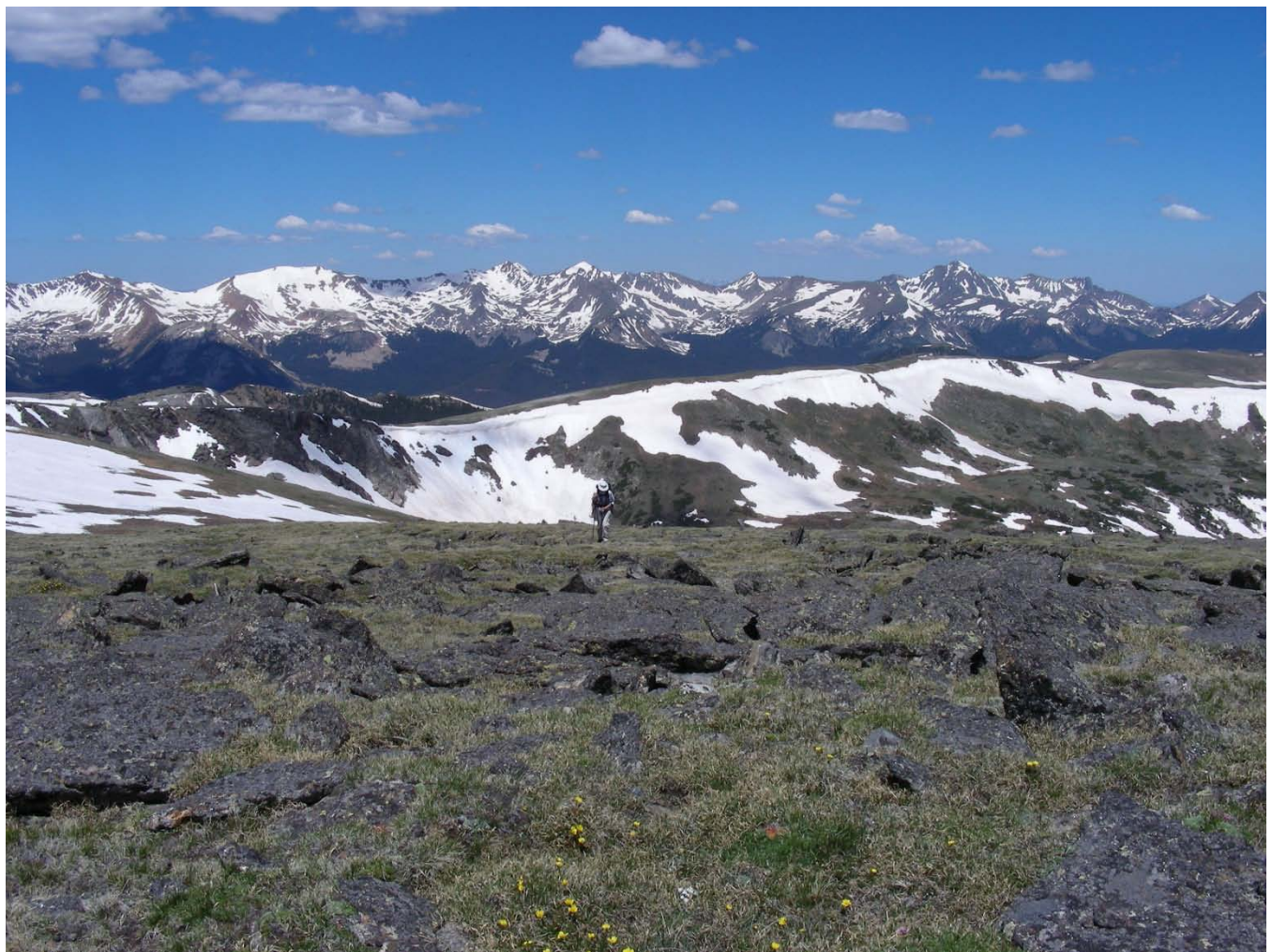




Alpine vegetation composition, structure, and soils monitoring for Rocky Mountain National Park

2009 Summary Report

Natural Resource Data Series NPS/ROMN/NRDS—2010/057



ON THE COVER

Ann Henson walking up the ridge to Mount Ida with one GLORIA sentinel site (PIK) and the Never Summer Mountains in the background, June 2009, Rocky Mountain National Park

Photograph by: Isabel Ashton

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Isabel Ashton
Mike Britten
Donna Shorrock
Billy Schweiger

National Park Service
Rocky Mountain Inventory and Monitoring Network
1201 Oakridge Dr, Suite 200
Fort Collins, CO 80525

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U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

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Executive Summary

Alpine ecosystems are important monitoring targets for the Rocky Mountain Inventory and Monitoring Network (ROMN) for a number of reasons, including their value to park visitors, wildlife, and water resources in the West and because the alpine is particularly vulnerable to climate change. Here, we present a summary of our efforts in 2008-2009 to monitor vegetation composition, structure, and soils in the alpine of Rocky Mountain National Park (ROMO). We found the following:

- In 2008, an alpine monitoring site was established at ROMO following the guidance from the Global Observation Research Initiative in Alpine Environments (GLORIA) whereby the park became part of an international effort to monitor biodiversity and climate change in the alpine.
- In 2008 and 2009, a GLORIA sentinel site was established at four peaks, Jackstraw Mountain and 3 unnamed peaks on the ridge to Mount Ida. The peaks range in elevation from 3520 to 3862 m.
- There were 106 species of vascular plants identified from the four peaks. We found a similar number of species on each peak, where most had about 60 vascular plant species.
- We measured the presence and frequency of lichens in 1 m² quadrats on all aspects of the four sentinel peaks. In general, we found more species of lichens in a quadrat than vascular plants and lichen species richness was consistent across summits and aspects, with quadrats averaging 27 species of lichens and only 18 vascular plant species.
- The four peaks are generally characterized by stable soils, high vegetation cover, low exotic species cover, and minimal human and herbivore disturbance.
- For the winter of 2008-2009, mean daily soil temperatures remained below freezing for most of the time between October and May. The east side of the peaks had more consistent snow cover than the other aspects.

In 2009, we found the alpine tundra at the four sentinel sites in ROMO to be a system little impacted by human disturbance or exotic species. Climate change and increased atmospheric deposition of nutrients are the greatest threats to alpine systems in ROMO. Continued monitoring of the vegetation and temperature at sentinel sites will allow us to determine whether climate change correlates with changes in biodiversity in the alpine. Warmer temperatures may contribute to the extinction of some plant species while simultaneously increasing the elevation and latitudinal limitations of other species.

Acknowledgments

I thank all those that assisted with field work, particularly Ann Henson who identified and measured the frequency of lichens in quadrats at all four peaks. Kurt Chowanski, Donna Shorrock, Joel Smoot, Rachel Lazcano, David Pillmore, Jennifer Burke, Simon Kingston, Tim Henson, and Elaine Thomas, Alex Cahlander-Mooers contributed a great deal of time and hard work to help sample the peaks in 2009. I also thank Paul McLaughlin, Mike Britten, Donna Shorrock, and John Spence for all their work in 2008 to establish the summits, install dataloggers, and provide preliminary species lists. I would also like to thank the staff at ROMO for being exceptionally helpful with logistics, housing, and accommodating our office needs particularly Cheri Yost and Judy Visty. Finally, the staff at the GLORIA office have been invaluable, particularly Barbara Friedmann and Christian Klettner, by providing databases, field sheets, and methods. This manuscript was improved by comments from Amy Miller and Regina Rochefort.

Introduction

The purpose of the National Park Service (NPS) Inventory & Monitoring (I&M) Program is to develop and provide scientifically credible information on the current status and long-term trends of the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. The Rocky Mountain I&M Network (ROMN) identified vegetation composition, structure, and soils as a vital sign that can be used to better understand the condition of park ecosystems (Britten et al. 2007). The alpine, defined as the vegetation communities that exist above treeline, is represented in three of the ROMN parks: Glacier National Park, Rocky Mountain National Park and Great Sand Dunes National Park. The area above treeline including vegetated and non-vegetated areas makes up 28%, 20%, and 3% land cover in each park, respectively. The ROMN selected alpine ecosystems as an important vegetation monitoring target in these parks for a number of reasons, including their value to park visitors, wildlife, and water resources in the West and because the alpine is particularly vulnerable to climate change. Here, we present a summary of our efforts in 2008-2009 to monitor vegetation composition, structure, and soils in the alpine of Rocky Mountain National Park and Preserve.

