High Country News
For people who care about the West

Dancing with Climate Change

Alpine species try to adapt to a warming world

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by J. Madeleine Nash

"Look! A bristlecone graveyard!" shouts U.S. Forest Service ecologist Connie Millar. Millar and her colleague, Bob Westfall, have just reached the western slope of a high ridge overlooked by California's 14,246-foot-high White Mountain Peak. Rounding a bend in the trail, I see them standing amid the remains of long-dead trees. In some cases, all that's left is a short stump or a toppled-over log. A few trunks stand oddly upright, with limbs that stretch skyward, as if in prayer. How old these relicts are is uncertain, but given the slow decay of bristlecone wood, some may have started out as seedlings more than four millennia ago, making them as old as the Great Pyramid of Giza.

But Millar is even more intrigued by the young trees that are starting to colonize this spectral grove. Some are 20-something-year-old bristlecones, easy to identify by their upright growth habit and dark green needles. Others are shrubby-looking limber pines that stand no more than thigh-high. The youngsters, Millar says, did not creep upslope; they've leapt up here, no doubt aided by pine-nut-loving birds. Their parent trees live more than a thousand feet below. "Striking, isn't it?" says Millar, who works out of the Forest Service research center in Albany, Calif. "Now we've got all these little trees coming in, and all these big old dead bristlecones, but absolutely nothing in all those years (between)."

A young bristlecone pine tree amid the remains of ancient bristlecone pines on the west side of a peak in the White Mountains of Inyo National Forest, California.

And it's not just here, Millar says. West of us, in the Sierra, and eastward, across the Great Basin, young pines are also on the move. In a few spots, seedlings and saplings are charging uphill; elsewhere they're simply filling in the spaces between the sparsely distributed adults. Mature trees, too, are kicking up their heels. At the highest elevations, thick-waisted bristlecones are growing faster than before, laying down annual layers of wood that are noticeably wider than in centuries past. It's a growth spurt without parallel in the past 3,700 years, say scientists at the University of Arizona Laboratory of Tree-Ring Research — a sign, they think, that these ancient conifers are responding to the warming of our world.

In itself, that comes as no surprise. Biology, after all, has been dancing to climate's beat for hundreds of millions of years. But given the rate at which heat-trapping gases are streaming into the atmosphere, the pressure on organisms this time around promises to be extreme. In coming decades, ecologists say, we might well witness a sequence of botanical arabesques and grand jetes not seen since the end of the last Ice Age, when spruce and fir pirouetted across boreal lands, bristlecones high-stepped up Great Basin ranges and oaks jumped from isolated pockets to waltz across the hills of California.

It's in anticipation of the drama to come, in fact, that about a dozen scientists, including Millar, are spending the week in this high place, operating out of the University of California White Mountain Research Station. This summer, as in past years, much of the activity centers around meticulous plant surveys taken for the Global Observation Research Initiative in Alpine Environments — commonly known as GLORIA — a long-term ecological monitoring effort launched in 2001 that presently encompasses some 80 sites on five continents. The participating scientists have added other climate change surveillance projects to the mix, ranging from an annual census of butterflies and other insects to Millar's ongoing observations of the changing growth patterns of pines.

This wide-angle perspective is proving instructive. In the White Mountains — White Mountain Peak is the high point of a 60-mile-long range — young trees are doing more than moving up in elevation, Millar has found. They are also diving downslope, into newly opened microclimate niches in steep-sided valleys and ravines. Below us, young limber pines are advancing down the sides of the Crooked Creek Valley, which lies at an elevation of 10,200 feet. Farther down, they are pushing into the Owens River Gorge, venturing as low as 6,700 feet. "It seems counterintuitive," says Millar, "until you try to understand how mountain climate works."

Mountain climate is patchy, she explains. The American West is warming more rapidly than other parts of the U.S., but that's just on average. Within the 11-state region lie tens of thousands of cooler pockets, due, in large part, to the presence of mountains. Biologically, this translates into resilience. On the flat, for example, an organism might have to travel several hundred miles to find a suitable niche, whereas in the mountains, a hop, skip and jump will often do the trick. "Because mountains are so topographically rough, so heterogeneous, they provide incredible opportunities for movement," Millar observes.

