth is also sometimes inferred from life-history theory to be a necessary corollary of increasing resource allocation to reproduction (Weiner and Thomas 2001; Thomas 2011). On the other hand, metabolic scaling theory predicts that mass growth rate should increase continuously with tree size (Enquist et al. 1999), and this prediction has also received empirical support from a few site-specific studies (Enquist et al. 1999; Sillett et al. 2010). Thus, we are confronted with two conflicting generalizations about the fundamental nature of tree growth, but lack a global assessment that would allow us to distinguish clearly between them.

To fill this gap, we conducted a global analysis in which we directly estimated mass growth rates from repeated measurements of 673,046 trees belonging to 403 tropical, subtropical and temperate tree species, spanning every forested continent. Tree growth rate was modelled as a function of log(tree mass) using piecewise regression, where the independent variable was divided into one to four bins.

We show that for most species mass growth rate increases continuously with tree size. Thus, large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees; at the extreme, a single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree. The apparent paradoxes of individual tree growth increasing with tree size despite declining leaf-level and stand-level productivity can be explained, respectively, by increases in a tree’s total leaf area that outpace declines in productivity per unit of leaf area and, among other factors, age-related reductions in population density.

For all continents, aboveground tree mass growth rates (and, hence, rates of carbon gain) for most species increased continuously with tree mass (size) (Fig. 1). The rate of mass gain increased with tree mass in each model bin for 87% of species, and increased in the bin that included the largest trees for 97%

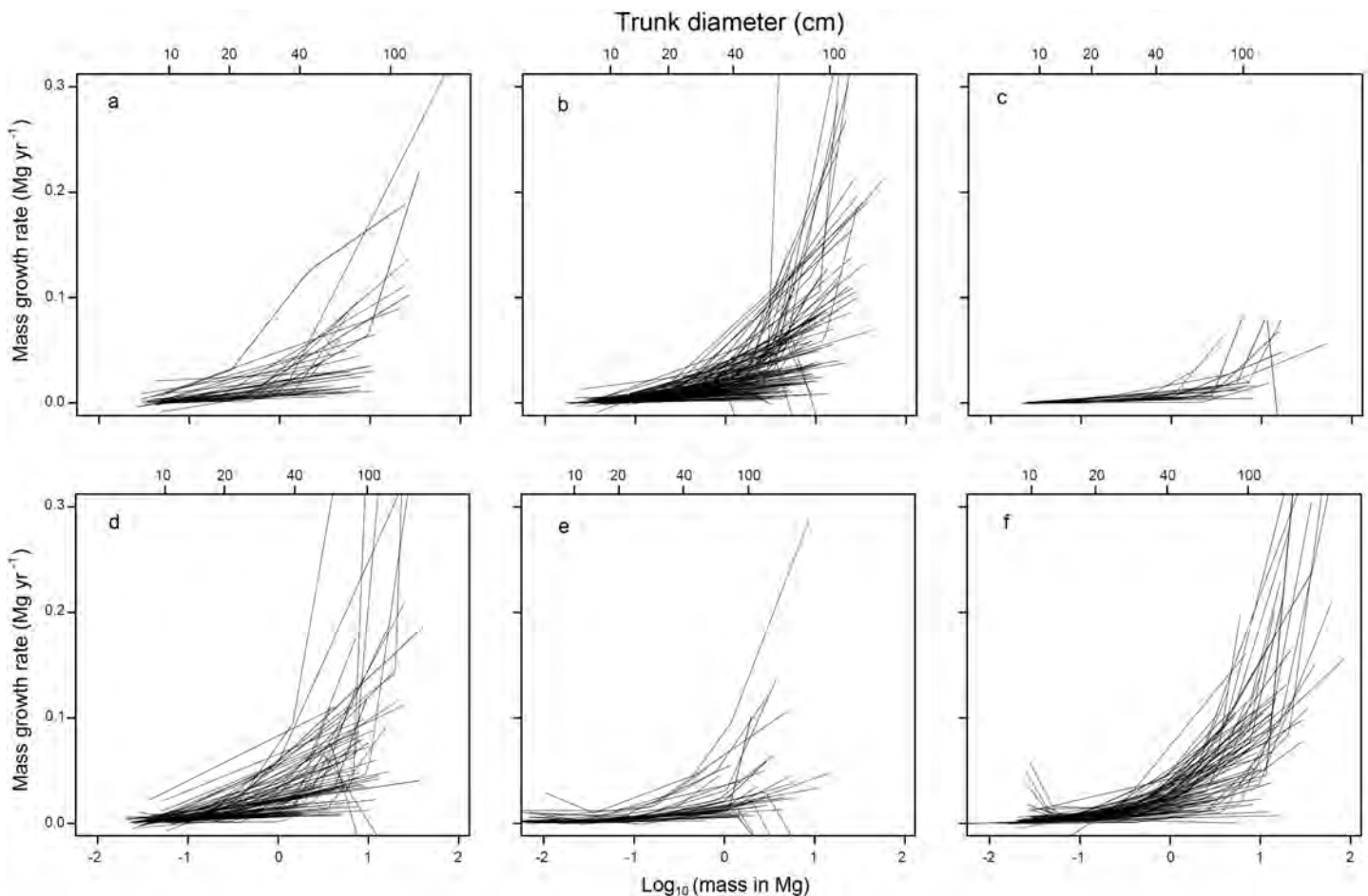


Figure 1. Aboveground mass growth rates for the 403 tree species, by continent. a, Africa (Cameroon, Democratic Republic of the Congo); b, Asia (China, Malaysia, Taiwan, Thailand); c, Australasia (New Zealand); d, Central and South America (Argentina, Colombia, Panama); e, Europe (Spain); and f, North America (USA). Numbers of trees, numbers of species and percentages with increasing growth are given in Table 1. Trunk diameters are approximate values for reference, based on the average diameters of trees of a given mass.

of species; the majority of increases were statistically significant (Table 1). Even when we restricted our analysis to species achieving the largest sizes (maximum trunk diameter, 100 cm; 33% of species), 94% had increasing mass growth rates in the bin that included the largest trees. We found no clear taxonomic or geographic patterns among the 3% of species with declining growth rates in their largest trees, although the small number of these species (thirteen) hampers inference.

In absolute terms, trees 100 cm in trunk diameter typically add from 10 kg to 200 kg of aboveground dry mass each year (depending on species), averaging 103 kg per year. This is nearly three times the rate for trees of the same species at 50 cm in diameter, and is the mass equivalent to adding an entirely new tree of 10–20 cm in diameter to the forest each year. Our findings further indicate that the extraordinary growth recently reported in an intensive study of large *Eucalyptus regnans* and *Sequoia*

sempervirens, which included some of the world's most massive individual trees, is not a phenomenon limited to a few unusual species. Rather, rapid growth in giant trees is the global norm, and can exceed 600 kg per year in the largest individuals (Fig. 2).

Our data set included many natural and unmanaged forests in which the growth of smaller trees was probably reduced by asymmetric competition with larger trees. To explore the effects of competition, we calculated mass growth rates for 41 North American and European species that had published equations for diameter growth rate in the absence of competition (Canham et al. 2006; Coates et al. 2009; Pretzsch and Biber 2010; Gomez-Aparicio et al. 2011; Das 2012). We found that, even in the absence of competition, 85% of the species had mass growth rates that increased continuously with tree size (Fig. 3), with growth curves closely resembling those in Fig. 1. Thus, our finding of increasing growth not only has broad generality across

Table 1. Percentages of species showing increasing mass growth rate in the largest trees (trees in the last bin fitted by the model).

Continent*	Number of trees	Number of species	% species with increasing mass growth rate in the largest trees (% significant at $P=0.05$)
Africa	15,366	37	100.0 (86.5)
Asia	43,690	136	96.3 (89.0)
Australasia	45,418	22	95.5 (95.5)
Central & South America	18,530	77	97.4 (92.2)
Europe	439,889	42	90.5 (78.6)
North America	110,153	89	98.9 (94.4)
Total	673,046	403	96.8 (89.8)

Note: The largest trees are those in the last bin fitted by the model. Countries are listed in the caption for Fig. 1.

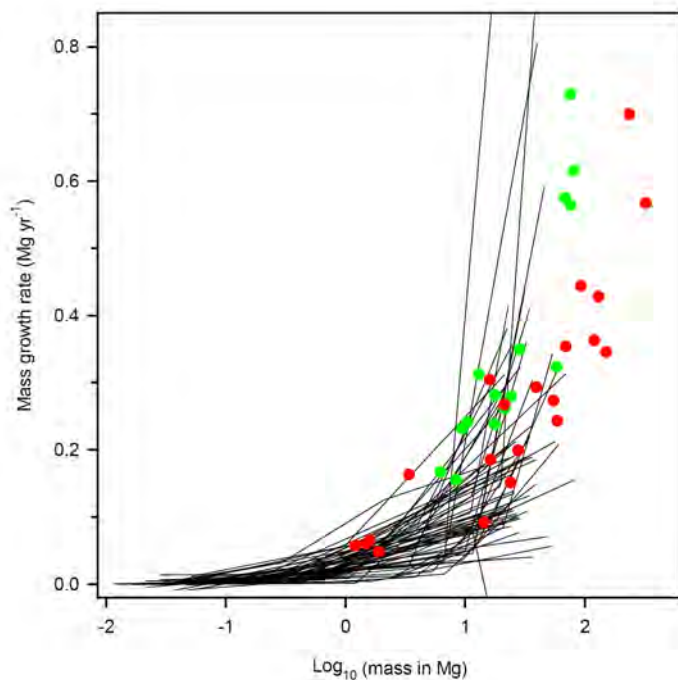


Figure 2. Aboveground mass growth rates of species in our data set compared with *E. regnans* and *S. sempervirens*. For clarity, only the 58 species in our data set having at least one tree exceeding 20 Mg are shown (lines). Data for *E. regnans* (green dots, 15 trees) and *S. sempervirens* (red dots, 21 trees) are from an intensive study that included some of the most massive individual trees on Earth7. Both axes are expanded relative to those of Fig. 1.

species, continents and forest biomes (tropical, subtropical and temperate), it appears to hold regardless of competitive environment (Fig. 4).

Our results resolve conflicting assumptions about the nature of tree growth, inform efforts to understand and model forest carbon dynamics, and have additional implications for theories of resource allocation and plant senescence. Importantly, our finding is compatible with the two classes of observations most often cited as evidence of declining, rather than increasing, individual tree growth: with increasing tree size and age, productivity usually declines at the scales of both tree organs (leaves) and tree populations (even-aged forest stands).