Since this was our initial monitoring effort, this report summarizes only the status of alpine in the park at four sentinel sites and does not explore trends. Sentinel sites are locations where monitoring will be long-term and is frequent and detailed (Britten et al. 2007). The long-term objectives of our alpine monitoring effort will focus on both status and trends. Specifically, our objectives are to:

- (1) Determine the status and trend in **vegetation composition and structure** of four sentinel alpine peak communities at a range of elevations.
- (2) Determine status and trend in **cover of invasive/exotic plant species** at four sentinel alpine peak communities at a range of elevations.
- (3) Determine the status and trend in **soil condition** based on a suite of physical and chemical properties that include: surface stability, soil carbon (C) and nitrogen (N) content, pH, texture, evidence of erosion, extent of bare (non-vegetated) soils, and compaction at four sentinel alpine peak communities.
- (4) Determine the status and trend in **anthropogenic and natural disturbance** at four sentinel alpine peak communities at a range of elevations based on a qualitative index of anthropogenic disturbances (e.g. distance to roads) and natural disturbance (e.g. evidence of fire) and the presence and frequency of feces, trampling, and browsing damage.
- (5) Determine the status and trend in **soil temperature** and **snow cover** period of four sentinel alpine peak communities at a range of elevations.

Methods

The ROMN adapted an alpine monitoring protocol from the Global Observation Research Initiative in Alpine Environments (GLORIA), an international monitoring network established in 2001 to assess and predict biodiversity and temperature changes in alpine communities in response to drivers such as climate (Pauli et al. 2004). The goals of the GLORIA program are to provide a global baseline for vegetation monitoring in alpine environments and to assess the risks of biodiversity loss and ecosystem instability from climate change. The methodology is extended by cooperators, such as the ROMN, to create a long-term monitoring network at the global scale. The ROMN Alpine Vegetation Composition, Structure, and Soils protocol follows established GLORIA protocols but adds components for soil condition, treeline movement, and human disturbances (Ashton et al. 2010).

Sample Design

We followed the GLORIA monitoring design (Grabherr et al. 2000) which for one GLORIA site calls for the establishment of four sentinel sites on alpine peaks representing an elevation gradient within a target region (e.g. west of the continental divide in Rocky Mountain National Park, CO). The sites are established on the top of the peaks (summits) and the summits vary from just above treeline to the highest life zones of vegetation. Within one region, all four summits share qualitatively similar geology, climate, disturbance, and land-use history leaving vegetation differences among the summits to be driven primarily by elevation.

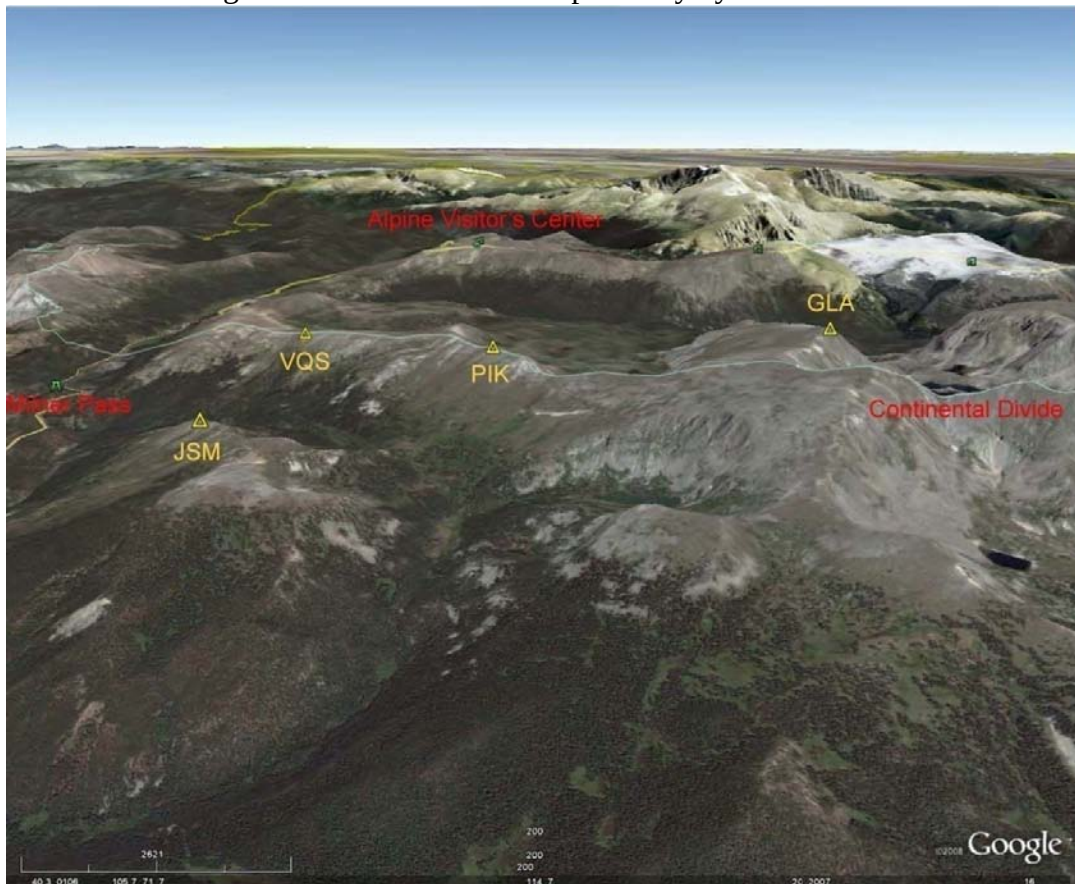


Figure 1. Locations of the four sentinel GLORIA peaks in Rocky Mountain National Park.

In 2008, we established monitoring sites at four summits within the Rocky Mountain National Park (US-RMN; Table 1). We examined topographic maps and photographs, discussed options with park managers, and hiked to potential sites to select the best summits. The summits we chose are within close proximity of one another (all within ~ 3 km) on a ridgeline that climbs to Mount Ida and the lowest site is nearby on Jackstraw Mountain (Figure 1). The four peaks have similar geology (mica gneiss, schist, and migmatite), similar land-use history and disturbance levels, and a similar climate. We permanently marked the sites to ensure accurate relocation, buried HOBO Onset pendant temperature loggers (UA-001-64) on the north, east, south and west side of all peaks to acquire hourly temperature data for the winter of 2008-2009, and drafted preliminary species lists for two of the four sites. At each peak, we installed one marker (a rebar with a labeled aluminum cap) at the highest point on the summit, and identified and marked 9 m² quadrat clusters in each cardinal direction at exactly 5 m in elevation below the summit (all four corners of the quadrat cluster are marked: one with capped rebar and 3 with nails; Figure 2).

Table 1. Name, location, elevation, and vegetation zone of the four alpine sentinel sites within the target region of ROMO.

GLORIA Summit code	Summit name	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Vegetation zone
GLA	Shoulder of Mount Ida	40.380617	-105.770072	3862	upper alpine
PIK	Unnamed	40.392956	-105.790538	3715	lower/upper alpine
VQS	Unnamed	40.406275	-105.799238	3623	lower alpine
JSM	Jackstraw	40.394304	-105.813083	3520	lower alpine/subalpine ecotone

Plot layout

In 2009, we relocated the GLORIA sites on all four summits that had been established the previous summer. We took a number of baseline measurements of quadrat locations and identified 4 lower and 4 upper summit area sections that describe each aspect to a distance of 10 m below the summit (e.g., the upper north section was the north side from the summit to 5 m below the summit and the lower was from 5 to 10 m below the summit).

Vegetation, Soils, Temperature, and Disturbance Monitoring

The quadrat clusters each contain 9-1 m² quadrats (Figure 2, 3) that are used to measure fine changes in vegetation cover and frequency. In addition, one temperature datalogger is buried at 10 cm depth in the center of each quadrat cluster to measure changes in soil temperature over time and variation in temperature associated with aspect. The 1 m² quadrats are also used to record the presence and frequency of herbivore damage including trampling, scat, and browsing. The summit area sections are used to measure the exact dimensions of the peak (area and slope), the coarse-scale ground cover of the peaks (7 cover classes: solid rock, scree, vascular plants, lichens, bryophytes, bare ground, and litter), and the presence of individual plant species used to estimate species diversity and exotic plant cover. For more details on the methods see the ROMN alpine monitoring protocol (Ashton et al. 2010).

