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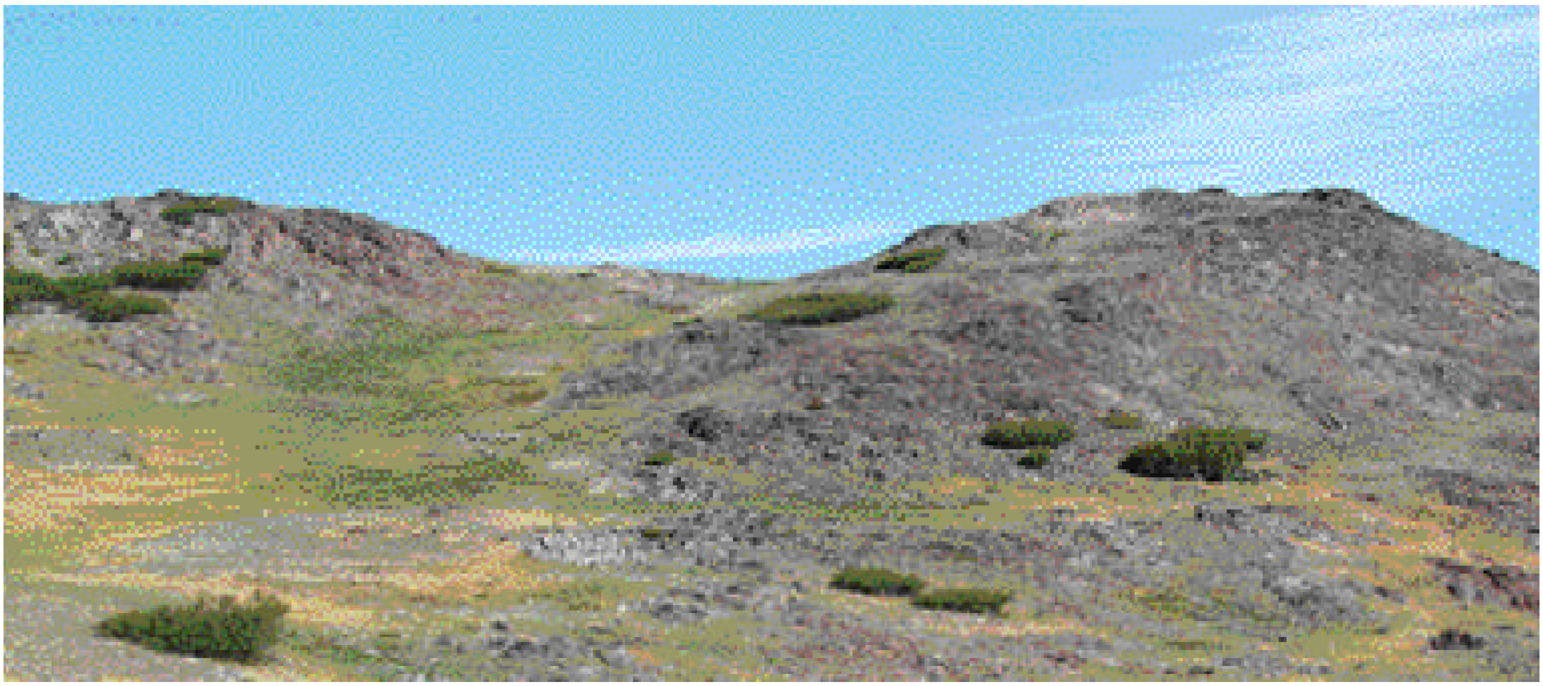
THE COVER: California bristlecone pine woodlands at their upper limit give way to the alpine zone above, a cold, treeless biome being studied carefully for evidence of climate change. Photo by Stu Weiss.

The early morning is cool and clear, as long shadows of the last and highest-elevation trees stretch across the open slopes ahead. Our team hikes steadily on towarÏd the summit, carrying measuring tapes, compass, level, strings, pin flags and markers, quadrat frames, data binders, cameras, small blackboard, and plant press. After pausing on top to distribute the equipment, everyone sets about a task—some lay out the survey system, some assemble the plant list.