Thanks to scientists like Millar, formerly simplistic ideas of how highland species will respond to climate change are giving way to a more nuanced view, one that is raising a raft of new questions. What species are relocating, and in what direction are they heading? How many will end up in climatological cul-de-sacs? How many will keep pace with the rate of change? The future is going to present species with opportunities as well as challenges, Millar observes: Witness the young pines that are currently colonizing so many different elevations.

Several years ago, Millar started seeding the subalpine zone with thermal sensors called iButtons in order to study these newly opened habitats. I watch as she climbs partway up a dead bristlecone to retrieve one. For over a year, this small but durable device has nested inside a protective sleeve of PVC pipe, recording the temperature at four-hour intervals. Millar deftly wrests the iButton free and hands it to Westfall, who downloads the data into a battered laptop computer. Then they repeat the exercise in reverse, putting the iButton back in the tree.

Connie Millar retrieves a temperature data logger from an ancient bristlecone pine tree.

A short time later, we head back to Crooked Creek, site of the field camp where Millar and the other scientists are staying. I'm quickly reminded of the fact that Millar hikes well over 1,000 miles each summer in pursuit of her ecological research. As I take small, careful steps, wary of stumbling, Millar bebops her way downhill, a supple, sinewy 56-year-old crowned by a halo of ginger-colored curls.

Mountains cover about 25 percent of the Earth's land surface. They are found on every continent and at every latitude. And because of their sharp elevational gradients, they are centers for biodiversity. In the White Mountains, for example, plants typical of the Mojave Desert lie surprisingly close — less than two vertical miles — to plants found near the Arctic Circle. In between lie other distinctive biomes, with limber and bristlecone forests rubbing elbows with sagebrush steppe and pinon-juniper woodlands. Given all the opportunities for short-distance migration here, it is hard to imagine a place where, in coming years, the jostling for advantage will be more intense.

Over time, it is expected that more species will do what Millar's pines are doing — move in response to rising temperatures. As a result, the number of species at any given elevation is expected to increase. Project GLORIA was founded after botanists at the University of Vienna sampled the plant communities on more than two dozen summits in the Alps and compared them to historical records. They identified nine species that were moving upslope at a pace that ranged from three to 12 feet per decade. Between 1994 and 2004, the summit zone of 11,497-foot-high Mount Schrankogel experienced an 11 percent gain in species diversity. Last month, at a conference held in Perth, Scotland, GLORIA's organizers reported that other mountainous areas in Europe are recording similar gains.

An increase in biodiversity may sound like a positive development, but in this case, it raises concern. In general, the higher you go, the cooler it gets, but that's true only in a relative sense. As the world warms, the high places are warming, too. Eventually, many scientists fear, an unknown number of species will find themselves trapped on mountaintops, unable to move any higher. By the end of this century, some could even face local or regional extinction. It's a scenario with such apocalyptic overtones that Rob Klinger, a U.S. Geological Survey ecologist based in nearby Bishop, calls it the Rapture Hypothesis.

But high-living species haven't run out of options just yet. Craggy terrain, as all mountain-dwellers know, harbors an expansive envelope of climatic conditions — warmer, colder, wetter, drier — that do not conform to elevational lines. West-facing slopes are both windier and rainier than those that face east. And north-facing slopes receive less direct sunlight than south-facing ones, making them moister and cooler. Now, new measurements are giving quantitative heft to these differences. Whether a slope faces north or south is not a trivial thing, says ecologist Stuart Weiss of the Creekside Center for Earth Observation in Menlo Park, Calif. "In fact, it's equivalent to about 1,500 feet of elevation and more than 5 degrees Fahrenheit in mean annual temperature."