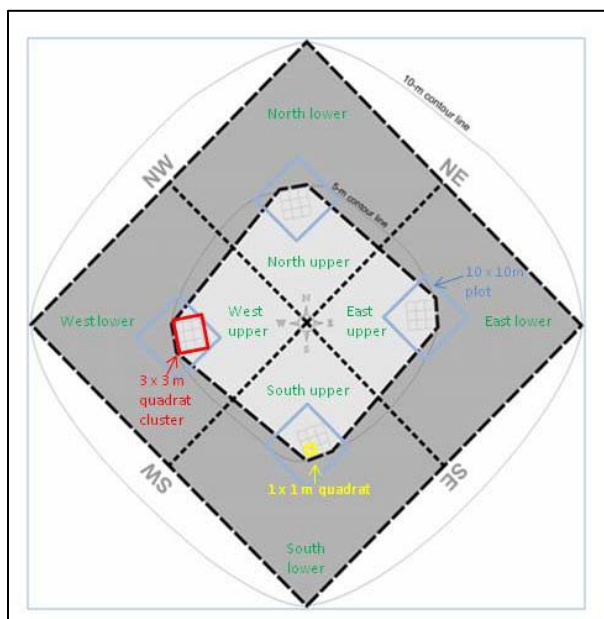


Figure 2. Field plot design for alpine monitoring where this design was replicated on four summits that varied in elevation. The design is centered by the highest point on the summit and extends to 10 m in elevation below the highest point. The 1 m² quadrats used to measure changes in plant frequency are indicated in yellow.

Table 2. Types of plots present on each GLORIA summit and data available for analyses. Each quadrat cluster contains 9 quadrats but only 4 are used for vegetation surveys.

Plot type	Size	Number of plots per peak	Number of plots in ROMO	Available Data
Summit	Variable from 0 to 10m below highest point	1	4	Natural and Anthropogenic disturbance
Summit Area	Variable from 0-5m and 5-10m below highest point for each direction	8	32	Species presence; Cover class
Quadrat cluster	9 m ²	4	16	Hourly Soil Temperature; Soil parameters
Quadrat	1 m ²	16	64	Cover class; Species cover; Species frequency; Frequency of herbivore damage

After establishing and photographing the quadrat clusters on all peaks, we downloaded and replaced the 4 temperature loggers per peak, measured plant cover and frequency in eight 1-m² quadrats per peak, and surveyed all summit area sections to determine variation in species diversity by elevation and aspect. We chose the lower left and upper right quadrats for sampling and priority will be given for sampling this subset in the future. Cover was measured in the quadrat by ocular estimate and frequency was measured as the presence of a species in one

hundred 10 x 10 cm grid cells with the quadrat. To aid in identification, some plant specimens were collected and identified using regional floras. We also collected a soil sample from each of the quadrat clusters to characterize soil chemistry and texture. The soil samples were air dried and sent to a cooperating laboratory at Colorado State University for analysis. Soil aggregate stability was measured at the quadrat cluster on VQS using a soil test kit developed by Herrick et al (2005) using classes from 1 (unstable) to 6 (stable) based on the rate of degradation in water. Soil aggregate stability was not measured at the other peaks after determining that the method was not appropriate or meaningful in the alpine (i.e. thin rocky soils and logistical difficulties of transporting water and maintaining soil structure in high winds). In order to qualitatively describe disturbance, we documented the presence of potential stressors in and around each site. Using applicable metrics from the 2008 Human Disturbance Index developed by the Colorado Natural Heritage Program, (Rocchio 2007) and the California Rapid Assessment Method for Wetlands (Collins et al. 2008) we indicated a condition score for each site that ranges from 0 (pristine) to 100 (highly disturbed).

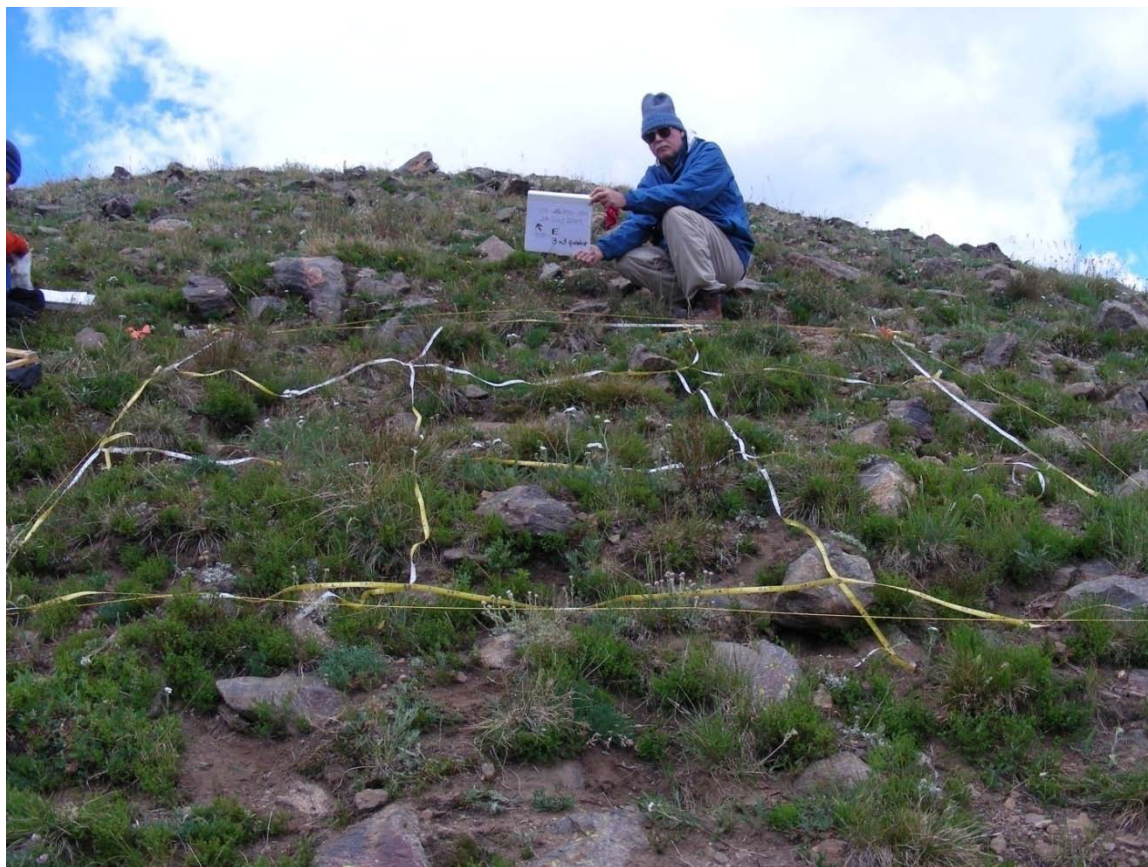


Figure 3. Tim Henson sitting on the lowest GLORIA peak (JSM) at Rocky Mountain National Park. A divided meter tape outlines a 9 m² quadrat cluster on the east side of the peak. Patches of bare soil can be seen on this slope of JSM (August, 2009; photograph by Joel Smoot).

In total, the field work in 2009 took 18 days, two of which were used for travel and access to and from backcountry campsites. It took four people (Henson, T. Henson, Ashton, and Smoot) four days to complete the establishment and data collection at JSM where the first day was spent packing into Jackstraw backcountry campground. It took five days to complete data collection at

the highest peak, GLA. In this case, four people worked one field day to locate the site, replace dataloggers, and take some initial measurements (Ashton, Burke, Kingston, and Henson). Four people (Ashton, Pilmore, Henson, and Lazcano) worked the remaining four days to collect species composition data, complete initial measurements of quadrat locations and photograph the sites. In this case, the peak was accessed from Jackstraw campground and 2 of the 4 days were used to access the site (both were ½ days). VQS and PIK were sampled as day trips from Milner Pass. It took 2 days to replace dataloggers, relocate sites, and learn the GLORIA methods (Ashton, Burke, and Henson). A further five days were spent sampling the two lower peaks (Henson, Shorrock, Cahlander-Mooers, Thomas, and Ashton). Bad weather and lack of trained personnel limited our time at the peaks. We measured only eight quadrats at the peaks rather than the full 16, and we were not able to complete the optional GLORIA sampling of 100 m² plots. These larger plots are intended to provide better cover estimates for the summit, particularly at sites with low vegetation cover. In the future, we expect the vegetation sampling to occur more quickly because we now have established species lists for each summit, but we will also allow for more days of field work to compensate for bad weather and short work days.

After field sampling, species lists were compiled, sent to the GLORIA offices, and fit to an international standard of nomenclature used by all GLORIA sites. The GLORIA office then customized and delivered to ROMN a data-entry database for the RMN target region and a separate photograph tracking database. All photographs from the RMN region are now in the database and identified by date, location and purpose of the photograph, and photographer. We estimate the data entry process will take 60 or more hours and the process is ongoing. We expect all data to be entered, the QA/QC process to be completed, and the complete database returned to the GLORIA office in the winter of 2009-2010. Data for this report was entered directly from field sheets to Excel and while some QA/QC was performed, all results should be considered preliminary until data has been approved by the GLORIA office.