A beautiful world of alpine plants lies at our feet; spectacular views meet our gaze in every direction. It is not yet mid-morning, but we check the sky for the first signs of cloud formation…nothing yet. As soon as the survey areas are defined with colored strings, the work of identifying each plant species and assessing its coverage begins. Meanwhile two people begin the extensive photo documentation protocol.



USING ALPINE FLORA TO MEASURE ECOLOGICAL EFFECTS OF CLIMATE CHANGE

by Jim Bishop

Our California team, which is working to establish monitoring sites in the higher mountains of the state, is part of an international effort to detect and measure changes in the alpine flora that would be expected to occur as the climate changes. As an ecosystem at a climate extreme—one that is very temperature dependent—the alpine zone is a sensitive indicator of such change.

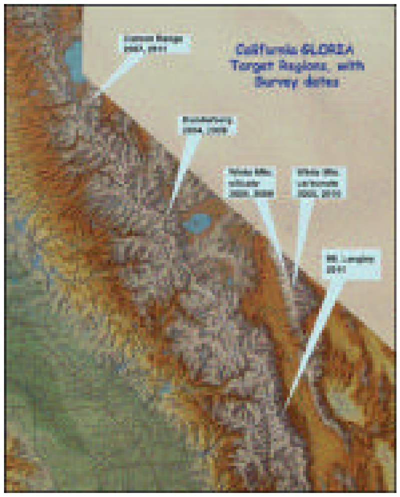
NEED FOR A UNIVERSAL ALPINE-MONITORING PROTOCOL

During the past century, scientists have observed changes in alpine flora and in tree line elevation. In Scandinavia, for example, tree lines have risen by over 500 feet. Where conditions become less harsh, a greater number of species can survive. Species richness of many alpine peaks has increased, and on one summit in the European Alps increased from 1 to 10 species over 100 years. That would be expected if the cold alpine elevations are warming. But until the last ten years, there had not been a standard, universal, and replicable process for assessing such changes.

In response to the need for better scientific data and more valid comparisons, the Global Observation Research Initiative in Alpine Environments (GLORIA, *http://www.gloria.ac.at/*) was conceived at the University of Vienna and established at field sites in Europe in 2001. GLORIA defines a protocol that can be applied to alpine summits anywhere in the world. The alpine zone is ideal for detecting biological effects of global climate changes. Human disturbance there is often minimal, it spans nearly all latitudes and elevations, and it samples the major climate zones of the world—maritime and continental, tropical, midlatitude, and polar.

UNDERSTANDING THE ALPINE ZONE

The story begins with the question of why there is an alpine zone. Understanding the environmental stresses on alpine plants and their adaptations is the foundation for viewing their responses. The alpine zone is defined as that above the upper tree line—a remarkably consistent elevation in a given region, with the trees dropping out completely over elevation increases of just—feet. Without the absence of trees there would be no alpine zone. Why should trees meet such a limit to their growth? Answering this question requires understanding how temperature limits plant cell growth, and how it limits tree growth. Plant cell metabolism is very temperature sensitive, slowing to almost no cell growth at about 42° to 46° F. If the daily mean air temperatures (the average for the day) averaged over the growing season falls much below about 44° F, trees can no longer subsist. That is a global observation, consistent over different taxonomic families, elevations, growing season lengths, latitudes, and precipitation regimes.



There are currently five areas in California where alpine-plant survey work is being conducted as part of the international GLORIA Project.

Tree foliage is effectively cooled by the air flow. Tree root zones are shaded by the crowns and remain close to the average air temperature. So in effect a tree experiences a cold temperature limit dictated by average air temperature. Average temperature in the lower atmosphere declines steadily with increasing altitude. Therefore, above tree line elevation, the growing season is simply too cool to sustain tree growth.

But other types of plants persist in the alpine zone, in spite of cooler air temperatures there—plants with the same temperature-limited basic metabolism as trees. How do plants that live above the tree line do it? The secret lies in their form and stature, allowing them to be warmer overall than air temperature would indicate.