There is also the widespread phenomenon of cold-air downwelling. At night, after rocks shed the heat they've absorbed during the day, the air at high elevations quickly cools. Then, because this cool air is denser than the warmer air below, it starts rolling downhill, into valleys and ravines. These "cold holes," as they're sometimes called, can prove surprisingly persistent. They occur in summer as well as in winter and on every scale imaginable. A mountain meadow, though relatively flat, has enough topographical roughness that a cold summer night can cause frost to form in some spots but not in others.

Within an area no larger than a football field there can be dramatic differences. Recently, for example, Weiss and Chris Van de Ven, a geologist from Michigan's Albion College, deployed an array of 26 iButtons, spaced several hundred feet apart, to generate a temperature map of the area around Crooked Creek. At dawn, they discovered, from late July through early October, temperatures on the valley floor are a good 15 degrees Fahrenheit lower than on surrounding slopes. Even in August, nighttime temperatures frequently dip into the 30s, sometimes below freezing.

The chill may help explain why young pines, though moving downslope in many areas, continue to avoid the floor of the Crooked Creek Valley. By contrast, the much-higher ridge I visited with Millar and Westfall seems almost balmy. There, the iButton record for the 2008 and 2009 growing season shows that nighttime minimums rarely dipped below 40 degrees Fahrenheit, while daytime readings frequently climbed into the 50s. Physiologically, this is important. In order to grow, trees apparently require a substantial stretch of time when temperatures stay reliably above 40 to 45 degrees. Where summer temperatures dip too low, they cannot make new pith, new heartwood or new cambium.

Still, it's hard to attribute all the observed tree growth to just one factor. Some experts, for example, point to the fertilizing effect of carbon-based gases. (For photosynthesizing plants, carbon is an essential building block; as carbon builds up in the atmosphere, many trees, shrubs and flowering plants are expected to grow significantly faster.) Then, too, as one descends in elevation, decreasing soil moisture becomes an important constraint. In the White Mountains, the precipitation gradient is steep, dropping from 20 inches a year on the peaks to a scant 5 inches on the Owens Valley floor. As a result, limber pines mostly peter out below about 9,400 feet, partly because of the decline in precipitation and partly due to higher rates of evaporation driven by warmer temperatures.

But there is an intriguing exception, Millar notes. A small colony of young limber pines can be found more than 2,500 feet lower, on the steep north-facing side of the Owens River Gorge. It's certainly cooler in the gorge, and moister, too, but that being the case, why haven't limber pines found their way there before? The same question could be asked about all the other young pines Millar has found deep-diving into Great Basin ravines. The answer, she suspects, can be found in the past, when the region's climate was significantly cooler and wetter. As recently as a century ago, these same ravines were likely choked with willows and cottonwoods, making it all but impossible for limber pines to take root. Now that the climate is warmer and drier, the riparian vegetation has died off, opening up habitat for young pines.

Whoosh. Whoosh. Whoosh. Despite his large frame, John Smiley pirouettes with the grace of a ballet dancer as he swipes his gauze net through the air. Soon he's caught the fluttery thing he spotted out of the corner of one eye. It's a clouded sulfur butterfly, pale lemon in color, with paper-thin wings and delicately patterned eyespots. He's delighted with the find — the species is new to this study — but does its presence here mean anything? The veteran biologist shrugs. A common butterfly in many parts of the United States, the clouded sulfur has been spotted before in the White Mountains, albeit a few hundred feet lower.