First, although growth efficiency (tree mass growth per unit leaf area or leaf mass) often declines with increasing tree size (Ryan et al. 1997; Mencuccini et al. 2005; Drake et al. 2010), empirical observations and metabolic scaling theory both indicate that, on average, total tree leaf mass increases as the square of trunk diameter (Niklas and Enquist 2002; Jenkins et al. 2004). A typical tree that experiences a tenfold increase in diameter will therefore undergo a roughly 100-fold increase in total leaf mass and a 50–100-fold increase in total leaf area depending on size-related increases in leaf mass per unit leaf area (Thomas 2010; Steppe et al. 2011). Parallel changes in growth efficiency can range from a modest increase, such as in stands where small trees are suppressed by large trees (Gilmore and Seymour 1996), to as much as a tenfold decline (Kaufmann and Ryan 1986), with most changes falling in between (Kaufmann and Ryan 1986; Mencuccini et al. 2005; Drake et al. 2010; Thomas 2010). At one extreme, the net effect of a low (50-fold) increase in leaf area combined with a large (tenfold) decline in growth efficiency would still yield a five-fold increase in individual tree mass growth rate; the opposite extreme would yield roughly a 100-fold increase. Our calculated 52-fold greater average mass growth rate

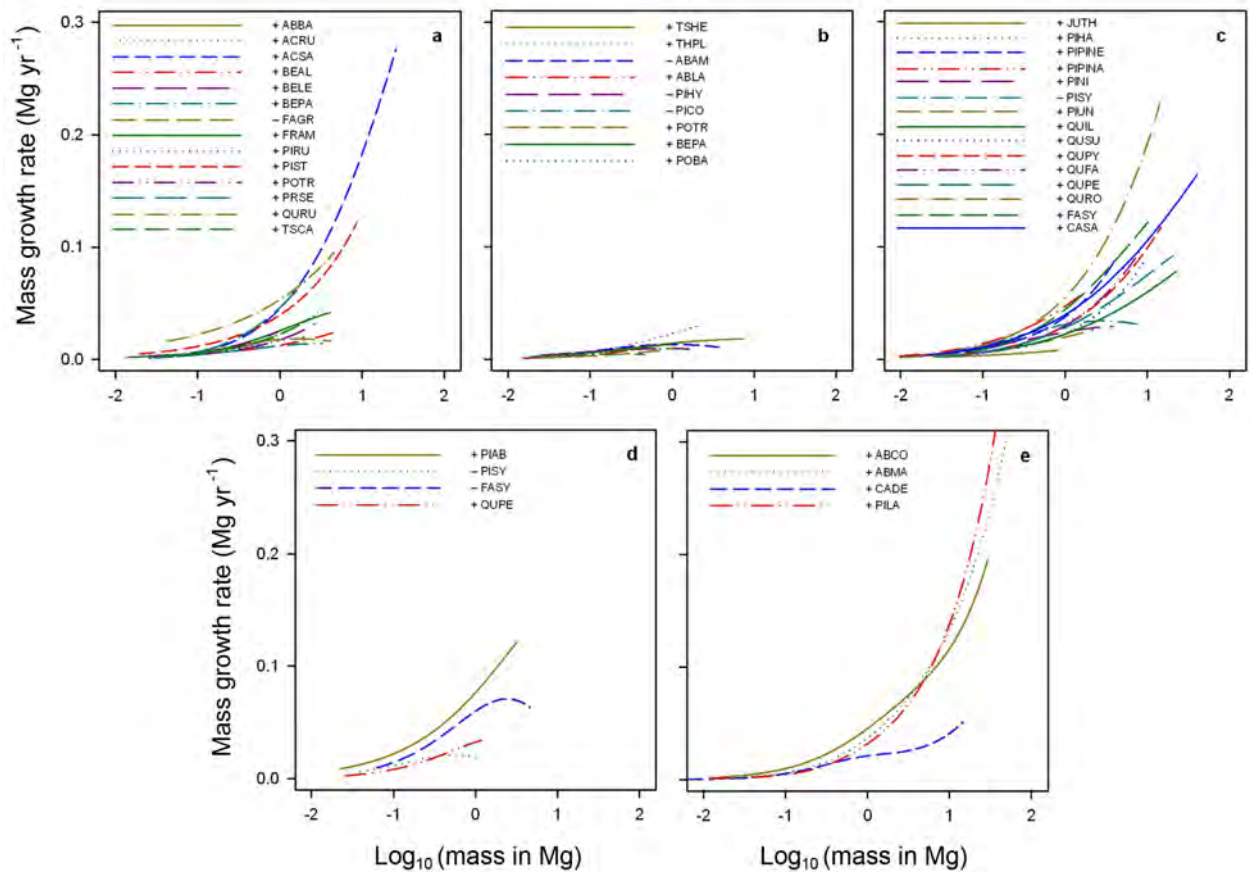


Figure 3. Aboveground mass growth rates for 41 tree species in the absence of competition. The '+' or '-' symbol preceding each species code indicates, respectively, species with mass growth rates that increased continuously with tree size or species with mass growth rates that declined in the largest trees. Sources of the diameter growth equations used to calculate mass growth were: a, Canham et al. (2006); b, Coates et al. (2009); c, Gomez-Aparicio et al. (2011); d, Pretzsch and Biber (2010); and e, Das (2012). ABAM, *Abies amabilis*; ABBA, *Abies balsamea*; ABCO, *Abies concolor*; ABLA, *Abies lasiocarpa*; ABMA, *Abies magnifica*; ACRU, *Acer rubrum*; ACSA, *Acer saccharum*; BEAL, *Betula alleghaniensis*; BELE, *Betula lenta*; BEPA, *Betula papyrifera*; CADE, *Calocedrus decurrens*; CASA, *Castanea sativa*; FAGR, *Fagus grandifolia*; FASY, *Fagus sylvatica*; FRAM, *Fraxinus americana*; JUTH, *Juniperus thurifera*; PIAB, *Picea abies*; PICO, *Pinus contorta*; PIHA, *Pinus halepensis*; PIHY, *Picea hybrid* (a complex of *Picea glauca*, *P. sitchensis* and *P. engelmannii*); PILA, *Pinus lambertiana*; PINI, *Pinus nigra*; PIPINA, *Pinus pinaster*; PIPINE, *Pinus pinea*; PIRU, *Picea rubens*; PIST, *Pinus strobus*; PISY, *Pinus sylvestris*; PIUN, *Pinus uncinata*; POBA, *Populus balsamifera* ssp. *trichocarpa*; POTR, *Populus tremuloides*; PRSE, *Prunus serotina*; QUFA, *Quercus faginea*; QUIL, *Quercus ilex*; QUPE, *Quercus petraea*; QUPY, *Quercus pyrenaica*; QURO, *Quercus robur*; QURU, *Quercus rubra*; QUSU, *Quercus suber*; THPL, *Thuja plicata*; TSCE, *Tsuga canadensis*; and TSHE, *Tsuga heterophylla*.

of trees 100 cm in diameter compared to those 10 cm in diameter falls within this range. Thus, although growth efficiency often declines with increasing tree size, increases in a tree's total leaf area are sufficient to overcome this decline and cause whole-tree carbon accumulation rate to increase.

Second, our findings are similarly compatible with the well-known age-related decline in productivity at the scale of even-aged forest stands. Although a review of mechanisms is beyond the scope of this paper (Ryan et al. 1997; Coomes et al. 2012), several factors, including the interplay of changing growth

efficiency and tree dominance hierarchies (Binkley 2004), can contribute to declining productivity at the stand scale. We highlight the fact that increasing individual tree growth rate does not automatically result in increasing stand productivity because tree mortality can drive orders-of-magnitude reductions in population density (Kashian et al. 2005; Pretzsch and Biber 2005). That is, even though the large trees in older, even-aged stands may be growing more rapidly, such stands have fewer trees. Tree population dynamics, especially mortality, can thus be a significant contributor to declining productivity at the scale of the forest stand (Coomes et al. 2012).



Figure 4. The world's biggest trees -- such as this large western white pine (*Pinus monticola*) in California's Sierra Nevada -- are also the world's fastest-growing trees, according to our analysis of 403 tree species spanning six continents. Photo: Rob Hayden

These results have several implications. For example, life-history theory often assumes that tradeoffs between plant growth and reproduction are substantial (Thomas 2011). Contrary to some expectations (Weiner and Thomas 2001; Thomas 2011), our results indicate that for most tree species size-related changes in reproductive allocation are insufficient to drive long-term declines in growth rates (Enquist et al. 1999). Additionally, declining growth is sometimes considered to be a defining feature of plant senescence (Thomas 2013). Our findings are thus relevant to understanding the nature and prevalence of senescence in the life history of perennial plants (Munné-Bosch 2008). Finally, our results are relevant to understanding and predicting forest feedbacks to the terrestrial carbon cycle and global climate system (Medvigy et al. 2009; Caspersen et al. 2011; Pan et al. 2011). These feedbacks will be influenced by the effects of climatic, land-use and other environmental changes on the size-specific growth rates and size structure of tree populations—effects that are already being observed in forests (Jump et al. 2006; Lindenmayer et al. 2012).

The rapid growth of large trees indicates that, relative to their numbers, they could play a disproportionately important role in these feedbacks (Enquist et al. 2009). For example, in our

western USA old-growth forest plots, trees 100cm in diameter comprised 6% of trees, yet contributed 33% of the annual forest mass growth. Mechanistic models of the forest carbon cycle will depend on accurate representation of productivity across several scales of biological organization, including calibration and validation against continuously increasing carbon accumulation rates at the scale of individual trees.

The study summarized here was a collaboration of 38 researchers from research universities, government agencies and non-governmental organizations from the United States, Panama, Australia, United Kingdom, Germany, Colombia, Argentina, Thailand, Cameroon, Democratic Republic of Congo, France, China, Taiwan, Malaysia, New Zealand and Spain. The study was initiated by Stephenson and Das through the USGS Western Mountain Initiative and the USGS John Wesley Powell Center for Analysis and Synthesis.

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BREVIA

Complex Interactions between Global Change Drivers Influence Mountain Forest and Alpine GHG Sequestration and Stream Chemistry

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Many mountain ecosystems are experiencing coincident increases in temperature, levels of atmospheric carbon dioxide (CO₂) and atmospheric nitrogen (N) deposition. All are important controls on rates of plant growth, soil microbial activity, nutrient cycling, and stream N export. It is difficult for experimental studies to explore ecosystem responses to more than one or two treatments at plot, let alone catchment, scale. One might expect, however, ecosystems to respond differently to the combined global change drivers than to climate, CO₂, or N alone. We explored this question for nine mountain catchments over the period 1980-2075 with a simulation model.

DayCent-Chem is a process-based ecosystem nutrient cycling model that simulates CO₂ fertilization effects while accounting for water, temperature, and nutrient N, phosphorus, and sulfur constraints on plant growth and soil organic matter cycling (Hartman et al. 2009; Hartman et al. 2007). We developed site-specific scenarios of climate (WARM and NO WARM, which



Figure 2. Louise Lake from Tatoosh, Rainier National Park: Photo: Rebecca A. Lofgren and Stefan Lofgren

was the site-specific observed weather from daily meteorological records with no temperature trend) and N deposition (LOW N and HIGH N) under two levels of CO₂ fertilization (LOW 600 ppm, and HIGH, 760 ppm) that are within predicted ranges for the period 2001-2075, and used them to explore changes in C allocations to above- and below-ground biomass and soil organic matter, NEP (net ecosystem production), net greenhouse gas (GHG) flux, nitrous oxide (N₂O) emissions, and stream nitrate (NO₃⁻) chemistry. The watersheds included four Long Term Ecological Research (LTER) sites (Hubbard Brook, Coweeta, Niwot Ridge and HJ Andrews old growth and younger stand) and four national parks (Acadia, Great Smoky Mountains, Rocky Mountain National Park, and Mt Rainier; Figs. 1, 2). All sites were forested except for alpine Niwot Ridge and Andrews Creek in Rocky Mountain National Park (Fig. 3). The sites differed from each other in their nutrient cycling rates and carbon storage ability due to site-specific elevation, climate, atmospheric N deposition, and site history.