The low stature and compact form of alpine plants reduce cooling from the air flow and allow absorption of sunlight to warm aboveground plant parts. Foliage of alpine plants can be sun-warmed above air temperature by some 36° F (so the temperature of an alpine plant might be well over 80° F on a 50° F day). The typically sparse distribution of alpine plants leaves much ground (usually over 50%, often 80% or 90%) exposed to solar heating, and their forms transmit more heat to

A team hiking to the Dunderberg target region in the central Sierra Nevada. Photo by Catie Bishop. All other photos by the author, except as noted.

Alpine flowers. CLOCKWISE FROM UPPER RIGHT: Cushion Townsend daisy *(Townsendia condensate)*, Sierra penstemon *(Penstemon heterodoxus)*, Pacific hulsea *(Hulsea algida)*, cushion buckwheat *(Eriogonum ovalifolium)*, White Mountain buckwheat *(Eriogonum gracilipes)*.

the ground than do raised crowns. Consequently their root system temperature is above the average of that for shaded sites. In effect, even though alpine plants grow at a higher elevation than trees, they experience a warmer microclimate.

As beautifully adapted as they are, alpine plants still live at the edge of adequate warmth and they benefit from the lack of competition from the cold-limited trees, so they are very vulnerable to temperature changes. Alpine plant ecosystems are also dependent on snow distribution. Snow shelters many of them from extremes of winter cold and desiccation. Late-season snowfields retard growth until they melt, and upon melting release a flush of nutrients and water. Alpine vegetation patterns are strongly controlled by the distribution of snowfields.

It is expected that at least two variables related to climate change could significantly affect alpine ecosystems—warmer temperatures, and amounts and patterns of precipitation and snowmelt. Warmer temperatures can raise the tree line, and will raise the elevations at which a variety of alpine and subalpine plants can be more competitive. Less snow or more snow, and changes in patterns of snow deposition and melt schedule can also alter alpine plant distributions.

GLORIA IN CALIFORNIA

GLORIA began in California in 2004 due to the tireless efforts of Connie Millar of the Pacific Southwest Research Station, USFS, and was the location of the first project sites in the Western Hemisphere. Millar remains the force behind all of the California projects and is also a contributor to other North American sites.

Each GLORIA project is organized around a "site""called a target region (TR), and includes a group of 3 or 4 summits, spaced in elevation from the highest peaks down to near tree line. California GLORIA summits now number 18, in 5 TRs, from Langley Peak in the southern Sierras to the Carson Range near Lake Tahoe, and at several locations in the central White Mountains. A team of volunteers, students, and agency employees (who have been granted release time from their normal duties to help) are doing fundamental studies of the alpine ecosystem and its changes. CNPS volunteers have been consistent and important contributors to the project.

Surveys will be repeated at five-year intervals to measure change in the alpine flora. The information that is gathered will be shared globally, as it is at sites in other countries around the world.

THE GLORIA SURVEY PROTOCOL

The summit-centered GLORIA protocol outlines a set of survey plots (successively smaller plots within larger ones) that occupy the slopes of the four main compass directions (N, E, S, and W) on each peak. The plots lie in two elevation bands: the uppermost band takes in the 5 meters (16.4 feet) in elevation just below the peak, and the lower band lies between 5 and 10 meters (33 feet) below the peak.

The materials required to conduct GLORIA surveys have purposely been kept low-tech and therefore are usable worldwide regardless of local resources. A compass, tape-measure, and a string-level (a builder's level that is attached to a string) are all that are needed for surveying. Colored string marks the plots, and pin flags have various uses. A one-meter-square quadrat frame with 100 cells is used for the finest-scale observations. All reference points are defined by compass direction and distance from the "high summit point."

Information collected includes each species present (including voucher specimens on the first survey); its degree of cover (as a measure of each species' abundance and its influence on available space, light, air, and water); and the cover of other elements such as rock or soil. The amount of rock and soil indicates the potential for expansion of plant cover, and plant cover may change as climate changes. (See Sidebar 1 for protocol details.)

Enhancements to the basic GLORIA protocol have been developed in California. One of them, the "California method," is now an option in the international protocol. The observation provides much better quantitative data on plant cover over an area that samples much of the variation on the summit. It covers a larger area than the one meter by one meter quadrats, but is not subject to the errors of visual estimates of plant cover on the large survey plots.