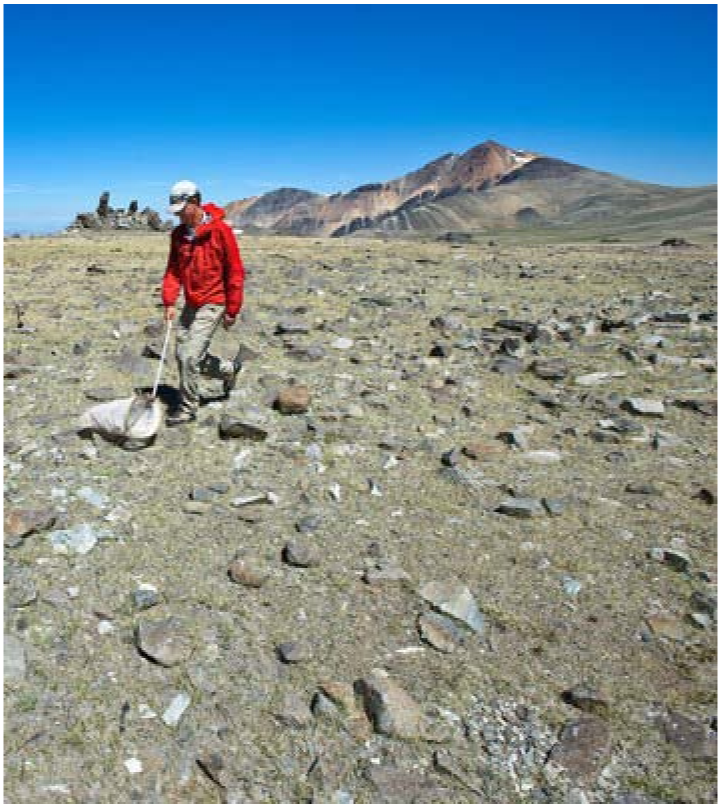
Smiley is the associate director of the White Mountain Research Station. He is also the leader of the annual butterfly count. I've been trailing behind him all day. Our first stop, a rocky meadow beneath White Mountain Peak, yields a fair number of butterflies called Shasta blues, though not quite as many as Smiley found here two years ago. Then, he and his colleagues counted a total of

875 Shasta blues in the space of just half an hour. The previous record was 230 sighted over a 24-hour period. "The Shasta blue is not a common butterfly," Smiley reflects. "So what we may have found here is a core area for the species, one from which it spills out to colonize other areas. Maybe Shasta blues do really well only in high alpine locations."

Butterflies including Shasta, Boisduval and lupine blues, and an orange lustrous copper, mud-puddle on a patch of moist ground.

As we make our way down the mountain, the list of species lengthens. We see lustrous coppers, Edith's coppers, Mexican cloudywings, common-banded skippers, a Riding's satyr, a Becker's white and blues of various kinds: Shasta blues, Melissa blues, lupine blues, Boisduval's blues. We see them singly and in flocks, doing what blues like to do, which is to engage in an activity called "mud-puddling." (The term refers to their habit of alighting on patches of wet ground that contain dissolved salts and other nutrients.)

Tagging along with the butterfly team are Jeff Holmquist, another White Mountain Research Station scientist, and his wife, Jutta Schmidt-Gengenbach. Butterflies, Holmquist says, are big and showy, but there aren't that many of them. Ditto for the colorful dragonfly I spot on the wing, and the hunting wasp I see sipping nectar from a purple aster. More important, ecologically speaking, Holmquist says, is the army of far tinier creatures — flies, spiders, ants, beetles — that serve as herbivores, pollinators and predators.



Scientist Jeff Holmquist uses a butterfly net to sweep for insects in California's White Mountains.

While the butterfly-census takers (there are three this year) spread out, Holmquist and his wife execute a well-practiced sequence of maneuvers. First, Holmquist takes a net and sweeps it over a defined area precisely 50 times. He then stops to dump what he's collected into a plastic bag that Schmidt-Gengenbach holds open. At that point, he switches to a garden-variety leaf blower, which, he explains, can also be used like a vacuum cleaner. To block the noise, Holmquist puts on earmuffs while his wife positions a small mesh trap on the ground. Then he focuses on sucking up everything possible from beneath the tent-like enclosure. After he finishes, I peer into the collection bag and see grains of soil, wisps of grass and a fair number of creepy crawlies.

Jeff Holmquist and Jutta Schmidt-Gengenbach use a leaf blower to vacuum up insects in a test plot of the Inyo National Forest.