We found no universal response among the forested and alpine sites to N deposition, warming, or their combinations (Fig. 4). DayCent-Chem simulations for forest and alpine sites revealed the importance of individual site characteristics, such as vegetation type and climate, and their history of N deposition



Figure 1. Acadia National Park. Photo: Melannie Hartman



Figure 3. Indian Peaks Wilderness, near Niwot Ridge LTER, illustrating subalpine and alpine environments similar to study stite. Photo: Melannie Hartman

in their response to global change. Initial conditions related to N availability and mean annual temperatures controlled the responses of the sites to N deposition and warming, respectively. Where initial N deposition was low, NEP and GHG sequestration were stimulated with the addition of N. Where mean annual temperatures were low, warming stimulated ecosystem processes. Warming and N deposition also acted synergistically to enhance NEP, N mineralization, and net GHG sequestration but only

at the cold forested sites (Hubbard Brook, Acadia, and Mount Rainier). All sites showed increased soil N_2O emissions (N_2O is a greenhouse gas) with warming and high N, and this reduced or even canceled the greenhouse gas reductions by soil C sequestration caused by N fertilization. There was no increase in net GHG sequestration in response to warming, N, or HIGH CO_2 at the alpine sites since increased respiration and N_2O emissions negated any increases in above- or belowground plant C accrual. LOW CO_2 fertilization increased aboveground biomass at the forested sites and alpine Niwot Ridge, but adding more CO_2 under the HIGH scenario had no additional effect.

Climate change and N deposition have ramifications beyond terrestrial C cycling. Our ecosystem model was developed in part to understand how changes in terrestrial C and N processes propagate downstream to aquatic ecosystems. Nitrate in upland waters contributes to nutrient enrichment and surface water acidification, and both these drive changes to aquatic ecosystem biodiversity, productivity, and water quality. The residual N from above- and belowground N uptake, and microbial N cycling, particularly mineralization, immobilization, and N gas emissions (N_2O , NO_x , and N_2), determine what gets flushed to surface waters (Aber et al. 1998). At sites with high initial N deposition, adding more N increased stream NO_3^- loss (Fig. 4).

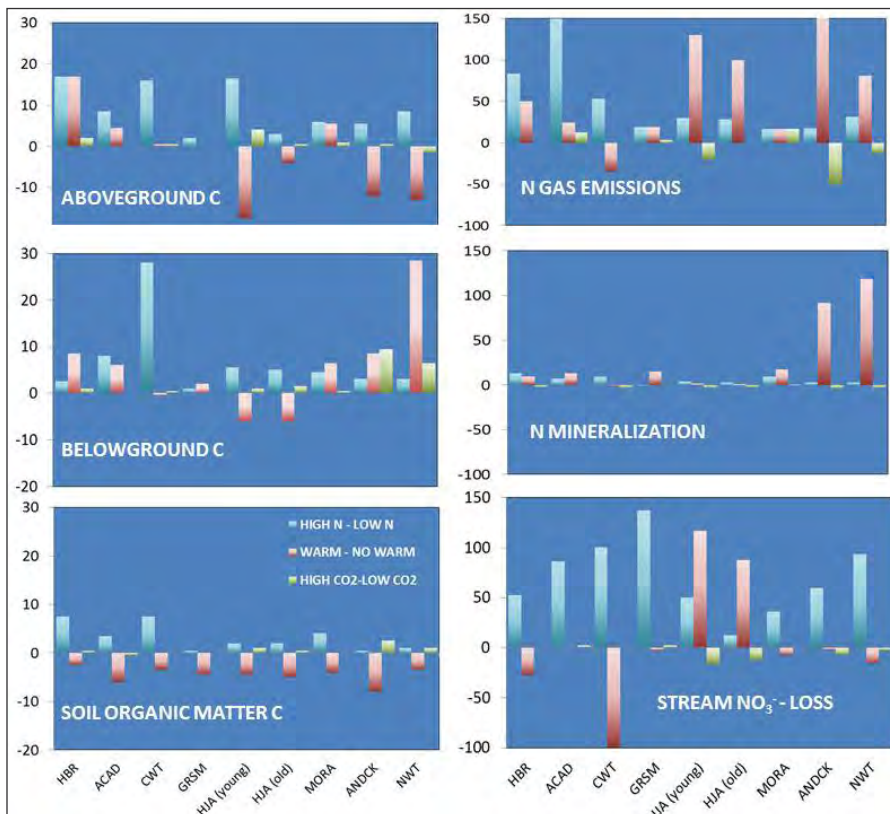


Figure 4. The mean difference in percent change from base conditions for the last ten years of simulations (2065-2075) between HIGH N and LOW N, WARM and NO WARM, and HIGH CO_2 and LOW CO_2 scenarios. a) above ground carbon; b) below ground carbon; c) soil organic matter carbon; d) Total N-gas (N_2O + NO_x + N_2) emissions; e) net N mineralization; f) stream nitrate fluxes. A negative value indicates a flux to the atmosphere or a loss from the ecosystem; a positive value indicates sequestration. Site abbreviations are as follows: HBR, Hubbard Brook LTER; ACAD, Acadia National Park; CWT, Coweeta Experimental Forest LTER; GRSM, Great Smoky Mountains National Park; HJA (young), HJ Andrews Experimental Forest LTER (75 year old stand); HJA (old), HJ Andrews Experimental Forest (old-growth stand); MORA, Mount Rainier National Park; ANDCK, Andrews Creek in Rocky Mountain National Park; NWT, Niwot Ridge LTER.

In conclusion, N deposition modestly strengthened terrestrial net GHG sequestration primarily by increasing C stored in wood biomass of montane forests by 9 – 20%. This was countered by increased CO₂ and N₂O emissions from accelerated soil organic carbon decomposition due to warming and high N deposition. High N deposition did not increase C storage for the alpine sites or for Great Smoky Mountains, which has received very high N deposition for many years. Warming increased net GHG sequestration only at the three coldest forested sites, and the combined effects of N deposition and warming further increased net GHG sequestration in these cold forests. Fertilization with 600 ppm CO₂ increased aboveground biomass, but there was only a minor additional response to higher CO₂ concentrations. While high rates of N deposition increased NO₃⁻ output at all sites, in scenarios with low N deposition, some stream NO₃⁻ losses actually declined below measured values, suggesting that water quality improvements could occur in the face of climate change if N deposition declines below current amounts. DayCent-Chem model output reinforces the growing consensus that there will be a limited ability for continued forest or alpine GHG mitigation stimulated by N deposition or warming. It also finds existing site characteristics and environmental history are critical controls on the magnitude of future GHG sequestration under global change.

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Utah juniper (*Juniperus osteosperma*), White Pine Range, Nevada. Photo: Scotty Strachan

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Climate Space: A New Approach for Projecting the Effects of Climate Change on Tree Growth

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Seattle, Washington

Albright, W.L., and Peterson, D.L. 2013. Tree growth and climate in the Pacific Northwest, USA: A broad-scale analysis of changing growth environments. *Journal of Biogeography* 40:2119-2133.

One of the principal challenges of ecosystem science has been how to use data that are limited spatially and temporally to develop general inferences about ecosystem function and processes. This challenge has been magnified as climate change begins to alter ecological relationships, making projections of climate-related phenomena both more important and more difficult. New approaches are clearly needed to develop these projections in a non-analog climate.

Tree growth and how it will be affected by climate change are of great interest for ecological analysis and a wide range of other ecosystem values. Although hundreds of dendrochronological studies have been conducted in North America, and many growth models have been developed, it has been difficult to project tree growth throughout a broad geographic distribution of a given species. A potential solution to this quandary was offered by Littell et al. (2008) by analyzing growth-climate relationships for an intensive sample of Douglas-fir (*Pseudotsuga menziesii*) throughout most of its existing “climate space” in the

northwestern United States, as defined by biologically meaningful properties of the physical environment.

Building on this approach, Albright and Peterson (2013) developed a novel method to examine potential growth responses to climate change at a broad geographic scale with a focus on visual inspection of patterns and applications beyond sampled areas. They examined projected changes in climate within species distributions of mountain hemlock (*Tsuga mertensiana*) subalpine fir (*Abies lasiocarpa*), Douglas-fir, and ponderosa pine (*Pinus ponderosa*) in Washington and Oregon based on three different future climate scenarios. By drawing on knowledge from previous climate–growth studies and organizing information into climate-space plots, they inferred directional changes in future radial growth.

This analysis found that increased moisture stress will reduce growth throughout the distribution of Douglas-fir, but growth may increase at some energy-limited locations (Figs. 1 & 2). Results for ponderosa pine were similar to those for Douglas-fir. Decreased snowpack will increase growing season length and increase growth of mountain hemlock and subalpine fir at most locations, although growth may decrease at some low-elevation sites (Figs. 3 & 4).

An altered Pacific Northwest climate will elicit different growth responses from common conifer species within their current distributions. The methodology based on climate space and biologically meaningful variables such as summer water deficit, actual evapotranspiration, and snow water equivalent can be used to qualitatively extrapolate climate–growth relationships from individual sites to entire species distributions. This approach can identify growth responses where climate–growth data are limited, thus helping to solve the “limited data” problem described above. If this analysis can be applied to additional tree species throughout western North America, especially where dendrochronological data are most numerous, it should be possible to project the effects of climate change on future tree growth more accurately.



Figure 1. Douglas-fir is common at low to mid elevations throughout the Pacific Northwest. Photo: U.S. Forest Service

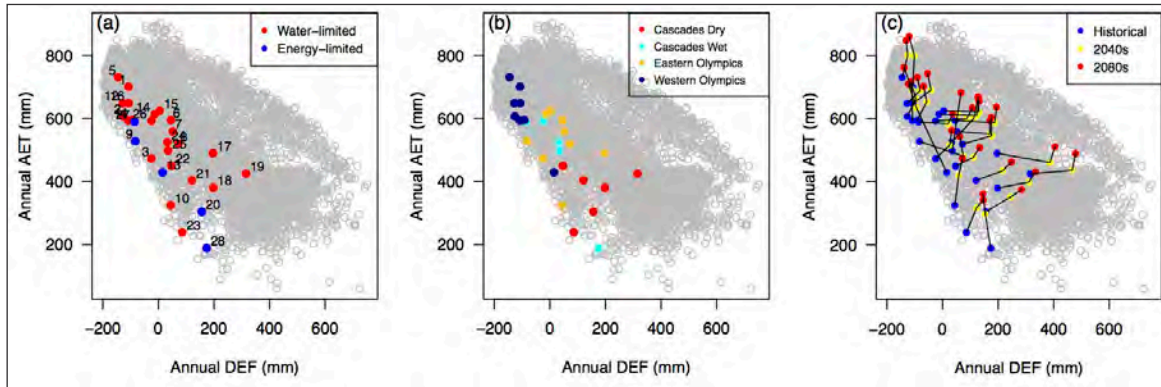


Figure 2. Douglas-fir distribution in climate space in Oregon and Washington [annual climatic water deficit (DEF) versus annual actual evapotranspiration (AET)] with sampled cells highlighted in panel (a), and cells grouped by geographical region in panel (b). Panel (c) illustrates the movement of individual cells in climate space from the historical time period to the 2040s and 2080s as projected by the HADGEM1_A1B (high-end warming) scenario. Lines connect the historical point of each cell to its projected position in climate space in the 2040s and 2080s.