The White Mountain Research Station is now a GLORIA World Master Site, where many studies of alpine ecology complement the basic GLORIA surveys. These additional studies encompass extended plant surveys, tree line and shrub line mapping, small-scale temperature modeling, insect monitoring, alpine meadow flora, and periglacial processes (freeze-thaw cycles). A set of weather stations now extends from the base of the White Mountains to the highest summit, providing a direct measure of the climate there over a range of elevations—important information to relate to any observed ecosystem changes.

LOOKING BELOW THE SUMMITS

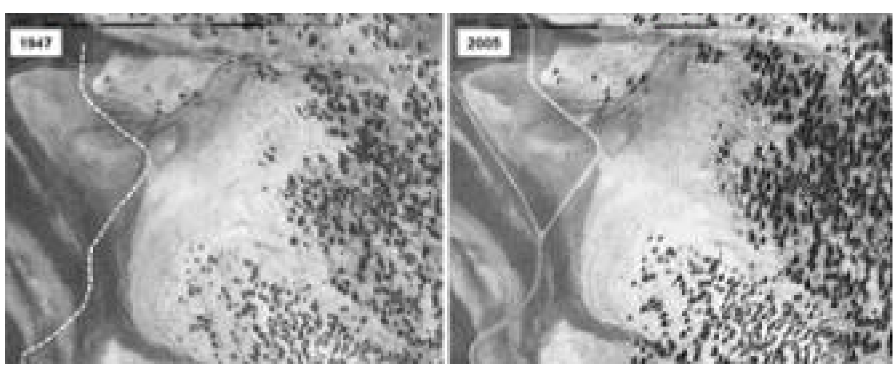
A major addition to the summit surveys are the "downslope surveys," observations that cover the alpine zone"*below* the GLORIA summits and provide a more comprehensive view of the alpine ecosystem throughout its entire elevation span. To date, such surveys have been conducted on four major slopes, collectively spanning the elevation from White Mountain Peak at over 14,000 feet down into the bristlecone-limber pine woodland at 10,800 feet. (See sidebar 2 for protocol details.)

The data gathered from the slopes reveals flora that could potentially be moving up toward the summits in response to warming. It shows the distribution of each species by elevation at a given time. Comparing this with the same species' elevation distribution at a later time (for example 10 years later) can produce a very useful measure of just how much the elevation distribution of that species has shifted over time, very possibly rising as the world warms.

EARLY RESULTS

What have we learned so far? The initial baseline surveys cannot of themselves reveal change. But they have provided useful and detailed information on the species that are present, their relative abundance, and their detailed distributions on summits and slopes of the alpine zone in California.

Upper edge of bristlecone-limber pine woodland at Patriarch Grove in the White Mountains, 1947 and 2005. Dashed line on 1947 photo indicates road trace corresponding to road in 2005 photo. Note the many young bristlecone pines within and beyond the woodland in the recent photo. Most of the global warming in this period took placed after 1970. Photos courtesy of Daniel Pritchett of the White Mtn. Research Station.



ELEMENTS OF THE GLORIA PROTOCOL

The main objective of the GLORIA protocol is to record the plants that grow on the summit, to note roughly where they are distributed around the peak, and to estimate how much area each species covers. That requires looking at both large-scale and small-scale plots, and on the differently-oriented slopes. The plots are outlined with colored string, and field workers examine each plot carefully for the plants that occur there.

A diagram of the survey plots as they would appear on the south slope of this summit (HSP is the high summit point). Orange marks the perimeters at the 5-meter and 10-meter levels; pink marks the boundaries of the south-slope plots; yellow is the California Method diamond; green is the grid that locates the one-meter quadrats.

A set of survey plots is laid out on the slopes of the four main compass directions or "aspects" (N, E, S, and W). They lie in two elevation bands: the uppermost band spans the 5 meters in elevation just below the peak, and the lower band lies between 5 and 10 meters below the peak.