In recent years, Holmquist says, the density of small invertebrates in these high meadows has appeared to rise and fall in lockstep with precipitation shifts. "We're at the point where we think we see a pattern," he says. "But ask me again in a couple of decades." When it comes to ecologically available moisture, he notes, temperature is also a player. This spring, for example, was unusually cool and wet; throughout May, high elevations in the Whites were covered in snow. And then, Holmquist says, "Somehow a switch got thrown, and it got hot. It seems like August already, not mid-July."

A transient shift in the character of a season means nothing, of course, but a persistent shift would have cascading effects. If summers turn hotter, for example, then plants could be forced into premature senescence. Earlier spring warm-ups could lead them to green up and flower out of sync with their insect courtiers. And if snow melts too soon, both plants and animals could be exposed to outbreaks of severe cold. That's because snow is an excellent insulator, keeping near-ground temperatures from dipping much below 32 degrees Fahrenheit, which is downright toasty compared to the subzero readings for air temperatures found here in the winter.

An illustration of the importance of snow comes from a long-term study of willow leaf beetles that Smiley and his colleagues have been conducting in the Sierra. A reduction in snow cover, they think, may be responsible for the fact that these small, speckled herbivores have all but abandoned areas below 9,400 feet. The mechanism is probably two-fold, Smiley says, with snow protecting overwintering adults from drying out as well as from freezing. The process also works in reverse. This year — not coincidentally a year of late snow melt — a couple of beetles were observed in areas from which they were thought to have disappeared.

Rock. Bare Ground. *Draba.* Rock. Rock. I'm watching Jim and Catie Bishop, volunteers from the California Native Plant Society, walk a transect line defined by orange string held taut by Bob Westfall. At precise intervals, they stop to call out what they see. Seated on the ground, Connie Millar jots it all down on a worksheet. The exercise goes quickly because the plants here — including *Draba oligosperma*, a pretty yellow-flowered member of the mustard family — are outnumbered by non-living substrates, with islands of plants and leaf litter surrounded by talus and scree. It's like looking at a moonscape with flowers.

After two days in the field, the botanical teams conducting the survey have mastered their arcane GLORIA protocol. They're hoping to finish this, the last of three peaks, by mid-afternoon. At their feet, amid sharp shards of dolomite and quartzite, blooms a diminutive garden, and, all around, strands of multicolored string radiate out from this obscure 12,258-foot-high peak. Like a compass rose, the design marks the cardinal and ordinal directions. A short way down, the smallest survey plots, outlined in shiny white measuring-tape, are enclosed by larger lime-green diamonds, and around the diamonds, a yellow string wraps completely around the summit.

Working in pairs, the surveyors swing into action. In places, they fall to their hands and knees to count each plant individually. Elsewhere they meander around, recording a list of the species they see and making estimates of their abundance. In this way, a picture of what's present — and, just as important, what's absent — slowly comes into focus. Earlier in the week, at the first summit they tackled, the team took note of two limber pine seedlings at the tip of the south-facing green diamond. They checked their records: The seedlings were not present in 2005, when the peak was previously sampled.

Finding the little pines in that particular place was just what the researchers were expecting, Millar says. The site, after all, rises directly above Patriarch Grove, a stand of ancient bristlecones where young trees are now pushing above timberline. The summit where the team is working today is not only a good 700 feet higher, it also sits at a farther remove from the grove. And while it would not be surprising, some day, to find a little limber pine here, so far no trees have materialized, just the expected contingent of high-elevation specialists like White Mountain buckwheat, pygmy fleabane and a rare alpine daisy along with more broadly distributed species: yellow rabbitbush, dwarf sagebrush, Sierra beardtongues.

"Ooh," says Catie Bishop, peering at a tiny *Draba* leaf through her hand lens. It's covered with delicate white hairs. "The phlox here has hairs, too," she says, "but they're not as spectacular." The hairs represent an adaptation to the harsh conditions that prevail at high elevations. Among other things, they shade the leaves from ultraviolet radiation; they also serve to deflect drying winds. The low stature of these plants is important, too. Almost uniformly, they huddle close to the ground, which, in summer, stays quite a bit warmer than the air and, in winter, lies under snow.