Figure 3. Mountain hemlock is a common high-elevation species throughout the Pacific Northwest. Photo: Washington Department of Natural Resources

Reference

Littell, J.S., D.L. Peterson, and M. Tjoelker. 2008. Douglas-fir growth in mountain ecosystems: water limits tree growth from stand to region. *Ecological Monographs* 78:349-368.

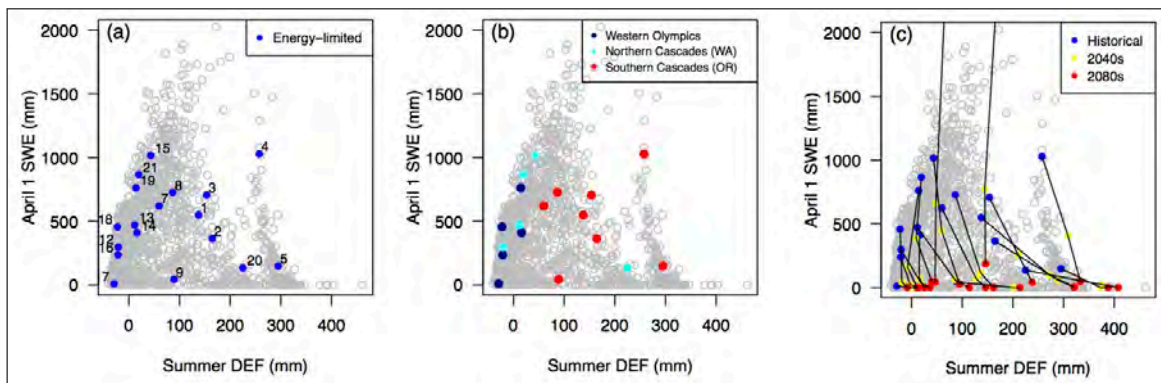


Figure 4. Mountain hemlock distribution in climate space in Oregon and Washington [summer climatic water deficit (DEF) versus April 1 snow-water equivalent (SWE)] with sampled cells highlighted in panel (a) and cells grouped by geographical region in panel (b). Panel (c) illustrates the movement of individual cells in climate space from the historical time period to the 2040s and 2080s as projected by the HADGEM1_A1B (high-end warming) scenario. Lines connect the historical point of each cell to its projected position in climate space in the 2040s and 2080s.

BREVIA

Forests in the Greenhouse: A New Synthesis on the Effects of Climate Change

David L. Peterson

U.S. Forest Service, Pacific Northwest Research Station
Seattle, Washington

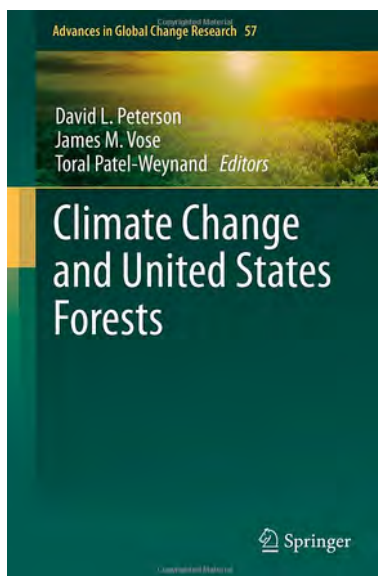
Peterson, D.L., Vose, J.M., and Patel-Weynand, T. (eds.). 2014. *Climate Change and United States Forests*. Springer, Dordrecht, The Netherlands.

The scientific community and media are focused on climate change issues this year, on the heels of the release of the IPCC Fifth Assessment Report and the U.S. Global Change Research Program National Climate Assessment. As part of this surge of information, a new synthesis on the effects of climate change on forest ecosystems has been published by Springer. Derived from technical input to the National Climate Assessment, *Climate Change and United States Forests* is the first volume to provide a comprehensive perspective on the effects of climatic variability and change on forest resources in the United States. Written with resource managers and decision makers in mind, the editors and 45 contributing authors focus on topics with the greatest potential to alter the structure and function of forest ecosystems by the end of the 21st century.

Part I provides an environmental context for assessing the effects of climate change on forest resources, summarizing changes in environmental stressors, followed by state-of-science projections for future climatic conditions relevant to forest ecosystems. Part II offers a wide-ranging assessment of vulnerability of forest ecosystems and ecosystem services to climate change. The authors anticipate that altered disturbance regimes and stressors will have the biggest effects on forest ecosystems, causing long-term changes in forest conditions.

Part III outlines responses to climate change, summarizing current status and trends in forest carbon, effects of carbon management, and carbon mitigation strategies. Adaptation strategies and a proposed framework for risk assessment, including case studies, provide a structured approach for projecting and responding to future changes in resource conditions and ecosystem services. Part IV describes how sustainable forest management, which guides activities on most public and private lands in the United States, can provide an overarching structure for mitigating and adapting to climate change.

A significant contribution of the book is its emphasis on how stress complexes—combinations of ecological disturbance and environmental stressors—influence structure, function, and species in forest ecosystems (Fig. 1). This approach is increasingly being used as a framework for assessing how climate change can exacerbate the effects of stressor interactions. Another contribution of the book is its emphasis on how risk assessment can be used quantitatively and qualitatively to evaluate resource conditions and climate-induced change, and to identify when intervention may be needed to reduce undesired outcomes. This approach to resource assessment and risk management is steadily being incorporated in IPCC assessments and the National Climate Assessment.



Enriched by 1000 references, *Climate Change and United States Forests* provides a benchmark to which future assessments can be compared. In order to quantify additional effects of a warming climate, it will be critical to maintain a time series of data and scientific documentation to provide evidence for future resource

policy and management. Although some of the projections in the book are sobering, a significant focus on adaptation, mitigation, and other productive social actions provide optimism for the coming decades.

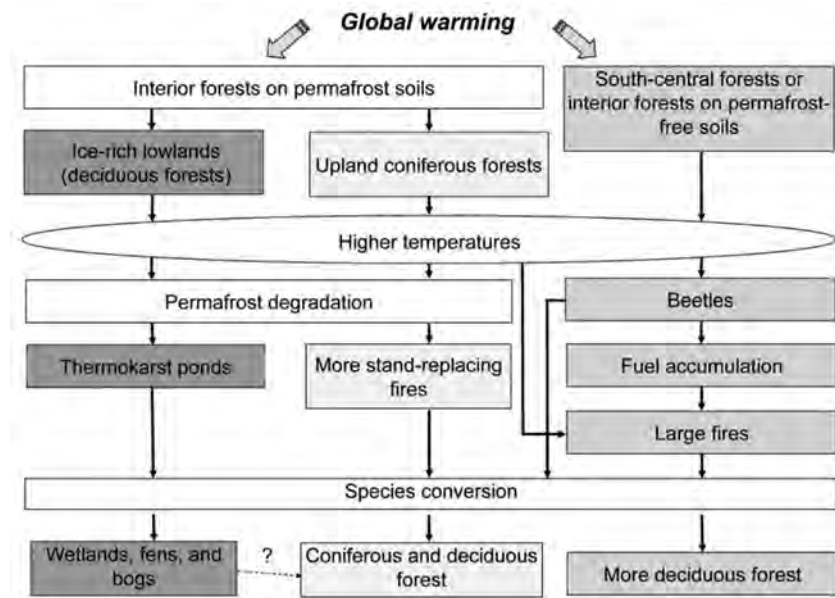


Figure 1. The stress complex for Alaskan boreal forest takes many biological and physical factors into consideration. The effects of a warmer climate differ, depending on whether or not permafrost is present.



Lisa Graumlich coring whitebark pine (*Pinus albicaulis*) along Scenic Point Lookout Trail, Glacier National Park. Photo: Greg Pederson

MtnClim 2014; CIRMOUNT's Tenth Anniversary

September 15-18, 2014, Midway, Utah

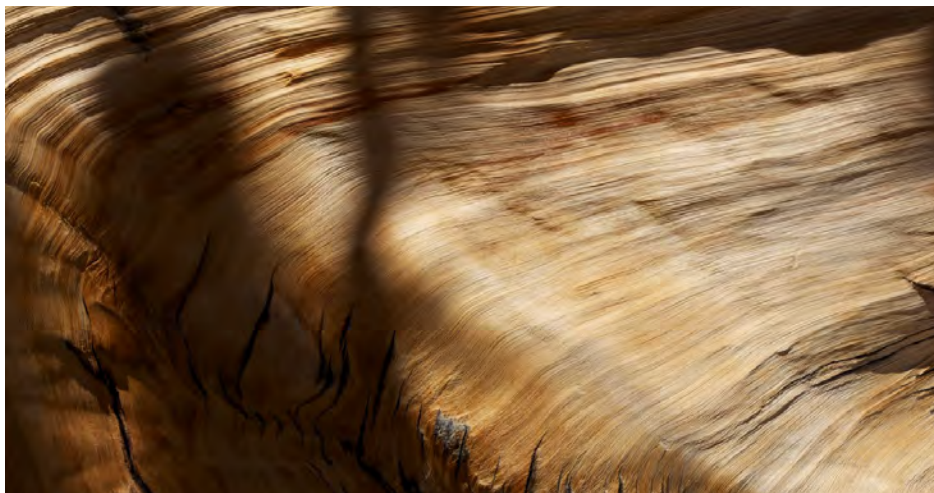
MtnClim 2014, the biennial climate conference sponsored by the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT) will convene Sept 15-18, 2014, at the Homestead Resort in Midway, Utah, USA, in the Wasatch Mtns, 1 hour drive from the Salt Lake City International Airport. The program includes invited sessions on mountain refugia, micro-climate processes, and climate adaptation; coupled human-social systems; early career scientists' research, and a panel on elevation-dependent warming. Invited talks will feature a 10-year perspective on research accomplishments and needs in mountain-climate science and management; a synthesis of hydroclimate and phenology; and an analysis of Great Basin forest ecosystems and their interaction with climate change and bark beetles. Keynote speakers include Barbara Benz, Julio Betancourt, Henry Diaz, and Kathy Jacobs. Contributed talks and posters are encouraged. Planned also is a field trip to the Uinta Mountains and a post-conference resource managers' workshop, both to focus on regional forest health and climate issues. Deadline for registration, abstracts, and lodging is July 15, 2014 (early registration is encouraged as attendance is limited to 120 participants).

MtnClim 2014 Conference Website: <http://www.fs.fed.us/psw/mtnclim/>

For questions, contact Connie Millar, USDA Forest Service, Albany, CA, USA, cmillar@fs.fed.us



Mt Timpanogos. Photo: B. Temper



Detail of limber pine (*Pinus flexilis*) wood. Photo: Jeff Mitton

Mountain Observatories Conference

Global Fair and Workshop on Long-Term Observatories of Mountain Social-Ecological Systems

July 16-19, 2014, University of Nevada, Reno, Nevada

The Mountain Observatories Global Fair and Workshop will bring together scientists and managers who gather data on mountain social, biological or abiotic systems with the opportunity to describe their work, explore the questions and phenomena driving observations, create new collaborations, and formalize cooperative arrangements. The goal of the Fair and Workshop is to move toward a more comprehensive, global mountain observation network by strengthening the ties between existing observation systems. The conference was developed in recognition that effective, evidence-based management of social-ecological systems requires strong, interlinked datasets that include information about all facets of the human-environment nexus. As a step toward providing quality, long-term, evidence-based datasets, the Global Fair and Workshop will help the mountain research community begin to synthesize a macroscopic observing system using existing regional networks and individual sites as building blocks.