In each summit area section (SAS)—the area on one aspect and within one elevation band—the plant cover is visually estimated. In the 1m x1m quadrats (outlined with a frame containing 100 cells), cover is estimated by noting the occurrence of each species in each of the cells. Each group of four quadrats is centered on a main compass direction at the 5m perimeter

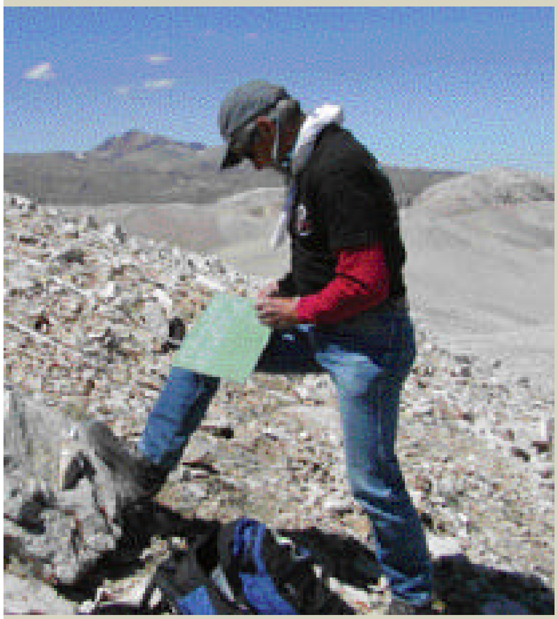
Over 60 photographs are taken on each summit, from broader photos of the SAS to the square meter of each quadrat. The photos also document the plants and their coverage, as well as the survey system reference points for placing resurveys.

To learn how the actual temperatures and snow cover are changing, a temperature recorder is buried 10 centimeters deep on each aspect. Temperature is recorded approximately hourly for several years. The recorder is then dug up, and the records are recovered. The soil-temperature curve has a narrower daily temperature range than the surface-temperature curve, but has a similar average. Changes in average air temperature will be reflected in soil temperature. But when snow covers the ground, the soil temperature remains essentially constant at 32°F, and in that way reveals precisely the periods of snow cover.

BELOW LEFT: Identifying plants. BELOW RIGHT: Searching for inconspicuous plants. Photos by Scott Sady/TahoeLight.com.

AN ADDITIONAL PROTOCOL: THE CALIFORNIA METHOD

A 10 X 10-meter "diamond" is centered in each aspect on the 5-meter perimeter. Within the plot, 400 sample points set on a Ω-meter grid produce very useful quantitative data on plant coverage at the mid-scale (surveys prior to 2009 used 100 points). Estimating plant cover visually is difficult, especially for plants that have low cover values, and such estimates are of very limited accuracy. The quadrat measurements are much more accurate than visual estimates, but they cover only small areas. The 10m X 10m areas yield good accuracy over intermediate areas.