Data analyses were performed in R 2.9.2 (2009) using linear models (aov or lme). Where appropriate, variables were log-transformed to meet assumptions of heteroscedasticity and normality. Post-hoc tests were done using Tukey's tests. For this report, we used these models to ask three types of questions: (1) Do summits differ significantly for a given variable? (2) Do aspects differ significantly for a given variable? (3) Was there a summit x aspect interaction?

Results

Vegetation Composition and Structure

Summit Area

The four sentinel GLORIA summits varied in composition and cover classes of rock, bare ground, and vegetation (Figure 4). GLA, the highest summit, has a large amount of bedrock and scree, particularly on the south and east sides that are mainly steep cliff faces (Figure 5). The north and west side are gentler slopes and consequently have a much higher plant cover. PIK, VQS and JSM are similarly well vegetated with between 50-60% plant cover. JSM has more bare soil than the other peaks, particularly on its eastern slope (Figure 3).

A total of 106 vascular plant species were found on the four summits (Appendix 1) and 75 lichen species were identified from four 1-m² quadrats on all peaks. The number of species varied among peaks (Table 2). For the lowest summit, JSM, we found 14 additional species after

surveying the sections from 5 to 10 m below the summit. This pattern is likely due to an increase in the presence of subalpine species in the lowest parts of the summit. Forbs and graminoids were the most common growth forms found on the summits, but we did find some rare instances of shrubs (e.g. *Salix brachycarpa*, *Ribes montigenum*, *Juniperus communis* var. *depressa*) and one tree (a small *Picea engelmannii*).

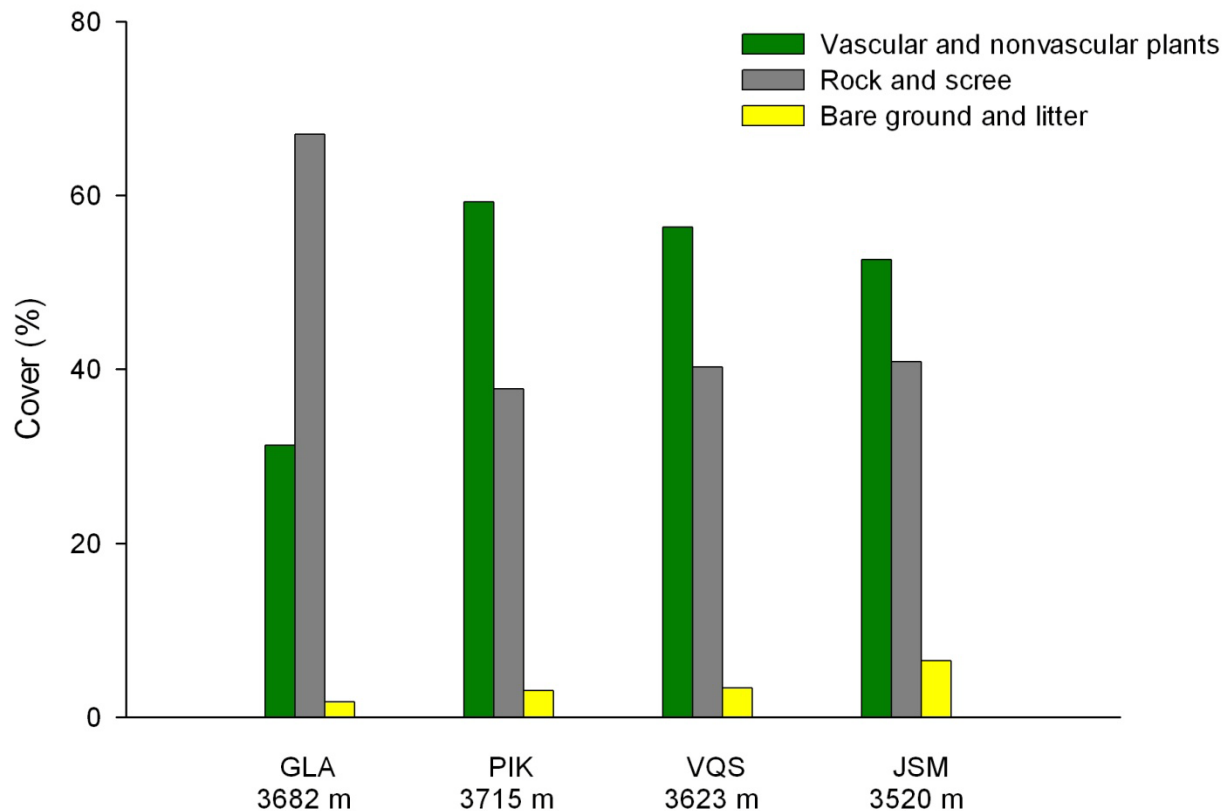


Figure 4. Mean vegetation, rock, and bare ground cover for each of the four sentinel GLORIA peaks at Rocky Mountain National Park. The cover classes are averaged from the summit to 10 m below the summit and for each direction.

The three highest peaks had similar plant communities. The most common species found on GLA were two sedges, *Kobresia myosuroides* and *Carex rupestris* and the following forbs: *Silene acaulis* ssp. *subacaulescens*, *Minuartia obtusiloba*, *Geum rossii*, and *Artemisia scopulorum*. PIK differed in only that *Castilleja occidentalis* was also quite common. On VQS, *K. myosuroides* was not as abundant, and the forbs *Arenaria fendleri* var. *fendleri*, *Trifolium dasyphyllum*, and *T. nanum* were common. JSM, the lowest peak, had many of the same species, but it was less dominated by any one species. Unlike the other peaks, *Vaccinium scoparium* was quite common on this lowest peak.

Table 2. Number of species present on four alpine sentinel sites within the target region of ROMO.

GLORIA Summit code	Elevation (m)	Number of species to 5 m below summit	Additional species found between 5 and 10 m below the summit	Total number of plant species on summit
GLA	3862	56	8	64
PIK	3715	50	8	58
VQS	3623	52	9	61
JSM	3520	48	14	62



Figure 5. Rachel Lazcano, a student career employee with the Denver Federal Service Center, taking a soil sample on the east side of GLA peak in Rocky Mountain National Park (August 2009, Photograph by Isabel Ashton). The peak is rocky and steep compared to the others in the region.

Frequency and Cover Quadrats

An array of 1-m² quadrats on each aspect of each peak was used to measure the fine-scale variation in plant cover and frequency (Figure 6). Total plant cover in the quadrats differed among summits ($F_{3,15} = 11.7$, $P < 0.001$), with GLA having significantly less cover of vegetation than the lower peaks ($P < 0.01$ for all comparisons). There was also a significant difference by aspect for vegetation cover ($F_{3,15} = 8.8$, $P = 0.001$) where the north side has higher cover than the east and south. However, this pattern is not consistent (there is a significant summit x aspect interaction; $F_{9,15} = 4.0$, $P = 0.009$) because on PIK the south aspect is more vegetated than the north. Total rock cover also varied among the summits ($F_{3,15} = 7.6$, $P = 0.002$) where not surprisingly, GLA, the highest peak, had much more solid rock than the lower peaks. The cover of scree also differed among the peaks ($F_{3,15} = 10.0$, $P < 0.001$), where JSM and GLA had less

scree (~11%) than VQS and PIK (~27%). These trends were similar to those seen in the larger summit areas (Figure 3).

We found that the number of plant species present in quadrats also varied by peak ($F_{3,15} = 5.7$, $P = 0.008$) where VQS had significantly more species than PIK ($P < 0.01$) and GLA ($P = 0.02$), but not JSM ($P = 0.18$). VQS averaged 21 ± 1.0 (mean ± 1 standard error) species per quadrat while, GLA averaged 16 ± 1.4 , PIK averaged 16 ± 2.2 , and JSM averaged 18 ± 1.0 species. These results differ from the summit area surveys that show JSM and GLA to have more species. I believe the discrepancy can be explained by higher diversity in the lower regions of JSM (due to subalpine species) and higher habitat diversity on GLA (e.g. cliff faces, small caves, talus slopes, and meadow) that was not represented in the 1-m² quadrats. We found numerous showy flowers and cushion plants typical of the alpine tundra (Figure 7).

We found no difference in the number of lichen species present among summits or aspects. In general, there were more species of lichens found in the quadrats than vascular plants. The average was 27 ± 2.5 species of lichens per quadrat. The most widespread species (found in all quadrats) were *Candelariella vitellina* and *Rhizocarpon geographicum*.