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

The Fair will feature:

- a) Expositions in which participants explain their observing network or products in a poster session format and
- b) Side Meetings for more in-depth discussions.

The Workshop will feature:

- a) Sessions where speakers present state-of-the-art thinking regarding mountain observations and
- b) Ateliers where participants work together to develop common solutions.

One day will be devoted to site visits around the Reno/Tahoe area, with longer field trips available after the conference to visit sites and facilities in the Sierra Nevada, Great Basin and Cascade ranges.

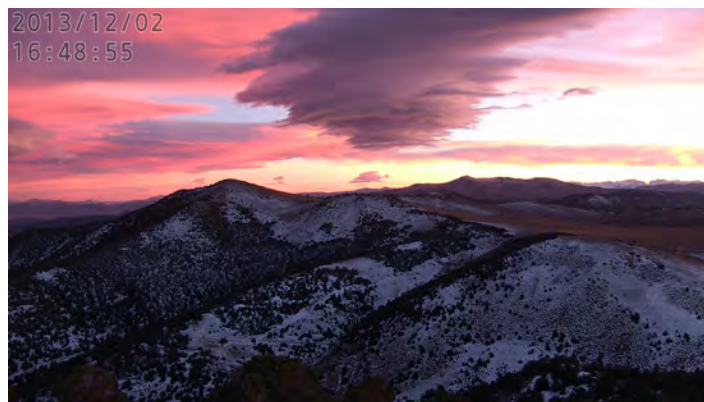
The early-bird registration deadline is June 4.

Fair and Workshop website: <http://mri.scnatweb.ch/en/events/fair-and-workshop-on-mountain-observatories>

For inquiries, address Greg Greenwood, Mountain Research Initiative, Bern, Switzerland; email, green@giub.unibe.ch



Scotty Strachan (UN, Reno) installing the Rockland Summit climate station, Pine Grove Hills, Nevada. Photo: Jehren Boehm



An image from the webcam at Rockland Summit climate station, capturing a southwesterly view to the Pine Grove Hills, Sweetwater Mountains, and Sierra Nevada, December 2, 2013.

Sixteenth Conference on Mountain Meteorology

August 18-22, 2014, San Diego, California

The 16th Conference on Mountain Meteorology, sponsored by the American Meteorological Society and organized by the AMS Committee on Mountain Meteorology, will be held 18-22 August 2014, at The Catamaran Resort Hotel & Spa in San Diego, CA.

Pre-Registration Deadline: 7 July 2014

Conference Website: www.ametsoc.org/meet/fainst/201416mountmet.html

Invited presentations include:

Evelyne Richard (laboratoire d'aérodynamique) - Scientific progress on the HYMEX field campaign

David Kristovich (U. Illinois) - Recent advances in lake-effect snow research

Robert Fovell (UCLA) - Real time prediction efforts in southern California

Allen White (NOAA/ESRL) - The Calwater2 initiative

Russ Schumacher (CSU) - Mesoscale prediction and dynamics of 2013 flash flooding along the Colorado Front Range



Giant white fir (*Abies concolor*), Spring Mountains, Nevada. Photo: David Charlet

Alpine and Arctic Treeline Ecotone Work Group

Upcoming Conference Sessions

Two sessions highlighting research related to alpine and arctic treeline ecotones are included in upcoming conferences:

Ecological Society of America, 2014 Annual Meeting, Sacramento, CA

Session Title: Advancing Knowledge of Alpine and Arctic Treeline Ecotones and Responses to Environmental Change (OOS 9740).

Date: Thursday, August 14, 8-11:30am

Conference Website: <http://esa.org/am/>

Session Description:

Treeline research has been advancing rapidly, motivated in part by the need to predict land surface feedbacks to regional and global climate change, water resources in mountain regions, and impacts of environmental change on high latitude and high elevation biodiversity. Upper elevation and northern treeline ecotones are boundary zones between forest and arctic or alpine treeless zones. Although presence of upright trees has defined the treeline per se, treeline is more accurately described as an ecotone structured by complex interactions among vegetation, soils, animals, climate, snow, topography, and disturbance regimes. Responses of this ecotone to environmental change have been observed, but complex lags and feedbacks -- in addition to topographic influences that confound responses in mountain treelines -- challenge predictions of change. This session brings together diverse perspectives and expertise in treeline research to report recent advances, both in basic understanding of treeline dynamics and in predicting responses of alpine and arctic treelines to environmental change. By including talks from diverse subfields in ecology the session seeks to foster new collaborations and insights that will advance integrative science of the treeline ecotone. A further objective is to bridge the historical divide between arctic and alpine treeline research. The session comprises ten talks on different aspects of treeline research: paleoclimate and paleoecology, tree demography, ecophysiology, modeling treeline, plant-animal interactions, experimental ecology, ecosystem processes, and the role of disturbance in structuring treeline. Speakers represent the international nature of treeline research and work in both arctic and alpine treeline ecotones.

Conveners: Lara Kueppers (Univ CA Merced, Lawrence Berkeley National Laboratory), Dave Cairns (Texas A & M), Melanie Harsch (Univ WA), and Connie Millar (USFS)

International Union of Forest Research Organizations (IUFRO) World Congress, Salt Lake City, UT

Session Title: Vegetation Zone Shifts in Response to Climate Change (Session #232)

Date: Conference dates: October 5-11, 2014. Session day and time will be announced in June on the conference website

Conference Website: <http://iufro2014.com/>

Session Description:

Shifts in mountain vegetation zones are often considered adaptation measures of forest ecosystems to climate change. This session explores the capacities and obstacles to adaptation related to autecological and synecological characteristics of dominant tree species. To date, projections of vegetation shifts in response to future climate change have been assessed primarily through modelling. The aim of this session is to compare model results with critically assessed field and observation data; linking of regional and subject (branch) approaches will be applied. Regional case studies will be presented from representative mountain regions including Paleoarctic (Alps, Carpathians, Pyrenees Mts.) and Nearctic (Rocky Mtns, Sierra Nevada, Cascade Mtns) ecozones. Case studies will critically assess soil, climatic, and ecologic (life-history characteristics, plant competition) conditions in response to climate change, focusing on opportunities and barriers to adaptation.

Conveners: Pavel Cudlin (Academy of Sciences, Czech Republic) and Connie Millar (USFS)



Detail of limber pine (*Pinus flexilis*), Sweetwater Mountains, California.
Photo: Connie Millar

Mountains of our Global Earth

October 4-8, 2015, Perth, Scotland (exact date to be confirmed)

Following previous conferences on global change and the world's mountains in 2005 and 2010, the Centre for Mountain Studies (CMS) at Perth College, University of the Highlands and Islands, and the Mountain Research Initiative (MRI) are organizing a global conference: 'Perth III'. It will have three aims: 1) to present, evaluate and synthesize progress in our understanding of global change in mountain regions, and share examples of innovative approaches, particularly in terms of progress towards addressing the gaps in global research in mountain regions noted at the 2010 conference; 2) to refine and coordinate agendas for collaborative research and action relating to global change and mountain regions, and to significantly increase the use of applied research findings on the ground in mountain regions; 3) to foster effective interdisciplinary and international interactions between participants: researchers, practitioners, and policy-makers.

The sessions will be structured around the three research themes of the international Future Earth research initiative (www.icsu.org/future-earth). Following a global call, scientists and practitioners worldwide have submitted a very wide range of themes for sessions, which will be in various formats. A conference website will be launched in June 2014; a call for papers will follow. If you would like to receive information as the conference develops, please send an email to: mountains.2015.perth@uhi.ac.uk

Martin Price
Centre for Mountain Studies, Perth College,
University of the Highlands and Islands, Perth, UK



Martin Price presides over the first global mountain climate conference in Perth, 2005



The Cairngorm Mountains of northern Scotland. Photo: Colin Maher

Did You See (Hear, Touch, Smell, Feel) It?

Oddities of Mountain Weather and Climate

This section of *Mountain Views Newsletter* highlights unusual mountain-weather events or climate-related phenomena of western mountains. I welcome your comments on processes and observations described, and encourage submissions for future issues.

– Editor

Drought in California: 2013-2014

Connie Millar

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

Drafted with information from the California Department of Water Resources
and Western Regional Climate Center

Much of the West started water year 2013 with severe drought conditions. Winter storms in 2014 brought relief to some regions, although precipitation remained below average for others. In particular California and adjacent southwestern regions persist in severe drought. Calendar year 2013 in California closed as the driest year in recorded history for many areas of the state, and the severe drought continues into late spring 2014. On January 17, 2014 California Governor Brown declared a drought state of emergency in which he directed state officials to take all necessary actions in response. Continued drought conditions prompted the Governor on April 25 to ask Californians to reduce water usage by 20%. This article highlights conditions in California as one case example of drought in the West.

Extreme lack of precipitation occurred during October through December 2013 at many stations, with southern California more severe than the northern state, and generally more severe in the mountains than at lower elevations. The accentuation of deficits over higher elevations was particularly ominous, because it is in mountain catchments where much of California's water resources are generated and stored into the long Mediterranean summer as snowpack and delayed runoff.

A little more than half the state's precipitation typically arrives via winter storms in December through February. December and January were extremely dry, and brought no relief. By the beginning of February, throughout the area, ranchers with no pasture for their cattle were forced to sell; wells were going dry, and wildfire responders were confronting small blazes in forests that are usually deep in snow at that time of year.

Modest precipitation during February and March helped to alleviate winter drought, but even by April 20, the average northern Sierra snow water equivalent was only 9% of normal for that time of year, and the state-wide average was 19% average. A larger rainfall, with mountain snowfall, occurred on April 25 and for several days thereafter, but did not significantly add to the overall precipitation totals. Since late April, a strong high pressure associated with a high-amplitude 500mb ridge developed over the far Eastern Pacific, and brought a record-breaking early-season heat wave to much of California. A number of daily high temperature records were set over a multi-day period over a geographic region spanning the far North Coast (near Eureka/Arcata) to the Mexican border (including San Diego County). This spring heat wave also coincided with the occurrence of powerful Santa Ana (offshore) winds in Southern California, with the typically windier mountain peaks seeing gusts in the ~100 mph range. These high winds—combined with ongoing extreme drought conditions—led to extreme fire weather conditions, and several wildfires did break out. In the wake of this heat wave, the Sierra Nevada snowpack fell further from near-record low levels to nearly dry.

The fifth and final snow survey of the season on May 1, 2014 recorded manual and electronic readings of the statewide snowpack's water content – which normally provides about a third of the water for California's farms and cities – at 18 percent of average for the date.

The figures and images that follow illustrate conditions of drought in California this year.

