



Alpine Vegetation and Soils Monitoring in Great Sand Dunes National Park and Preserve

2010–2015 Data Report

Natural Resource Data Series NPS/ROMN/NRDS—2019/1229



ON THE COVER

View of Uppper Sand Creek Drainage from below, Great Sand Dunes National Park and Preserve.
Photography by Phyllis Pineda Bovin/NPS

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Executive Summary

In 2008, the Rocky Mountain Inventory and Monitoring Program identified and installed alpine vegetation and soils long-term monitoring sites on four summits in Great Sand Dunes National Park and Preserve (GRSA) following a protocol developed by the Global Observation Research Initiative in Alpine Environments (GLORIA). The goals of monitoring the GRSA summit sites are to determine the status and trends in vegetation composition and structure, soil condition and temperature, invasive plant cover, and anthropogenic and natural disturbances. The GRSA alpine monitoring sites were installed and monitored according to an adapted version of the GLORIA protocol in 2009 and 2010, and they were resurveyed according to the same protocol in 2015. In this report, we present a summary of our 2015 monitoring efforts and compare vegetation and soils data between the 2010 and 2015 monitoring years. We found the following:

- In 2015, a total of 96 vascular plant species were documented on the four monitoring summits. This includes thirty-six species that were not identified during the 2009/2010 sampling effort.
- Species richness increased on all summits between monitoring years, though the increase was not statistically significant and could be a result of increased knowledge of the flora. Vegetative cover and dominant species remained relatively constant.
- In 2010 and 2015, the impact of non-native species within the monitoring sites was low with only one species (*Taraxacum officinale*) observed on two of the four summits.
- There was no significant increase in soil temperature during the monitoring period. There was some significant change in several soil chemistry parameters. In particular, there was a significant increase in ammonium and phosphorus that could be a result of deposition.
- Anthropogenic and natural disturbances were qualitatively assessed for all summits as was done in 2010. We found little evidence of natural or anthropogenic disturbances within the monitoring sites.

In 2010 and 2015, we found the alpine tundra at the four monitoring sites in GRSA to be a system little impacted by human disturbance or exotic species. Climate change and increased atmospheric deposition of nutrients are likely the greatest threats to alpine systems in the park. Continued monitoring of the vegetation and soil temperatures at monitoring sites will allow us to determine whether climate change or other stressors correlate with changes in biodiversity and community composition in the alpine.

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- Dr. Julia Sharp at Colorado State University provided advice for analyzing soil temperature data.
- Billy Schweiger with the Rocky Mountain Network provided contributions and helpful comments on the report.

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 identified vegetation composition, structure, and soils as vital signs that can be used to better understand the condition of park ecosystems (Britten et al. 2007).

Alpine ecosystems are an important monitoring target for Great Sand Dunes National Park and Preserve (GRSA) and the Rocky Mountain Network

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 (Figure 1). Annual temperatures have been increasing in the western United States by an average of 0.5 to 0.2°C (0.9 to 3.6°F) over the last century (Diaz and Eischeid 2007; Pederson et al. 2010). The consensus among climate projections is that Colorado will warm by 1.4 to 2.8°C (2.5 to 5°F) by the year 2050 (Lukas et al. 2014). Alpine vegetation is predicted to be heavily affected by climate changes (Beniston 1994; Harte and Shaw 1995; Seastedt et al. 2004; Pauchard et al. 2009; Gonzalez et al. 2010). Studies have shown increasing elevation



Figure 1. A conceptual diagram showing the potential effects of climate change on alpine and subalpine ecosystems. Predicted biological responses to climate change include alterations in treeline, an increase in number of invasive plants, changes in plant community structure, and a loss of alpine-obligate species (Ashton 2010).

limits of some alpine species in the Alps in response to warming temperatures (Grabherr et al. 1996; Pauli et al. 2012). Such changes are likely to occur in other mountainous regions as species migrate to maintain similar environmental niches. Monitoring alpine vegetation over time may help determine whether species elevational and latitudinal distributions are shifting, and if so, what the consequences of these changes may be.