Of course, a number of the species that grow here can also be found at lower elevations and so should be able to handle some degree of temperature rise. Even within a single species, there are always individuals capable of accommodating a greater degree of climate stress. Virtually every species, for example, comes equipped with genes that encode so-called "heat shock" proteins, but there may well be subtle differences between, say, one *Draba* and another. In the Sierra, Smiley and his colleagues have discovered, willow leaf beetles equipped with one variant of the heat shock-gene do noticeably better under warmer conditions.

Condensed phlox and purple pygmy fleabane among dolomitic rocks in the White Mountains, Inyo National Forest.

But the ability of species to cope with climate change is not infinite. Game changers — extreme events like disease outbreaks, wildfires and multi-year droughts — can reconfigure landscapes almost overnight. As resident plants and animals die off, migrants from adjacent areas swiftly move in to take their places. Even slow-paced change adds up. Indeed, it's easy to imagine how, over time, ground-hugging cushion plants might be marginalized by taller, faster-growing species that are making their way up from less harsh environments. There is a trade-off, says botanist Steve McLaughlin, a University of Arizona professor emeritus who is helping with the survey. "The general principle is that the adaptations that increase survival in stressful habitats, such as those that presently prevail at high elevations, reduce the potential for rapid growth."

Around noon, members of the team stop for lunch, parking themselves on a slope that opens to a panorama. From here, you can see the snow-streaked Sierra crest, the purpling ranges that roll like waves across the Great Basin, the dark, brooding canyon at the heart of the newly created White Mountains Wilderness Area. Closer in, white knobs of dolomite, a type of limestone, alternate with darker humps of granite and quartzite, which is metamorphically hardened sandstone. There are patterns in the vegetation as well. Bristlecone pines hew to soils derived from dolomite, whereas sagebrush gravitates towards the granite and the quartzite. No one knows exactly why, but the effect is pleasing.

"It's a mosaic," Millar says. And, indeed, you do get the sense of looking through a kaleidoscope that climate, along with other forces, has repeatedly twisted over time. The next turns of the kaleidoscope, however, are going to rearrange a landscape that is only partly natural. Even in this protected place, where the human footprint is relatively small, weedy Eurasian annuals can be found here and there, waiting to take advantage of any disturbance. "On the one hand, it's comforting that native species must be at least somewhat adapted to climate change," Millar reflects. "On the other hand, we are not going to like certain consequences, like species declines and weedy invasions."

Among the most unsettling impacts of climate change will be the transformation of iconic landscapes, a process that, in parts of the West, is already well under way. Over the past decade, for example, the Rocky Mountains have experienced a massive dieback of lodgepole and whitebark pine forests due to a combination of factors, ranging from drought exacerbated by rising temperatures to bark beetle infestations. It's as if a once-locked door has swung wide open, inviting passers-by in. In some cases, these forests may rebound; in others, they are likely to be replaced by some novel combination of native and non-native species.

The lunch break ends; the GLORIA team goes back to work. *Draba*. Rock. Rock. The cadence seems soothing, somehow reassuring, as does the steady progress Millar and the others are making. Quietly, methodically, they are compiling a chronicle of one of the most extraordinary epochs in Earth's history, the "Anthropocene" or human epoch, and their account seems destined to become a classic. Thanks to them, future generations won't have to speculate about the ecological impacts of greenhouse warming on mountain flora and fauna. They will be able to look back through the lists being assembled today and know how much has changed. Because an awful lot is going to change: All the ruggedness of this high, wild place cannot reverse the warming that is occurring, Millar says. It can only modulate its impacts.

"Right now," she says, "the only thing we know for sure is that there will be surprises."

J. Madeleine Nash is a freelance journalist and science writer based in San Francisco, California. Her 2009 HCN *story "Bring in the Cows" (www.hcn.org/issues/41.9/bring-in-the-cows) recently won a 2010 Science in Society Journalism Award from the National Association of Science Writers, in the Local or Regional Science Reporting category.*

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