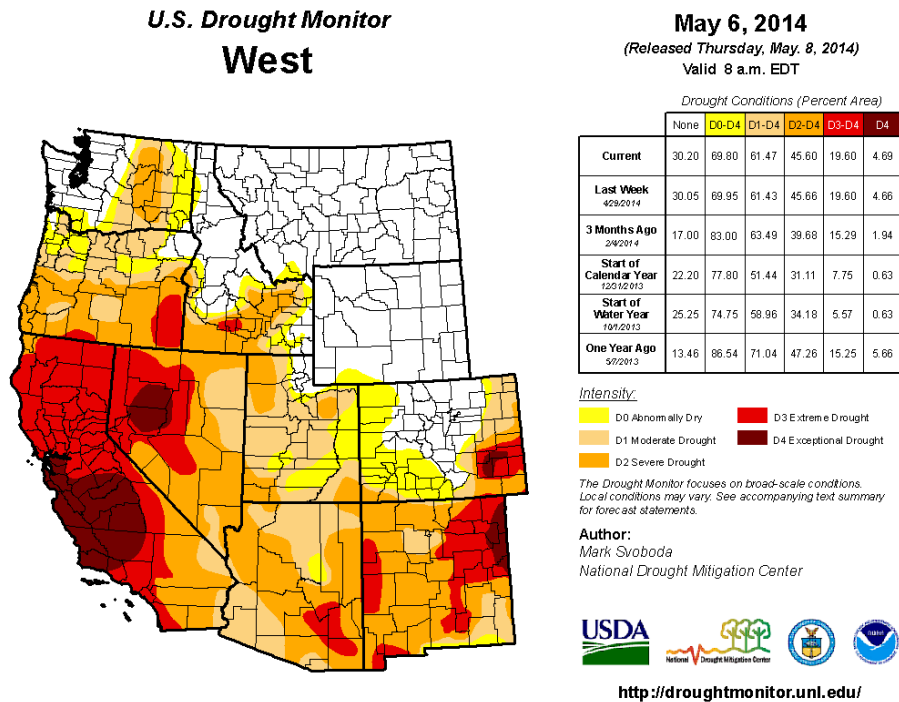


Figure 1a. The Western U.S. Drought Monitor as of May 6, 2014 indicated severe drought in California, persisting drought in other parts of the Southwest, and drought relief in western Washington, the Intermountain region, and the Rocky Mountains.

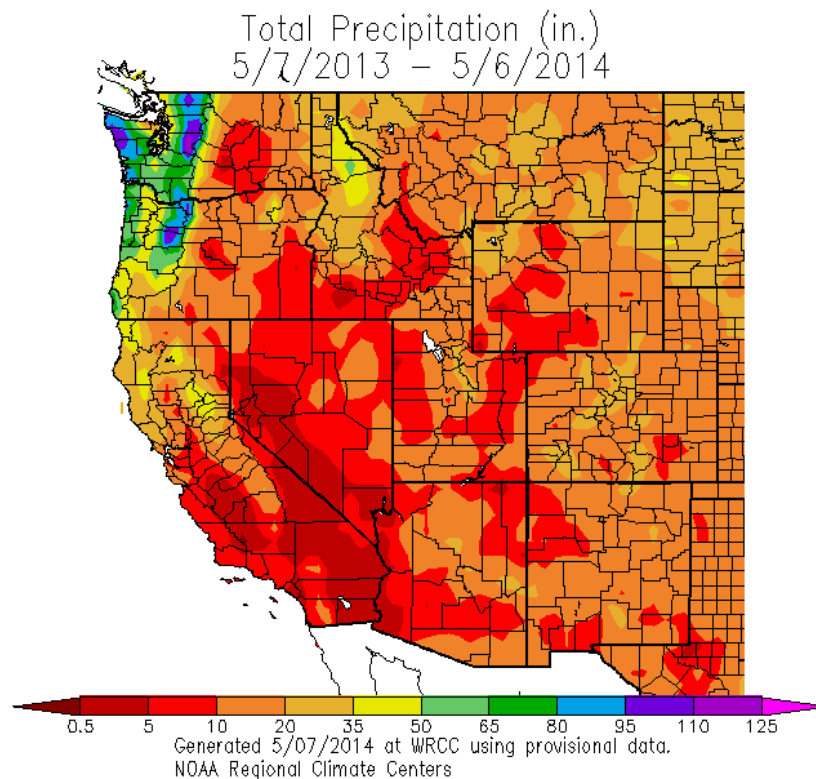
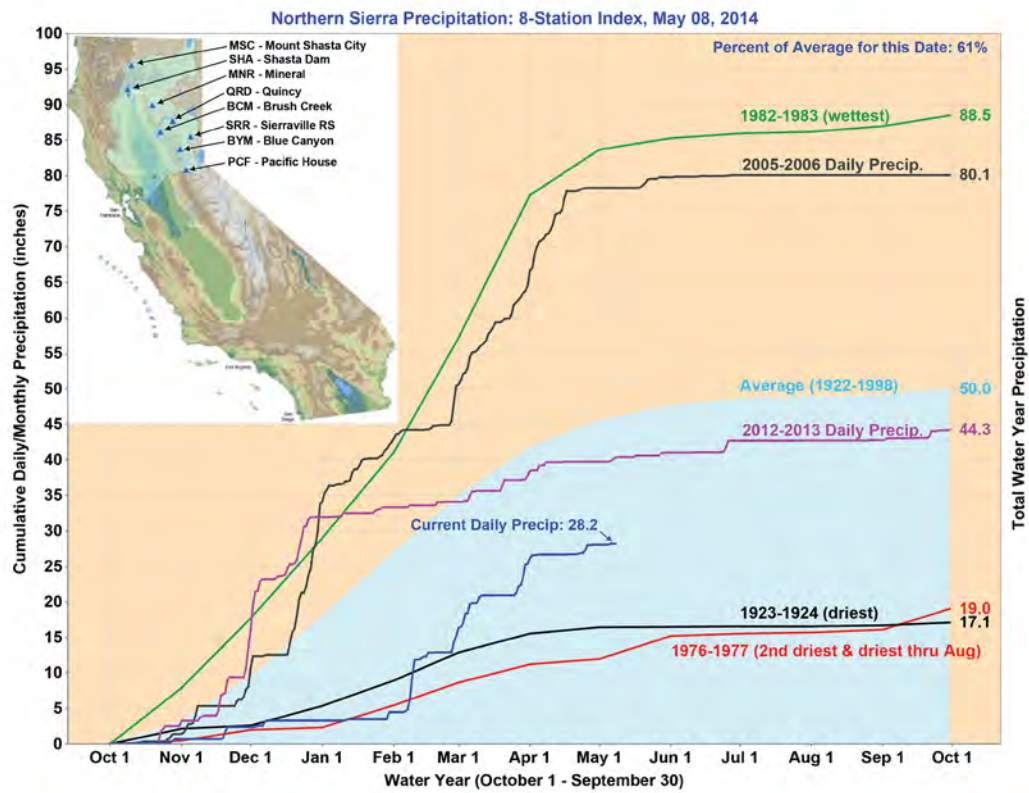


Figure 1b. Total precipitation for 12-month period ending May 6, 2014.

A.



B.

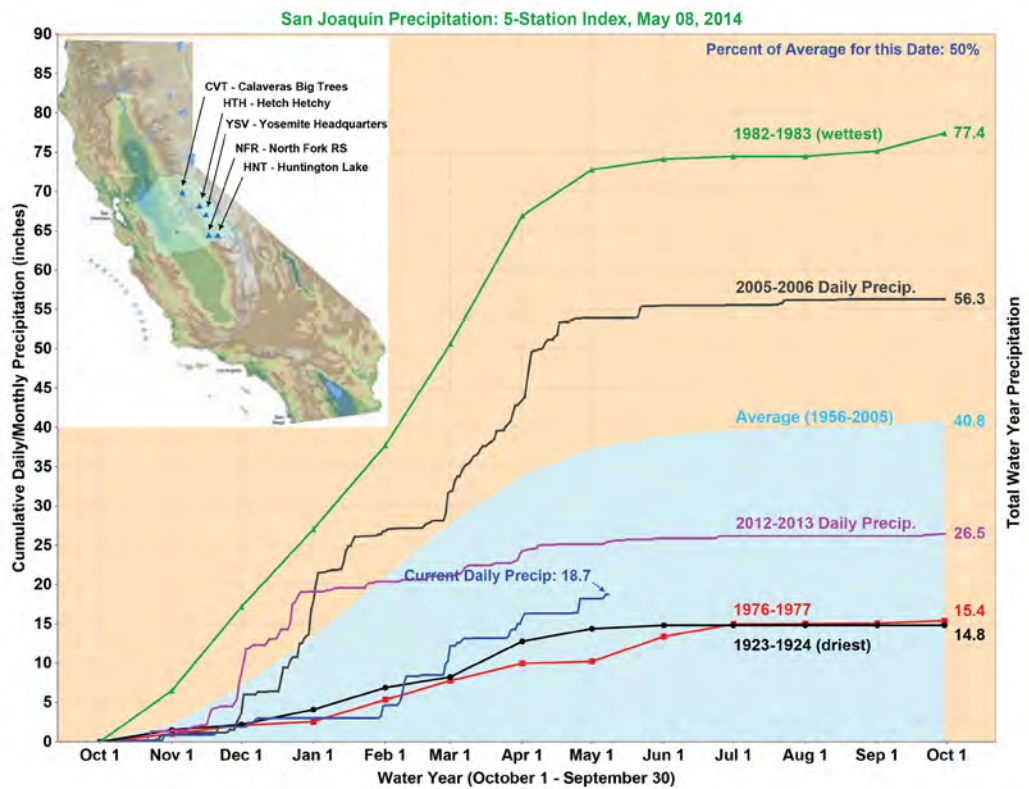


Figure 2. Precipitation. Historic record years, average (1922-1998), and current (as of May 8, 2014)
A. Northern Sierra Nevada. B. San Joaquin Valley. From California Department of Water Resources

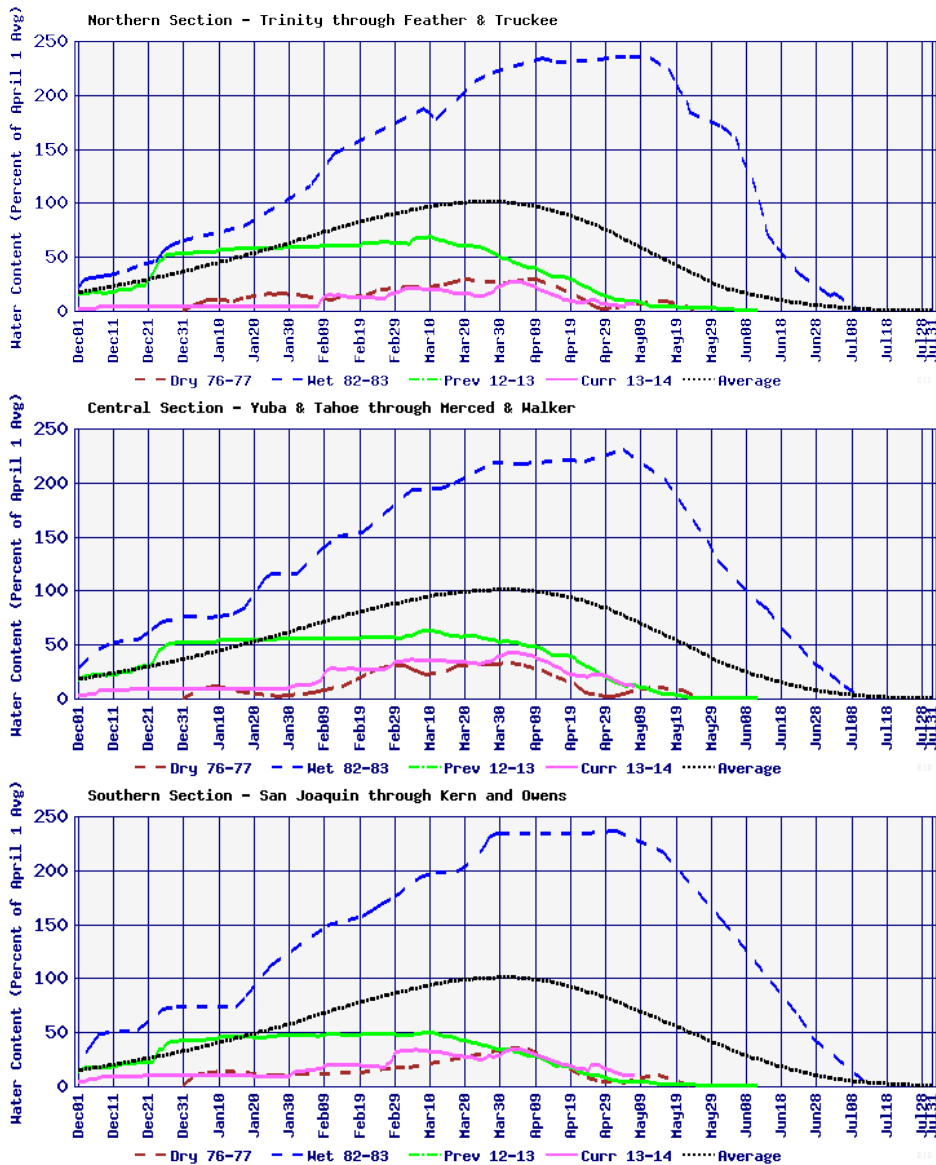


Figure 3. Snow water content summaries showing record years, average, and current year through May 6, 2014. From California Department of Water Resources