The Global Observation Research Initiative in Alpine Environments (GLORIA) was established in 2001 as an international monitoring network designed to assess and predict biodiversity and temperature changes in alpine communities in response to drivers such as climate (Pauli et al. 2004). In 2010, the Rocky Mountain Network established a GLORIA target region composed of four summits within the preserve portion of GRSA.

Baseline monitoring of alpine vegetation, soils and other parameters defined in the GLORIA and network protocols (Ashton et al. 2010b) were monitored for the GRSA target region summits in 2010. Summary reports of those efforts were produced and provide details on the specifics of the protocols, the site selection, the characteristics of the summits, and the initial results from those first monitoring exercises (Ashton 2010a).

The following are objectives of this long-term monitoring:

1. Determine the status and trend in **vegetation composition and structure** of four alpine peak communities at a range of elevations.
2. Determine status and trend in **cover of invasive/exotic plant species** at four 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 alpine peak communities.
4. Determine the status and trend in **anthropogenic and natural disturbance** at four alpine peak communities at a range of elevations based on a qualitative index of anthropogenic disturbances (e.g. distance to roads) and natural disturbances (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 alpine peak communities at a range of elevations.

In 2015, the GRSA monitoring summit sites were fully resurveyed following the Rocky Mountain Network-adapted GLORIA protocol (Ashton et al. 2010b). In this report, we present a summary of our 2015 monitoring efforts and compare vegetation and soils data between the 2010 and 2015 survey years. Future statistical analysis and more detailed assessments of these data will be possible following a more thorough data quality control review. Data from GRSA can also be analyzed in conjunction with other Rocky Mountain GLORIA sites at Rocky Mountain National Park, Yellowstone National Park, and Glacier National Park for a regional comparison of potential changes in these systems.

Methods

Four Great Sand Dunes National Park and Preserve (GRSA) summit survey sites, established and monitored in 2010 (Table 1; Figure 2), were located and resurveyed in 2015 according to the Rocky Mountain Network Alpine Vegetation Composition, Structure, and Soils Protocol (Ashton et al. 2010b). This protocol follows established GLORIA protocols while adding components for soil condition and human disturbance. The specific details on the installation of the sites are provided in Ashton et al 2010b.

Sample design

In 2010, four summits (identified by their GLORIA site codes – HUK, MUD, PAD, and SIX) within the Sangre de Cristo Range in the preserve portion of GRSA were established as alpine vegetation and soil monitoring sites (Table 1; Figure 2). The summits were chosen to best fit the GLORIA guidelines (Grabherr et al. 2000), including having the same bedrock geology, having the same climates, and having minimal human disturbance. The elevation range from the lowest to highest summit is 450 m. They are located within close proximity to each other on the west side of the range between upper Medano and upper Sand Creeks.

Field Methods

In 2015, we revisited the GRSA target region and relocated the initial survey plots using GPS and measurement data describing the locations of plot markers installed during the initial survey. The monitoring sites were marked according to the GLORIA plot design during the initial monitoring to ensure accurate relocation (Figure 3). At each peak, one marker (rebar with a labeled aluminum cap) was installed at the highest point on the summit and 9-m²

quadrat clusters were installed and marked in each cardinal direction at exactly 5 m in elevation below the summit (all four corners of the quadrat cluster were marked: one with capped rebar and three with nails).

Preliminary species lists for the four sites were drafted in 2015, and on each of the four GRSA summits we completed the vascular plant surveys in all of the summit area sections and quadrat clusters according to the network-adapted GLORIA protocol (see Ashton 2010b). Most species identifications were made by qualified botanists in the field, however approximately 100 unknown species were collected and identified through comparisons with herbarium specimens housed at the Colorado State University Herbarium.

In 2015, HOBO® Tidbit v2 Data Loggers (UTBI-001) were buried within the sampling quadrats on the four cardinal aspects of all peaks to acquire hourly soil temperature data. The Tidbit loggers, which are specified to have a 5-year battery life with a 1 minute or greater logging interval, replaced the HOBO Onset Pendant temperature loggers we previously used. We switched to the Tidbits to extend the interval between downloading loggers. Table 2 describes the types of plots present and data available on each summit within the target region. Lapses occurred between July of 2013 and 2014 when new loggers were accidentally deployed while not recording.