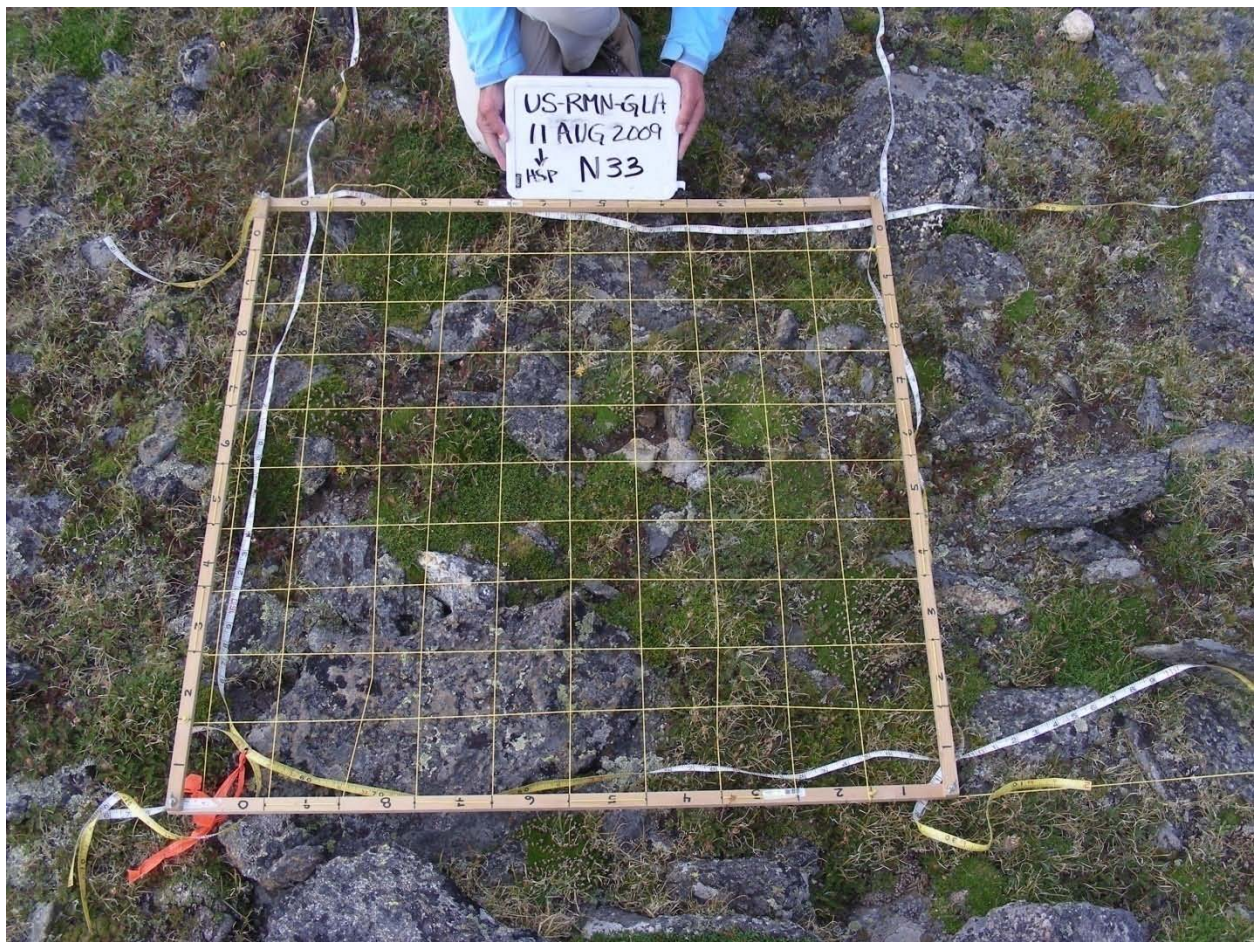


Figure 6. A 1 m² quadrat used to measure fine scale changes in species cover and frequency on the north side of GLA peak in Rocky Mountain National Park (August 2009, Photograph by Isabel Ashton). The large rocks in this photo are well covered by alpine lichens.



Figure 7. Three common alpine species found in the US-RMN region. From the left: *Mertensia lanceolata* (prairie bluebells), *Tetraneuris grandiflora* (graylocks four-nerve daisy) and *Castilleja occidentalis* (western Indian paintbrush). (July 2006; photographs by Isabel Ashton)

Invasive/Exotic Plants

Of the 106 species identified from ROMO, only one species of exotic plant was found: *Taraxacum officinale* (dandelion). *T. officinale* was present only on the lowest peak, JSM, with a few individuals on the south and east aspect. There were no exotic species present on the other three peaks.

Soil Condition

In general, the soils in the alpine at the sentinel sites in ROMO were thin and rocky. The soils at the sites are considered gravelly sandy loam and typically range from 0-20 inches thick. On the highest peak, scree and rock covered large portions of the summit and there was relatively little soil on the southeast and southwest sides. We found no evidence of soil erosion in the form of rills, gullies, or pedestals at sites. There was however, a great deal of soil disturbance at JSM peak presumably caused by elk, steep slopes, and burrowing rodents. Soil chemistry samples were taken from all peaks, but results are still forthcoming.

Anthropogenic and Natural Disturbance

Disturbance in frequency quadrats

Disturbance was measured as the frequency of visible trampling (hoof prints, flattened plants), browsing (broken stems and/or missing flower heads), and scat in the 100 10 x 10cm cells within 1 m² quadrats on all summits. In general, we found little evidence of trampling or browsing within the quadrats and there was no significant difference in trampling or browsing across peaks or by aspect. Scat was fairly common on all peaks but the frequency found in quadrats varied by peak ($F_{3,11} = 4.3$, $P = 0.030$). In general, the quadrats on VQS and PIK had more scat (~12%) than GLA and JSM (~2%). Elk, marmots, bighorn sheep, and ground squirrels were seen on the peaks during the sampling period.

Qualitative disturbance indices

In addition to measures of disturbance at the quadrat scale, we also conducted a qualitative assessment of anthropogenic and natural disturbance on the site to ~ 1 km around the site. Using these assessments, we found all four summits to be pristine (Figure 8). In other words, the landscape was void of disturbances such as nearby roads, intense recreation, or logging

pressures. Moreover, the area was unfragmented, dominated by native vegetation, and there were no hydrologic or physical modifications of the landscape. VQS is the closest peak to a trailhead and it has a small rock structure on the southwest area of the summit that is used for Native American vision quests (personal communication, Paul McLaughlin). There is a well-used but unmarked and mapped hiking trail to Mount Ida that lies about 50 m from VQS and 100 m from PIK. It was not unusual to see a dozen hikers on the trail on a given day in the summer. The nice views and rock structure on VQS make it an attractive lunch spot and we saw many hikers take advantage of this. The more remote locations of GLA and JSM make them less likely to be visited by hikers. Despite the visitors on the lower peaks, we found very little evidence of trampling of vegetation.

Natural disturbances were more common. We found there to be a moderate level of disturbance at JSM (Figure 8). The area surrounding Jackstraw Mountain, including the JSM site, burned in 1871. There is still evidence of burned stumps above treeline suggesting that the area was once forest, rather than tundra. Pine-beetles are present and active in the forest surrounding JSM peak and numerous trees are now standing dead. The other three peaks are further from treeline, so it is unlikely that they have been affected by fire or will be affected by beetle-kill; however there is evidence of rodents and some native herbivory from sheep and elk.

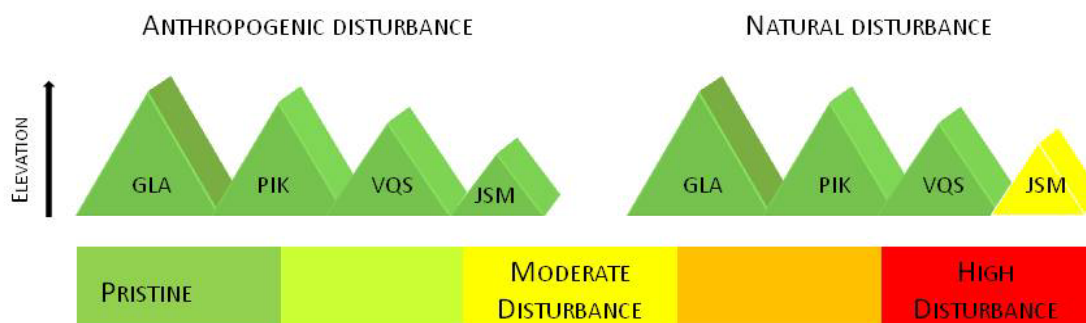


Figure 8. Scales of natural and anthropogenic at four sentinel peaks in Rocky Mountain National Park.