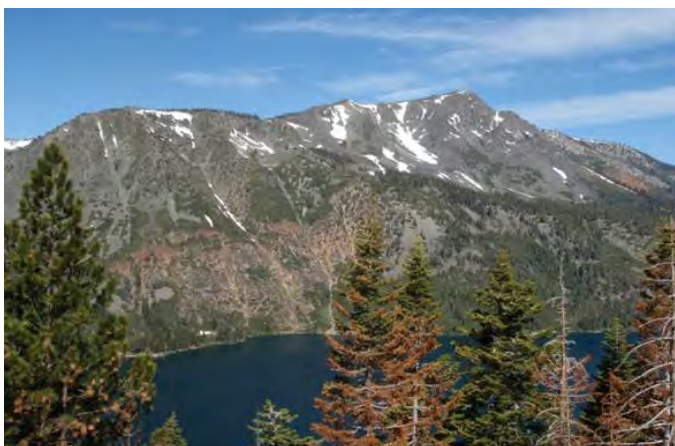


Figure 4. Mt Tallac in the Tahoe Basin, December 2013. Photo: Hugh Safford



Figure 5. Bodie Mountains, eastern California, New Years Day, 2014. Photo: Connie Millar



Figure 6. The Owens Valley, (center) southern Sierra Nevada (left), White Mountains (right), January 27, 2014.
Photo: Earth to Sky Calculus Club, Bishop, CA



Figure 7a. Looking for snow in Lava Beds National Monument, northern California. February 2, 2014.
Photo: Jim Blanchard



Figure 7b. Modoc Plateau from Black Crater. February 2, 2014.
Photo: Jim Blanchard



Figure 8. The Mono Basin looking northeast from Lee Vining Creek, February 12, 2014. Photo: Ellen Jung

A.



B.



Figure 9. Drought Conditions in southern California. A. Tejon Ranch. B. San Joaquin Valley, late February 2014. Photos: Daniel Griffin

You might recall a year ago that I featured a Science Fair project on mountain micro-climates. This year the same authors, Caelen McQuilkin (7th grade) and Jordyn Harper (6th grade), challenged iButtons (temperature dataloggers) to a more complex question involving thermal properties of snow and their relation to winter animal survival. Their 2014 Science Fair project, summarized below, again won gold medals at the local, county, and regional fairs, and third place at the California state fair. --Editor

Freezing Warm: Thermopoles in the Snow

Caelen McQuilkin and Jordyn Harper
Lee Vining Elementary School, Lee Vining, California

Question

Why do animals make subnivean homes in the freezing cold snow?

Hypothesis

Animals sleep in subnivean homes at night because they are warmer than above the snow.

Procedures

1. Program the iButtons to take a temperature every half hour.
2. Record the serial number of each iButton and its thermopole location so that we don't lose track of them.
3. Wrap the iButtons in screen (their cases) and attach them to the 7 thermopoles
4. Make cases for the spot-on iButtons and record them.
5. Put the thermopoles in 4 different scenarios: open air, through a bush with no snow, through a bush covered with snow, and through the snow. The scenarios will all be in the same area. (Figs. 1, 2)



Figure 2. Thermopole in snow



Figure 1. Installing thermopoles

6. Collect the thermopoles a week later (Fig. 3).
7. Download data from iButtons using the iButton data reader.
8. Build our own snow cave (subnivean home) and put thermopole and iButtons inside and out of it. Spend 2 hours in the snow cave.
9. Build a mini subnivean home and put a stuffed animal with hand warmers (to represent body heat) inside it. This will help us analyze the effect of body heat.
10. Analyze our data by comparing all of our temperatures and answer our questions about where it's warmer for animals and if their body heat has a big effect or a small one.

Materials

iButtons

Thermopoles —

our own invention made of 1.5 meter long PVC pipe, with holes drilled in them every 3 or 9 centimeters. We attached stapled mesh pockets with wire going through them to hold iButtons.

Screen and staples; Wire; PVC Pipe; Rebar and Mallet

Stuffed animal (for mini snow cave)

Hand warmers (for mini snow cave)

Warm winter clothes (for snow cave)

Data recording sheet

Results

With our experiment, we found that...

- Our thermopoles were a successful way to measure snow and air temperature in the same place and at the same time.
- After graphing our data, we found that...

It's much warmer in the snow than in the open air at night. For example, at the Red Zebra thermopole at 5:30 am on January 23rd, it was -2 °C in the snow, while it was -12.5 °C above in the air (Figs. 4, 5). You can see why animals choose to go into the snow at night.

Snow closer to the ground is warmer than snow closer to the air.

Body heat has a substantial effect on a snow cave's warmth. In our snow cave, it was about 20 °C warmer than it was outside.

Snow caves aren't toasty warm like your bed, but are the warmest option for animals and are warm enough to keep them alive at night.

If air gets into the snow cave, it can make it much colder. We found this when we compared an iButton from our Red Rainbow thermopole at the very bottom of a snowy root wad (hole 1), where it was much warmer than the entrance toward the home. The iButton on hole 1 wasn't affected by the air that leaked into and was much warmer than the iButton near the top of the root wad (hole 4), that was affected by the air leaking in.

- Snow isn't like a heater, but it is like a blanket, keeping warmth in instead of creating it.
- There are lots of subnivean animals around our area, including rabbits, mice, squirrels, shrews, and weasels.
- When we were conducting our experiment, we saw many tracks from animals like Douglas Tree Squirrels, mice, rabbits, and weasels. These tracks entered holes leading to subnivean homes. At some of these entrances, we found pinecone shavings from a Douglas Tree Squirrel's snack. We placed our Red Rainbow thermopole at one of these entrances, hoping that an iButton would sense the heat of an animal living in the snow home. That didn't happen.
- We were able to measure the impact of body heat in a snow cave, however, through our mini snow cave with hand warmers and the big snow cave with us (the body heat) in it. The heat from us and the hand warmer lasted the whole night, even after we left the snow cave and the hand warmer stopped producing heat.