The Colorado National Heritage Program (CNHP) crew collected soil samples from all aspects of the four target peaks as was done during the initial sampling. Temperature sensors were collected and replaced by a separate crew earlier during the 2015 field season. The resampling event was completed

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

GLORIA summit code	Summit name	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Vegetation zone
SIX	Unnamed	37.861501	-105.492034	4000	alpine/nival ecotone
PAD	Unnamed	37.87965	-105.478217	3870	upper alpine
MUD	Unnamed	37.887517	-105.47665	3700	lower alpine
HUK	Unnamed	37.89615	-105.473733	3550	lower alpine/subalpine ecotone

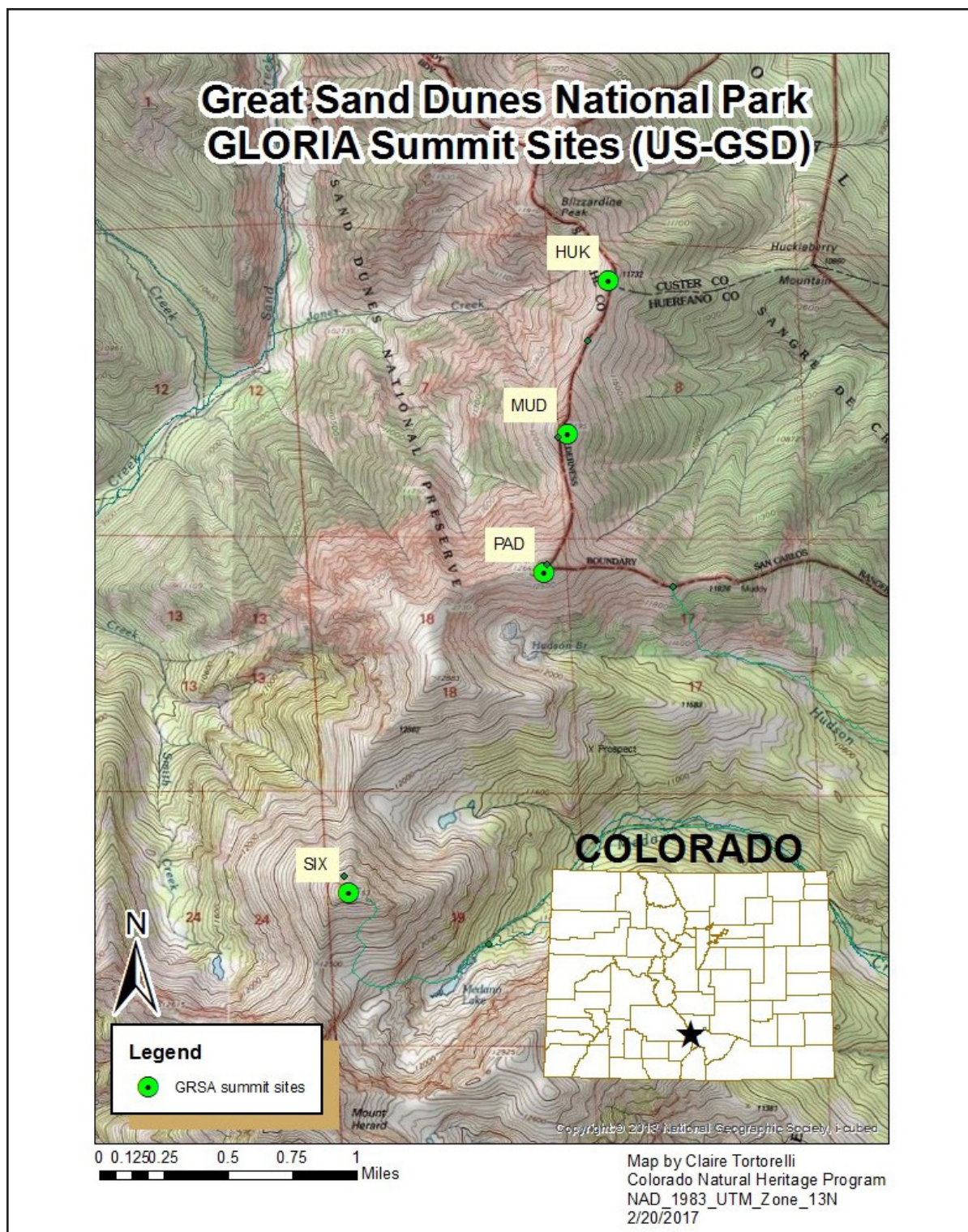


Figure 2. Location of the four summit monitoring peaks (identified by their GLORIA site codes - HUK, MUD, PAD, and SIX) in GRSA.