Temperature

The soil temperatures at 10 cm below the surface were generally very cold on the GLORIA peaks from October 2008- May 2009 (Figure 9). Freezing temperatures began in October 2008 and were common through May 2009. January was the coldest month with an average daily soil temperature across the peaks of -6.9°C (19.5°F). July was quite warm on GLA and JSM peak with mean temperatures of 9.4°C (48.9°F) and 13.1°C (55.6°F), respectively. The temperature dataloggers on PIK and VQS were downloaded and replaced in late May 2009, so data for the summer of 2009 will not be available until they are downloaded in spring 2010. The fairly consistent temperatures on the east side of the peaks (compared to the west) during the winter months suggest that an insulating snow cover (~ 0.5 m) was present for this period. When the loggers were collected in May there was still ~ 0.5 m of snow cover on the east side of PIK but VQS was clear of snow. It is likely that the south side of the two highest peaks and the north side

of the lower peaks were also insulated by snow for much of the winter. The west side of the peaks is often subject to greater winds than the other aspects, limiting snow accumulation on the surface of the soil.

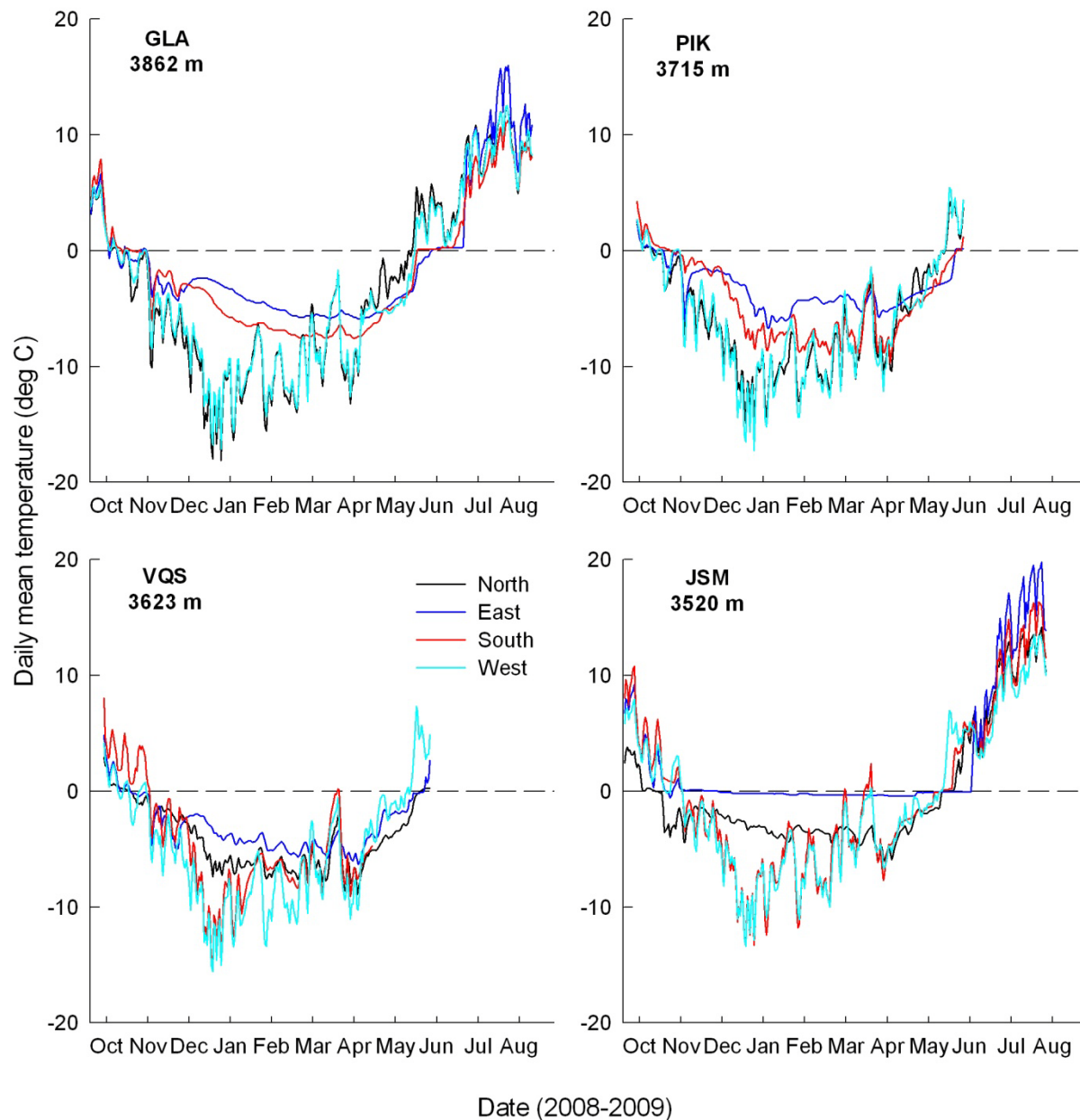


Figure 9. Daily soil temperatures from October 2008- August 2009 on the north, east, south, and west sides of GLA, PIK, VQS, and JSM peak in Rocky Mountain National Park. The dataloggers on PIK and VQS were downloaded and replaced in late May so data for summer 2009 will not be available until summer 2009 when they are downloaded.

Discussion

The goal of our alpine monitoring efforts in ROMO is to determine the status and trend in five parameters: vegetation composition and structure, invasive/exotic cover, soil condition, disturbance, and soil temperature. As of 2009, we have completed the first full season of field work and while we have increased our understanding of the status of the alpine at the four sentinel sites, we cannot yet describe trends. Moreover, our sampling was conducted at only the four sentinel sites limiting our ability to make park-wide inferences on the status of the alpine. Below, we summarize the results from above and highlight some of the most interesting aspects of the alpine monitoring program.

We found the vegetation structure and soils of the alpine tundra in ROMO to be typical of fell-field and alpine turf communities (Zwinger and Willard 1996) as it was dominated by sedges with a high diversity of forbs. Compared to other grassland types, the alpine tundra shows high local diversity (Gough et al. 2000) and this was certainly true of our sites. In one quadrat on VQS we recorded 22 species of vascular plants in a 1 m² area. In addition to vascular plants, the 1 m² quadrats had an average of 27 species of lichens. Trees and shrubs were rare in the sites, but not completely absent. We found woody species at the two lowest peaks, but the site lowest in elevation, JSM, was the only where we found trees (an Engelmann spruce sapling).

Climate changes may affect biodiversity and species richness in the alpine by contributing to the extinction of some species while simultaneously increasing the elevation and latitudinal limitations of other species. A survey of summit sites in the Alps of Switzerland showed that vascular plants have been establishing at higher altitudes than recorded earlier (Grabherr et al. 1994). Thus, it is assumed that an upward and northward migration of plants, induced by recent climate warming, is an already ongoing process in some areas. In the future we will monitor the changes in species distribution, particularly woody species, to determine if species are migrating upward in this region. We expect the greatest changes to be seen at the lowest peak, JSM, where woody species and some subalpine species are already present. There was a fire 140 years ago that burned all the trees present on JSM and the community shifted from subalpine forest to tundra. Climate changes may accelerate the migration of trees and woody species onto this peak. As we continue monitoring vegetation at these peaks, we expect to see increases in the number of species observed at the lower peaks, but over the longer term it is possible that some alpine species will be lost from these sites resulting in no-net change or a loss of species.

In addition to the upward migration of species, climate change may allow for the spread of exotic/invasive species into the alpine where they are typically limited by the harsh environment (Pauchard et al. 2009). We found only one exotic species in ROMO at the lowest alpine sentinel sites and no exotics at the sites at higher elevation. *Taraxacum officinale*, or common dandelion, the exotic present at the lower sites (less than 1% cover), originated in Eurasia and is considered naturalized throughout the United States. It is one of the few exotics that is found in the alpine and has also been found in GLAC and GRSA GLORIA sentinel sites. Work from the alpine in Chile suggests *T. officinale* can compete with native alpine wildflowers for pollinators and affect their reproduction potential, but only when present in high densities (Muñoz and Cavieres 2008). It is unknown how this species may be affecting the native plant community on JSM. If climate changes continue and temperatures warm at ROMO, we expect that sampling in future years will

reveal an increase in the frequency of *T. officinale* and an increase in the number of other exotics present.

Observing and documenting land use and natural episodic events can provide insight into status and trends in vegetation composition, structure, and soils. At the GLORIA sites in ROMO current anthropogenic disturbances are minimal and hikers in the summer are the biggest user group. The trail to Mount Ida is currently not on park maps, so this presumably limits the number of visitors. An increase in visitation may result in trampling, particularly at VQS, which appears to be visited often. We also found little evidence of natural disturbance from grazing at the four sentinel peaks. Elk, marmot, and ptarmigan scat was found at all the sites but there was little evidence of browsing or trampling damage. Elk browse heavily on willow species in the alpine and can dramatically impact the structure of alpine communities. Surprisingly, we did not find any willow species at our sites and this may be related to high historic herbivory rates by elk. However, there are many alternative explanations for the lack of willows including low water availability and dispersal limitations.