Figure 3. Measuring thermopoles

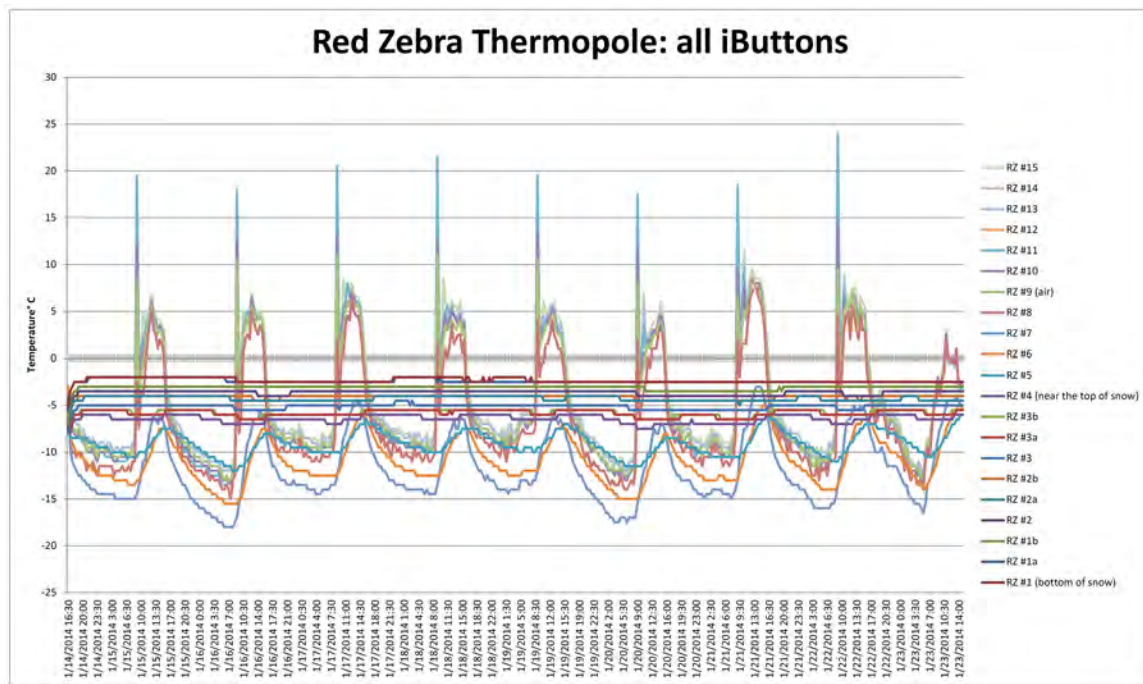


Figure 4. Red Zebra thermopole results; full graph

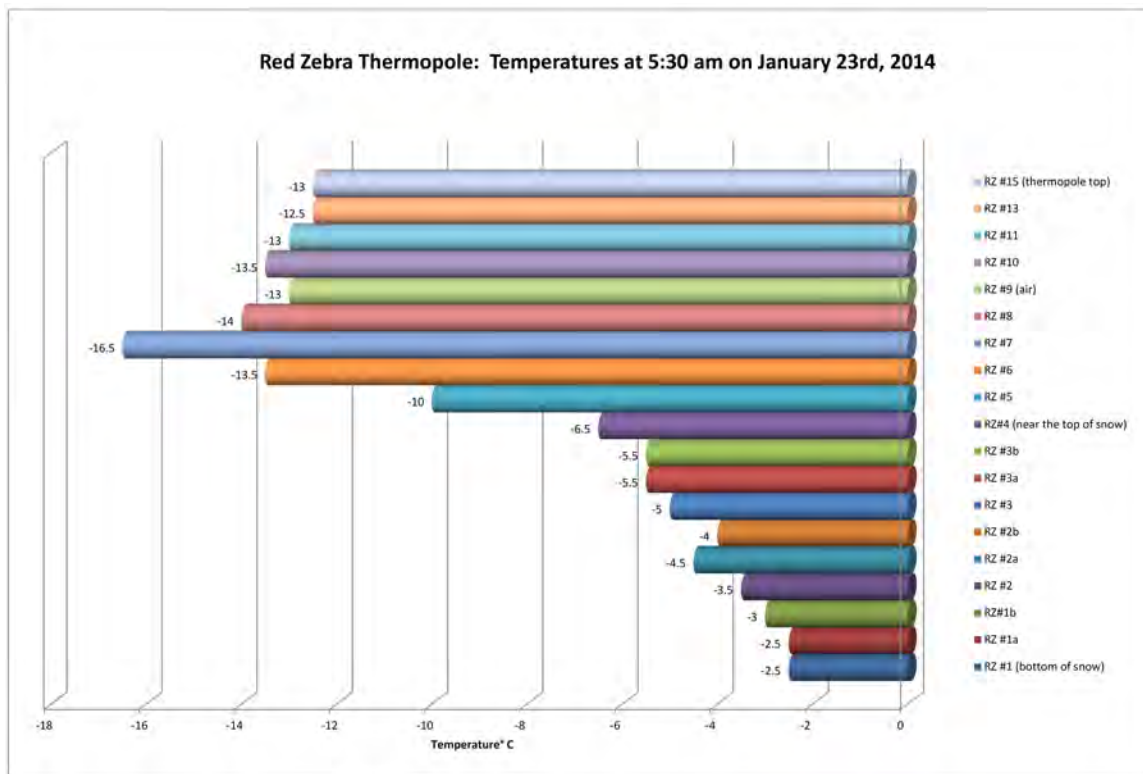


Figure 5. Red Zebra thermopole, temperatures at one time

Conclusions

Our results show that it is much warmer in the snow at night than it is in the outside air, or in a sheltered tree or bush. This gives animals a perfect place to survive the dangerously low temperatures at night.

Our data support our hypothesis: that animals sleep in the snow because it is warmer and more sheltered.

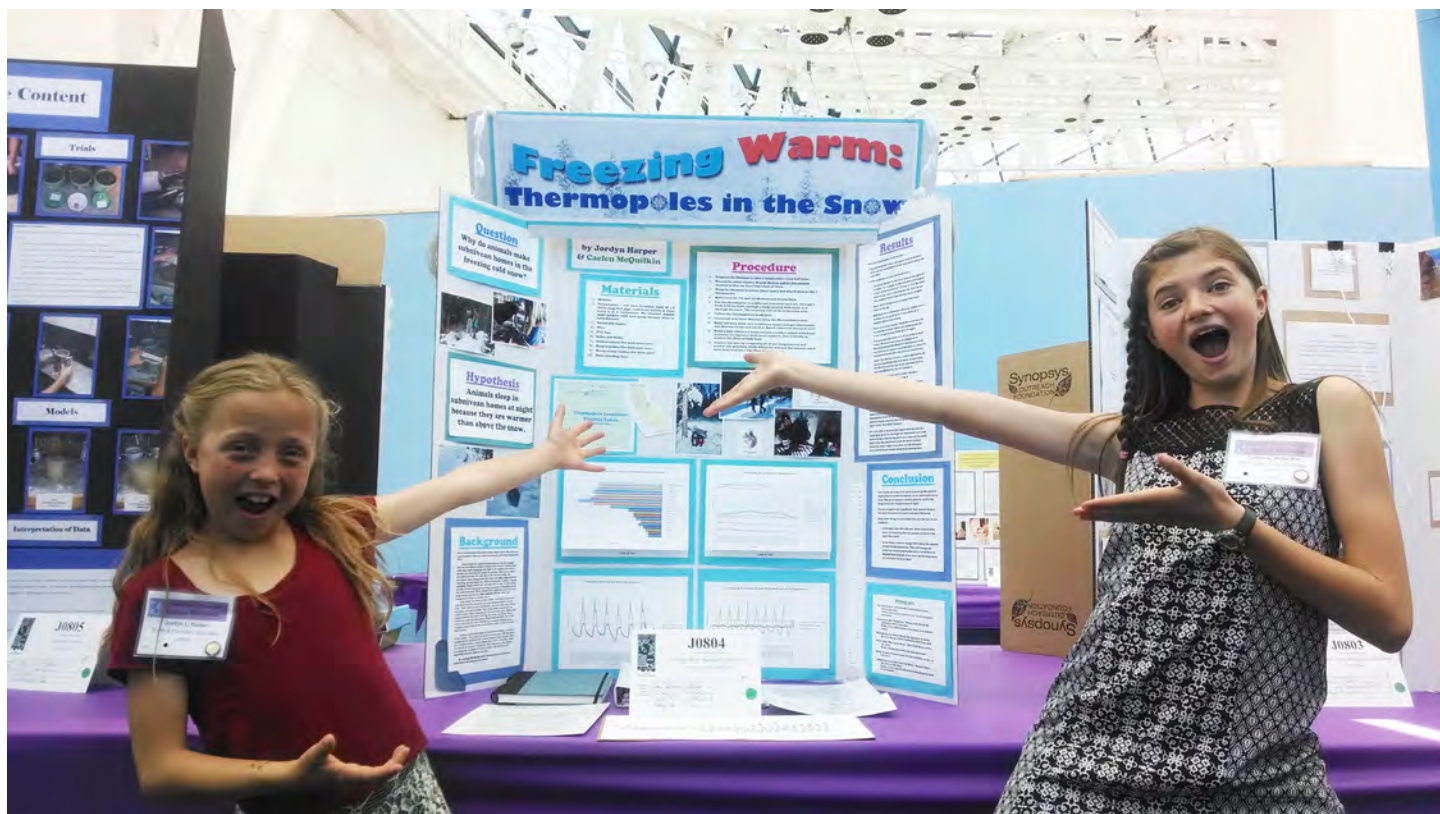
Some other things we concluded that are relevant to our world are...

- In drought years like this one, when there is little snow, it is much harder for animals to survive the night than usual.

- In the future, climate change will reduce the amount of snow in the mountains. This will change the subnivean animal population of the world forever because these animals won't have the freezing snow to keep them warm at night.

Summary Statement

By making thermopoles to measure snow and air temperatures and placing them in different locations, we found that freezing snow is warmer than air at night.



Jordyn (left) and Caelen (right) with their science project at the State Fair. Photo: Geoff McQuilkin

Contributing Artists

Thanks to the following colleagues who contributed artwork, poetry, and photographs to this issue of *Mountain Views*:

Reproductions of watercolor paintings and ink drawings in this issue are by Valerie Cohen. Valerie is a former National Park Service law enforcement officer, and has been painting for more than 20 years. She lives in the Sierra Nevada, CA, and often accompanies the GLORIA expeditions in the White Mountains. To see more of Valerie's artwork, visit her website: <http://valeriepcohen.com/>

Bob Coats is a research hydrologist with Hydroikos Ltd. in Berkeley, CA. Bob has been studying climatic, hydrologic, and ecological processes in the Lake Tahoe Basin – and writing poetry -- for more than 40 years. His poems have appeared in *Orion*, *Zone 3*, *Windfall*, *The Acorn*, and the Pudding House anthology, *Fresh Water: Poems from the Rivers, Lakes and Streams*.

Photographs of trees in this issue were contributed by:

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Jessica Lundquist, Department of Civil and Environmental Engineering, University of Washington, Seattle, WA contributed her photo of sastrugi.



Spiral grain in limber pine (*Pinus flexilis*), Sweetwater Mountains, California. Photo: Connie Millar

Mountain Visions

From the palettes of our CIRMOUNT community

At Summit Lake

Wind-hewn ribbons of sastrugi glint
the ridge in afternoon sun.
Already the summit's shadow slides
across the frozen lake.

Huddled in the lee of a slanting boulder
I catch the sun's last rays,
nibble chocolate, sip water,
tend to boot laces and ski wax.

For a moment, this is enough:
the arching cupric sky,
wind whistling through scraggly pines,
rocks and glowing snow.

Then the sun dips behind a gendarme,
its shadow creeping over me.
I zip parka, shoulder pack,
set skis for the long glide home.

– Robert Coats, 2003



Sastrugi. Brooks Range, Alaska. Photo: Jessica Lundquist

What to do on August 26th

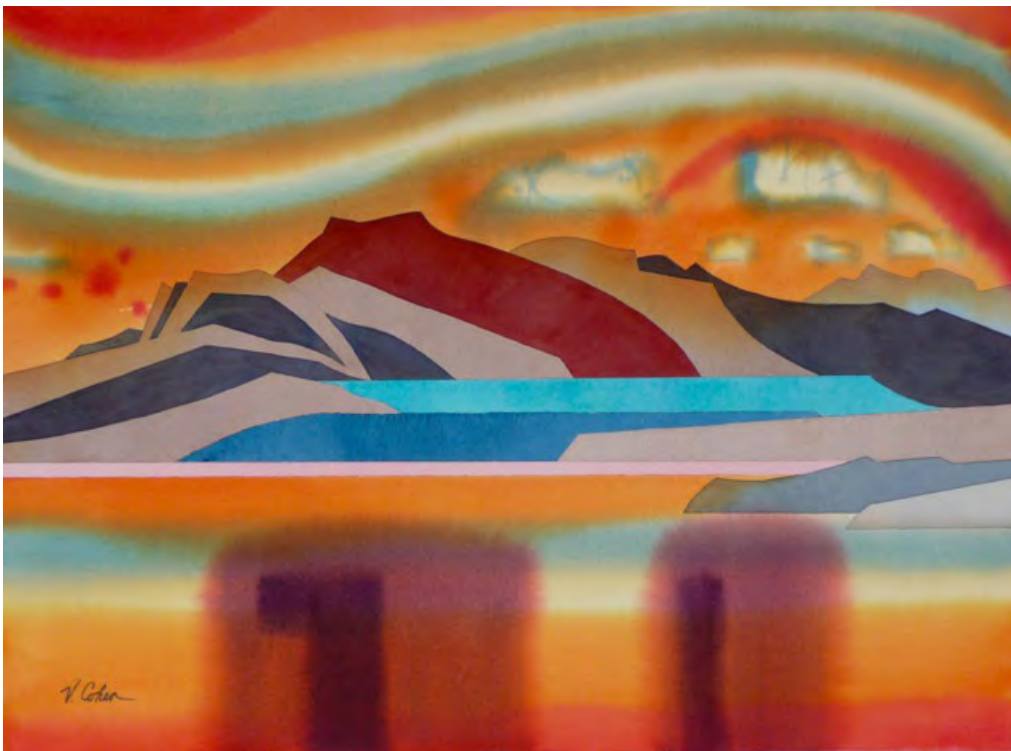
Go to Rock Lake, Plumas country.
Before sunrise, stand
on the slate ledge that juts the lake.
Look to the western shore,
watch sunlight creep down
the red bank of schist.

Now turn east, look up
to the canyon rim
where Jacob's ladders converge
at a dark hemlock
silhouetted
against the bright sky.

In the moment before
the sun crests the wall
the entire tree--bole,
branches, foliage--
will flash
into silver filigree.

Then the orb's leading edge
will clear the jagged ridge, shooting
gold deep into liquid indigo
warming your face
flooding you
with light.

– Robert Coats, 1995



Valerie Cohen, "Boundary Layers II" (Mono Lake and Mono Craters), Watercolor, 22" x 30"



Valerie Cohen, Limber Pine #1, India ink on rag paper, 13.25" x 10.5"