across three field hitches (approximately ten total sampling days) by a subset of eight CNHP field botanists, ecologists, and field technicians. A trip report documenting the timing, logistics, and other specifics

of the field effort is provided in Appendix B of this report. To evaluate the results of the 2015 monitoring effort, we compared them with data from the 2010 monitoring effort.

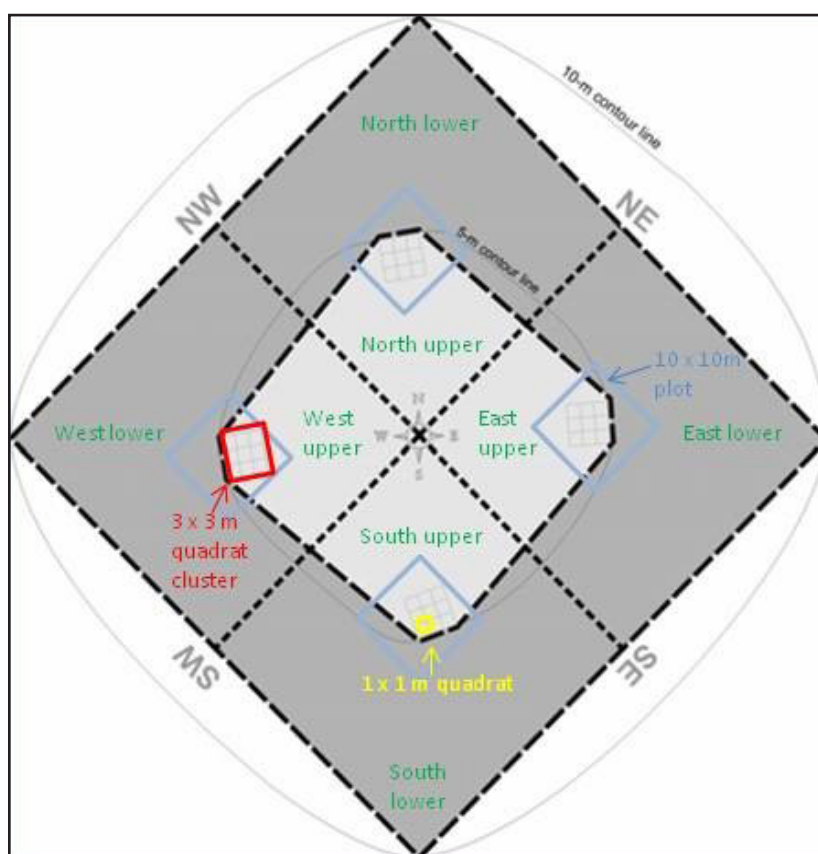


Figure 3. Field plot design used for alpine monitoring that was replicated on four summits varying in elevation. The design is centered on the highest point on the summit and extends to 10 m in elevation below the highest point. The corner 1-m² quadrats were used to measure changes in plant frequency as indicated in yellow.

Table 2. Types of plots present on each GLORIA summit and data available for analyses. Each quadrat cluster contains nine 1-m² quadrats but only the four 1-m² quadrats in the corners of the clusters are used to calculate vegetation cover and abundance.