In high elevation systems with historically low nitrogen availability, the influx of nitrogen (N) from pollution has caused changes in vegetation, soil, snow, and water chemistry (Fenn et al. 2003). Field measures of N deposition are beyond the scope of our qualitative assessment of anthropogenic impacts. The National Atmospheric Deposition Program (NADP) measures wet deposition of inorganic N (ammonium and nitrate) in three nearby locations which may be used to infer loadings at the sites. In 2008, 3.2 kg/ha of inorganic N fell in Loch Vale (3159 m), 4.1 kg/ha fell at the saddle of Niwot Ridge (3520 m) and 1.3 kg/ha fell at Beaver Meadows, CO (2490 m) (NADP 2009). These levels are similar or slightly less than what they have been in the past decade and are higher than those found in southern Colorado. In the future, we will continue to track N deposition rates in the area to determine whether they may be affecting the vegetation at the four sentinel summits.

The alpine at ROMO is characterized by extremely cold temperatures and a short growing season (Figure 9). Temperatures generally decreased with increasing elevation, and therefore the highest peak, GLA recorded the lowest average temperatures. The variation in vegetation across aspects, experience in the field, and the temperature record suggests that the west side is consistently the coldest aspect of the peaks. On GLA and PIK, the south aspect was similar to the west and was quite cold but on the lower peaks, JSM and VQS, it was the north side that was most similar to the west. This difference may be due to the unique topography of each peak, in the case of PIK the north side was slightly sheltered from wind by a neighboring peak and on GLA the south side was an exposed cliff. When the sites were established, we assumed they were all in the same climate region (a prerequisite of a GLORIA target region). The broad scale patterns in the temperature data suggest that this is the case. For instance, all peaks experienced a fairly warm period in March and a cooler April (Figure 9). Over time, the temperature records collected at these sites will greatly add to our understanding and documentation of climate change in the alpine at ROMO.

In summary, the four sentinel sites at ROMO represent healthy alpine ecosystems. We found 106 vascular plant species in the target region and only one exotic species. The soils were generally thin but stable, vegetation cover was high compared to many alpine areas, and human and herbivore disturbance was minimal. As with much of the alpine zone in the Rocky Mountains,

mean daily temperatures remained below freezing for most of the time period between October 2008 and May 2009. We found some variation in vegetation and cover across the peaks, driven primarily by the GLA which was rockier than the rest of the peaks. The number of species we found was similar across all peaks, with a high diversity at the highest summit. This is in contrast to the trend that diversity often declines with elevational, a pattern which is thought to be driven by a reduction in area at high elevations (Rahbek 1995). This high diversity may be explained by a larger diversity of micro-habitats on GLA (e.g. cliff faces, talus slopes, and dry meadow) compared to the other peaks which were primarily dry meadow. Future monitoring efforts should document change at these alpine sentinel sites with a particular focus on species diversity and climate change.

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Appendix 1: US-RMN target region species list

Species	GLA 5m	GLA 10m	PIK 5m	PIK 10m	VQS 5m	VQS 10m	JSM 5m	JSM 10m
<i>Achillea millefolium</i> L. var. <i>occidentalis</i> DC.					X		X	X
<i>Agoseris aurantiaca</i> (Hook.) Greene								X
<i>Agoseris glauca</i> (Pursh) Raf. var. <i>agrestis</i> (Osterh.) Q. Jones ex Cronquist	X				X		X	X
<i>Androsace chamaejasme</i> Wulfen	X		X					
<i>Androsace septentrionalis</i> L.	X		X	X	X	X	X	X
<i>Antennaria media</i> Greene		X		X			X	X
<i>Arabis drummondii</i> A. Gray							X	X
<i>Arenaria fendleri</i> A. Gray var. <i>fendleri</i>			X	X	X	X	X	X
<i>Artemisia arctica</i> Less. ssp. <i>arctica</i>			X	X	X	X		
<i>Artemisia scopulorum</i> Gray	X	X	X	X	X	X	X	X
unknown aster							X	X
<i>Athyrium americanum</i> (Butters) Maxon	X							
<i>Besseyia alpina</i> (Gray) Rydb.	X	X	X					
<i>Calamagrostis purpurascens</i> R. Br.				X	X	X	X	X
<i>Campanula rotundifolia</i> L.	X	X	X		X	X		X
<i>Carex albonigra</i> Mack.	X	X						
<i>Carex elynoides</i> T. Holm	X			X		X		
<i>Carex heteroneura</i> W. Boott var. <i>chalciolepis</i> (T. Holm) F.J. Herm.	X	X	X	X	X	X	X	X
<i>Carex pyrenaica</i> Wahlenb. ssp. <i>pyrenaica</i>							X	X
<i>Carex rossii</i> Boott							X	
<i>Carex rupestris</i> All. var. <i>drummondiana</i> (Dewey) Bailey	X	X	X	X	X	X	X	X
<i>Carex scopulorum</i> T. Holm				X				
<i>Castilleja occidentalis</i> Torr.		X	X	X	X	X	X	X
<i>Castilleja puberula</i> Rydb.	X	X						
<i>Cerastium arvense</i> L. ssp. <i>strictum</i> (L.) Ugborogho					X	X		
<i>Chamerion angustifolium</i> (L.) Holub ssp. <i>circumvagum</i> (Mosquin) Hoch								X
<i>Chionophila jamesii</i> Benth.	X	X						
<i>Cirsium scopulorum</i> (Greene) Cockerell ex Daniels		X						
<i>Claytonia megarhiza</i> (Gray) Parry ex S. Wats.	X	X	X			X		
<i>Danthonia intermedia</i> Vasey	X	X					X	X
<i>Deschampsia cespitosa</i> (L.) P. Beauv.	X	X	X	X			X	X
<i>Draba aurea</i> Vahl ex Hornem.	X	X	X	X	X	X	X	X
<i>Draba breweri</i> S. Watson var. <i>cana</i> (Rydb.) Rollins						X		
<i>Draba streptocarpa</i> A. Gray	X							
<i>Elymus scribneri</i> (Vasey) M.E. Jones	X	X	X		X	X	X	X
<i>Erigeron melanocephalus</i> (A. Nelson) A. Nelson				X				
<i>Erigeron peregrinus</i> (Banks ex Pursh) Greene ssp. <i>callianthemus</i> (Greene) Cronquist								X
<i>Erigeron pinnatisectus</i> (Gray) A. Nels.	X	X	X		X	X	X	X

Species	GLA 5m	GLA 10m	PIK 5m	PIK 10m	VQS 5m	VQS 10m	JSM 5m	JSM 10m
<i>Erigeron simplex</i> Greene	X	X	X	X	X	X	X	X
<i>Eritrichium nanum</i> (L.) Schrad. ex Gaudin var. <i>aretioides</i> (Cham.) Herder	X	X	X	X	X	X		
<i>Erysimum capitatum</i> (Dougl. ex Hook.) Greene			X		X	X		
<i>Festuca baffinensis</i> Polunin	X	X						
<i>Festuca brachyphylla</i> J.A. Schultes ex J.A. & J.H. Schultes	X	X	X	X	X	X	X	X
<i>Gentiana algida</i> Pall.	X	X				X		
<i>Gentiana prostrata</i> Haenke		X	X	X				
<i>Geum rossii</i> (R. Br.) Ser. var. <i>turbinatum</i> (Rydb.) C.L. Hitchc.	X	X	X	X	X	X		
<i>Heterotheca pumila</i> (Greene) Semple						X		
<i>Heuchera parvifolia</i> Nutt. ex Torr. & Gray			X				X	X
<i>Hieracium gracile</i> Hook. var. <i>gracile</i>								
<i>Juncus drummondii</i> E. Mey.				X			X	X
<i>Juniperus communis</i> L. var. <i>depressa</i> Pursh								X
<i>Kobresia myosuroides</i> (Vill.) Fiori	X	X	X	X	X	X		
<i>Lewisia pygmaea</i> (Gray) B.L. Robins.			X	X				X
<i>Lloydia serotina</i> (L.) Rchb.	X	X	X	X	X	X		
<i>Luzula spicata</i> (L.) DC.	X	X	X	X	X	X	X	X
<i>Mertensia lanceolata</i> (Pursh) DC.	X	X	X	X	X	X	X	X
<i>Minuartia obtusiloba</i> (Rydb.) House	X	X	X	X	X	X	X	X
<i>Minuartia rubella</i> (Wahlenb.) Hiern.		X					X	X
<i>Oreoxis alpina</i> (Gray) Coult. & Rose	X	X	X	X	X	X	X	X
<i>Oxyria digyna</i> (L.) Hill	X	X						
<i>Packera wernerifolia</i> (A. Gray) W.A. Weber & A. Löve				X				
<i>Paronychia pulvinata</i> A. Gray	X	X	X	X	X	X	X	X
<i>Penstemon whippleanus</i> Gray							X	X
<i>Phleum alpinum</i> L.								X
<i>Phlox pulvinata</i> (Wherry) Cronquist	X				X	X		
<i>Picea engelmannii</i> Parry ex Engelm.								X
<i>Poa abbreviata</i> R. Br. ssp. <i>pattersonii</i> (Vasey) A. Löve & D. Löve & Kapoor		X						X
<i>Poa alpina</i> L.					X	X		
<i>Poa arctica</i> R. Br.					X	X		
<i>Poa glauca</i> Vahl subsp. <i>rupicola</i> (Nash ex Rydb.) W.A. Weber	X	X	X	X	X	X	X	X
<i>Polemonium viscosum</i> Nutt.			X	X	X	X		
<i>Polygonum bistortoides</i> Pursh	X	X	X	X	X	X	X	X
<i>Polygonum viviparum</i> L.	X	X				X		
<i>Potentilla diversifolia</i> Lehm.		X			X		X	X
<i>Potentilla ovina</i> Macoun	X				X	X		
<i>Potentilla subjuga</i> Rydb.	X	X	X		X	X	X	X
<i>Primula angustifolia</i> Torr.	X	X	X		X	X		
<i>Ranunculus adoneus</i> A. Gray			X		X			
<i>Rhodiola integrifolia</i> Raf.	X					X		
<i>Ribes montigenum</i> McClatchie								X
<i>Salix petrophila</i> Rydb.	X	X	X	X			X	X
<i>Salix brachycarpa</i> Nutt.						X		