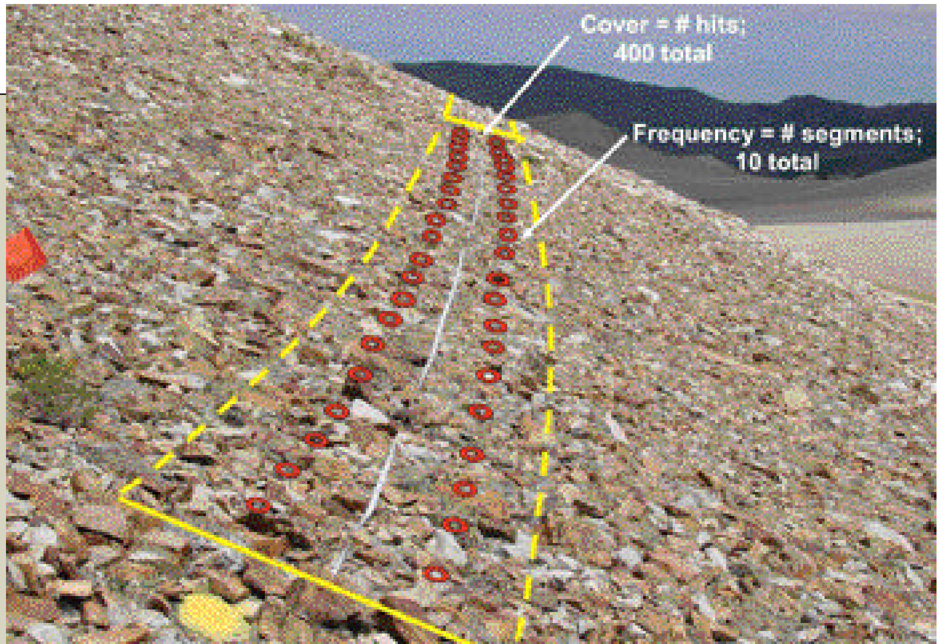


ABOVE LEFT: Taking data on the quadrat grid • Top: Documenting photo points. • LEFT: Leveling the string from which to determine the 5-meter and 10-meter perimeters. Photo by Catie Bishop. • ABOVE: Measuring the distance to reference points, which are used to guide the placement of resurveys.

In California, four of five target regions have been resurveyed, and two of the downslope surveys in the White Mountains have been repeated. Many of the repeat surveys show increased species richness. The recent downslope resurveys also showed an increase in the number of annual species (perennial habit is best suited to the demands of the alpine environment, and alpine annuals are uncommon). However, that may be due, in part, to a wetter-than-normal year.

Findings over the ten years from 1994–2004 from the European Alps has shown reductions in cover of the highest elevation species (those in the zone of permanent snow, or the “nival” zone), with lesser reductions and some increases within the alpine subzones below that. These changes show that the highest plants are losing ground to plants from lower elevations, at least over a recent decade.

Even if the changes observed in the GLORIA resurveys are significant, it is not possible to attribute change over five years to long-term climate trends. Inter-seasonal variation can easily affect the flora represented in a given year. The value of the current comparisons is that they demonstrate the potential of



Outline of one segment, 1 meter wide and 10 meters long, centered on the white tape, of the 100-meter belt transect at that elevation. All species are noted within the segment. Sample point positions for plant species or cover type are indicated on this photo with red circles. “Frequency” refers to the total number of segments a species occurs in; “Cover” refers to the number of sample points that contact a given species or cover type.

DOWNSLOPE SURVEY PROTOCOL

Downslope surveys are conducted on some of the slopes below the GLORIA summits, into the subalpine woodland. Meter-wide belt transects along the elevation contour are spaced every 25 meters (82 feet) in elevation. Each transect is 100 meters long (100 square meters total area), divided into10-meter segments. All species present in each 10-meter segment are recorded. At sample points spaced every half meter (400 for the entire transect) the plant species or other cover type is identified. The downslope transects duplicate, in area and sampling density, the 10m X 10m California-method plots on the summits.

LEFT: A pointer that marks two sample points, one at each end, is moved along and placed every one-half meter along the tape. • BELOW: Botanists look closely for small plants, since it is easy to miss some of the Alpine species, which can be quite tiny.

the protocols to reveal change. However, only changes in a direction consistent with a warming world, sustained over two or more decades, will indeed be compelling evidence.

Current data is also being compared to earlier botanical data from the White Mountains. For example, the uppermost occurrence on granitic substrates of dwarf sagebrush (*Artemisia arbuscula*) as reported in 1961 has been compared to the recent upper shrub line surveys and downslope surveys. Based on those observations, which span a 50-year interval, this species' upper limit has risen 500 feet, and several common alpine plants have been reduced in cover wherever the *Artemisia* has encroached. Aerial photo comparisons from the late 1940s into the 2000s show bristlecone pine woodland filling in along its upper margins and young trees spreading upslope.

Much remains to be learned, and only time will reveal long-term change. But the baseline data being established, and the early look at changes, are an important contribution to assessing the impacts of climate change on the alpine ecosystem across the world.

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The team is finishing up its work on the summit. Strings are wrapped on cardboard holders, data books carefully packed away. We enjoy last views of the magnificent landscape, and begin the hike down. Beginning with a few morning cumulus over the highest peaks, the clouds have now become tall and massive, bright against the mountain sky. A faint roll of thunder is heard from just a few miles away. It is good to be on our way down.

Back at camp we'll finish up some challenging plant identifications and file the data sheets. We'll gather the equipment for the next day's work, and vow to begin early enough to finish before storms end the field day.