Plot type	Size	No. of plots per peak	No. of plots in GRSA	Available data
Summit	Variable from 0 to 10 m below highest point	1	4	Natural and anthropogenic disturbance
Summit Area	Variable from 0–5 m and 5–10 m below highest point for each direction	8	32	Species presence; Cover class
Quadrat cluster	9 m ²	4	16	Hourly soil temperature; Soil chemistry and bulk density
Quadrat	1 m ²	16	64	Cover class; Species cover; Species frequency

Analysis Methods

Analyses presented here are preliminary comparisons between 2011 and 2016 data and have not been peer-reviewed; Rocky Mountain Network plans to do a thorough analysis and comparison of alpine monitoring data in the future.

To analyze vegetation composition and structure, we considered total number of vascular plant species identified, species cover, and richness of graminoids, trees and shrubs, and non-native species. Species abundances were measured based on percent of the total vegetative cover within the 64 1-m² quadrats across all four GRSA summits for each monitoring year.

Additionally, we compared the ground cover (percent cover of vegetation, rock/scree, bare ground, and litter) within the 64 1-m² quadrats between the two monitoring efforts. Nearly half of the 1-m² quadrat sampling data are missing from the 2010 monitoring year. From 2010, we are missing data from two of the four 1-m² quadrats from each aspect of HUK, MUD, and PAD, and one of the four 1-m² quadrats from each aspect of SIX. To account for these missing data, only data quadrats measured in both 2010 and 2015 were compared.

To evaluate soil condition, we used linear mixed models to explore differences in soil chemistry parameters between years using the lme4 package in R (Bates et al. 2015). Most soil parameters were log transformed to achieve assumptions of normality. Year was modeled as a fixed effect while aspect nested within summit was a random effect. Soil samples were analyzed at the Colorado State University Soil Testing Lab.

We used a non-parametric seasonal Mann-Kendall trend test to determine if there was a directional trend in soil temperature. We considered a “season” as one month; the test treats each season separately, only comparing data from the same season in different years, and sums the test statistic for an overall determination of trend. We accounted for serial dependence in the data (e.g. January soil temperatures in 2014 were related to January temperatures in 2015). Due to the large amount of missing data from 2013 to 2015, the significance tests were run from 2011 to 2013 and from 2011 to 2015 to ensure missing data did not change results; it did not. We used the monthly median value of the soil temperature on each peak to obtain one observation per season. We ran the test using the function `KendallSeasonalTrendTest` in the R package `EnvStats` (Millard 2013).

We also compared monthly mean soil temperatures and daily soil diurnal temperature range (DTR) from the monitoring period (2010–2015) across years, elevations, and aspects. Although tolerance to low soil temperatures is highly variable among species (Bliss 1962), a standardized growing season soil temperature threshold allows comparison of growing season length across elevation and year. For the purposes of this report, we have defined the alpine growing season as the period where soil temperature remains consistently above 5°C (42.8°F) as defined by Körner and Paulsen (2004) in their study of high altitude tree line soil temperature. The first and last date of mean daily soil temperature above 5°C and the number of days with a mean daily soil temperature above the 5°C threshold were evaluated across peaks as an indication of alpine growing season (Körner and Paulsen 2004).

Results

The following results provide preliminary comparisons of the monitoring data collected in 2010 and 2015. They have not been peer-reviewed and should be interpreted with caution. Without further quality checks and analyses, any changes in the data reported here should not be attributed to environmental and ecological changes. However, additional data from future resurveys will provide a more statistically robust dataset and help us to describe potential trends in vegetation composition and structure, cover of invasive/exotic vegetation, physical soil conditions, soil temperature, and anthropogenic and animal disturbances. The most notable patterns and observations recorded are summarized below. We structure results by indicator class.

Vegetation Composition and Structure

The vegetation observations between the 2010 and 2015 Greater Sand Dunes National Park and Preserve (GRSA) summit monitoring cycles suggest that vegetative cover and dominant plant communities have remained relatively stable over the last five years.