Species	GLA 5m	GLA 10m	PIK 5m	PIK 10m	VQS 5m	VQS 10m	JSM 5m	JSM 10m
<i>Saxifraga chrysantha</i> Gray	X	X						
<i>Saxifraga flagellaris</i> Willd. exSternb.	X				X			
<i>Saxifraga rhomboidea</i> Greene			X	X			X	X
<i>Sedum lanceolatum</i> Torr.	X	X	X	X	X	X	X	X
<i>Selaginella densa</i> Rydb.	X	X	X	X	X	X	X	X
<i>Senecio fremontii</i> Torr. & A. Gray var. <i>blitoides</i> (Greene) Cronquist								X
<i>Senecio soldanella</i> Gray		X					X	
<i>Sibbaldia procumbens</i> L.	X		X	X	X		X	X
<i>Silene acaulis</i> (L.) Jacq. var. <i>subacaulescens</i> (F.N. Williams) Fern. & St. John	X	X	X	X	X	X		
<i>Solidago multiradiata</i> Aiton					X	X	X	X
<i>Stellaria longipes</i> Goldie			X		X	X	X	
<i>Stellaria umbellata</i> Turcz. exKar. &Kir.	X							
<i>Taraxacum officinale</i> Weber								X
<i>Tetraneuris acaulis</i> (Pursh) Greene var. <i>caespitosa</i> A. Nelson						X		
<i>Tetraneuris grandiflora</i> (Torr. & A. Gray ex A. Gray) K.F. Parker			X	X	X	X		
<i>Thalictrum alpinum</i> L.	X		X					
<i>Thlaspi montanum</i> L. var. <i>montanum</i>					X	X	X	X
<i>Tonestus lyallii</i> (A. Gray) A. Nelson								
<i>Tonestus pygmaeus</i> (Torr. & Gray) A. Nels.	X	X	X	X	X	X	X	X
<i>Trifolium dasyphyllum</i> Torr. & Gray	X	X	X	X	X	X	X	X
<i>Trifolium nanum</i> Torr.	X	X	X	X	X	X		
<i>Trifolium parryi</i> A. Gray	X	X	X	X	X	X	X	X
<i>Trisetum spicatum</i> (L.) K.Richt.	X	X	X	X	X	X	X	X
<i>Vaccinium scoparium</i> Leiberg ex Coville				X			X	X

Lichen species list from 1 m² quadrats

Species	GLA	PIK	VQS	JSM
<i>Acarospora fuscata</i>	X	X	X	X
<i>Acarospora molybdina</i>	X	X	X	X
<i>Allocetraria madreporiformis</i>	X	X	X	
<i>Arthonia glebosa</i>		X	X	
<i>Aspicilia</i> sp. #X (cinerea?)	X	X	X	X
<i>Aspicilia</i> sp. #X (caesiocinerea?)	X	X	X	
<i>Aspicilia</i> sp. #X ("desertorum"- laevata?)	X	X	X	X
<i>Brodoa oroarctica</i>	X	X		
<i>Buellia insignis</i>		X	X	X
<i>Caloplaca</i> - unknown sp.	X	X	X	X
<i>Caloplaca ammiospilla</i>	X	X		X
<i>Caloplaca arenaria</i>	X	X	X	X
<i>Caloplaca cerina</i>		X	X	
<i>Caloplaca epithallina</i>	X	X	X	
<i>Caloplaca holocarpa</i>		X	X	
<i>Caloplaca tirolensis</i>	X	X	X	X
<i>Caloplaca trachyphylla</i>	X			
<i>Calvitimela armeniaca</i>	X	X	X	X
<i>Candelariella citrina</i>		X	X	
<i>Candelariella vitellina</i>	X	X	X	X
<i>Cetraria aculeata</i>	X	X	X	
<i>Cetraria islandica</i> ssp. <i>islandica</i>		X		
<i>Cladonia</i> sp. unknown	X	X	X	X
<i>Dimelaena oreina</i>	X		X	
<i>Diploschistes muscorum</i> subsp. <i>muscroum</i>		X	X	X
<i>Diploschistes scruposus</i>				X
<i>Evernia divaricata</i>	X	X	X	
<i>Flavocetraria nivalis</i>	X	X		
<i>Lecanora agropholis</i>	X			
<i>Lecanora bicincta</i>	X	X	X	X
<i>Lecanora cenisia</i>				X
<i>Lecanora garovaglii</i>				
<i>Lecanora muralis</i>			X	X
<i>Lecanora novomexicana</i>	X	X	X	X
<i>Lecanora polytropa</i>	X	X	X	X
<i>Lecanora rupicola</i>	X	X		
<i>Lecidea atrobrunnea</i>	X	X	X	X
<i>Lecidea auriculata</i>	X	X	X	X
<i>Lecidea lyngeni</i>	X	X		
<i>Lecidea</i> sp. unknown		X		
<i>Lecidea tessellata</i>			X	X
<i>Lecidella patavina</i>	X		X	
<i>Lecidella stigmatea</i>		X		X
<i>Lepraria neglecta</i>	X	X	X	X

Species	GLA	PIK	VQS	JSM
<i>Melanohalae infumata</i>	X	X		
<i>Ochrolechia upsaliensis</i>	X	X	X	
<i>Peltigera rufescens</i>	X	X	X	X
<i>Phaeophyscia sciastra</i>		X		
<i>Phaeorhiza nimbosa</i>				X
<i>Physcia caesia</i>	X			
<i>Physconia muscigena</i>	X	X	X	X
<i>Placidium lachneum</i>	X	X		X
<i>Pleopsidium chlorophanum</i>	X		X	
<i>Polysporina simplex</i>		X		
<i>Protoparmelia badia</i>	X	X	X	
<i>Pseudophebe minuscula</i>	X	X		
<i>Pseudophebe pubscenes</i>	X			
<i>Psora montana</i>	X	X	X	X
<i>Psora sp. unknown</i>		X		
<i>Rhizocarpon disporum</i>	X	X		X
<i>Rhizocarpon geographicum</i>	X	X	X	X
<i>Rhizocarpon polycarpon</i>				X
<i>Rhizoplaca chrysoleuca</i>				X
<i>Rhizoplaca melanophthalma</i>	X	X	X	X
<i>Rinodina terrestris</i>		X		
<i>Sporastatia testudinea</i>	X	X	X	X
<i>Thamnolia vermicularis ssp subuliformis</i>	X			
<i>Umbilicaria decussata</i>	X	X	X	
<i>Umbilicaria hyperborea var hyperborea</i>	X	X		
<i>Umbilicaria krascheninnikovii</i>	X	X	X	X
<i>Umbilicaria virginis</i>	X	X	X	
<i>Vulpicida tilesii</i>		X		
<i>Xanthoparmelia coloradensis</i>	X	X	X	
<i>Xanthoparmelia wymongica</i>	X	X	X	X
<i>Xanthoria elegans</i>	X	X	X	X