Summit Area

In 2010, a total of 83 vascular plant species were identified across the four GRSA summit sites. During the 2015 sampling effort, a total of 96 vascular plant species were identified on the summits (see Appendix A for the complete vascular species list recorded for the GRSA target region in 2010 and 2015). Eight plant taxa were identified in 2010 but not in 2015 while 36 taxa were identified in 2015 but not in 2010. An additional 17 taxa were only identified to the genus or family level due to insufficient diagnostic material.

Many of the 36 plant species unique to the 2015 survey were short-lived annuals, graminoids (which are difficult to distinguish before inflorescences have developed), or other inconspicuous species typical to alpine habitats. It is possible that these were present during the initial survey event, but went undocumented due to either human or environmental variables. However, some newly documented species, such as *Agoseris aurantiaca* var. *purpurea*, *Phacelia hastata*, *Arabis drummondii*, and *Vaccinium scoparium* are conspicuous species typical to lower alpine and montane habitats. These would be more

difficult to overlook during a monitoring event. Thus, such species are more likely to have established in the last five years.

Vascular plant taxa unique to the 2010 GRSA summit sampling effort

- *Danthonia intermedia* Vasey
- *Draba breweri* S. Watson var. *cana* (Rydb.) Rollins
- *Populus tremuloides* Michx.
- *Potentilla pulcherrima* Lehm.
- *Pulsatilla patens* (L.) Mill. ssp. *multifida* (Pritz.) Zämelis
- *Senecio soldanella* Gray
- *Taraxacum eriophorum* Rydb.
- *Vaccinium caespitosum* Michx.

Vascular plant taxa unique to the 2015 GRSA summit sampling effort

- *Agoseris aurantiaca* (Hook.) Greene var. *purpurea* (A. Gray) Cronquist
- *Agoseris glauca* (Pursh) Raf. var. *dasycephala* (Torr. & Gray) Jepson
- *Arabis drummondii* Gray
- *Campanula uniflora* L.
- *Carex heteroneura* W. Boott var. *chalciolepis* (Holm) F.J. Herm.
- *Carex obtusata* Lilj.
- *Cerastium arvense* L.
- *Cystopteris fragilis* (L.) Bernh.
- *Danthonia parryi* Scribn.
- *Draba crassa* Rydb.
- *Draba fladnizensis* Wulfen
- *Draba grayana* (Rydb.) C.L. Hitchc.
- *Erigeron formosissimus* Greene
- *Eriogonum jamesii* Benth. var. *flavescens* S. Watson
- *Festuca minutiflora* Rydb.
- *Gentiana algida* Pall.
- *Gentianella amarella* (L.) Borner ssp. *acuta* (Michx.) J.M. Gillett

- *Gentianella tenella* (Rottb.) Börner ssp. *tenella*
- *Minuartia rubella* (Wahlenb.) Hiern
- *Muhlenbergia tricholepis* (Torr.) Columbus
- *Osmorhiza* sp. in GRSA alpine
- *Packera werneriiifolia* (Gray) W.A. Weber & A. Löve
- *Penstemon hallii* Gray
- *Poa fendleriana* (Steud.) Vasey
- *Poa leptocoma* Trin.
- *Potentilla concinna* Richards.
- *Potentilla hippiana* Lehm.
- *Potentilla nivea* L.
- *Potentilla rubricaulis* Lehm.
- *Primula parryi* A. Gray
- *Pseudocymopterus montanus* (A. Gray) J.M. Coult. & Rose
- *Rhodiola rhodantha* (A. Gray) H. Jacobsen

- *Senecio amplexans* A. Gray
- *Silene drummondii* Hook.
- *Solidago multiradiata*
- *Vaccinium scoparium* Leiberg ex Coville

Species richness within the summit area sections on all summits differed between monitoring years (Figure 4). All summits had higher species richness in 2015 than in the original survey effort, although this trend was not statistically significant ($p = 0.18$, $df = 3$). The slight increase could be attributed to the fact that the 2015 field crew had the benefit of species lists which may explain some or most of the increase in number of species. In addition, despite our best efforts to monitor each GLORIA site during peak growing season, alpine phenology fluctuates yearly based on environmental factors and cannot always be predicted or planned for. This directly affects which species are visible and identifiable at the time of sampling.

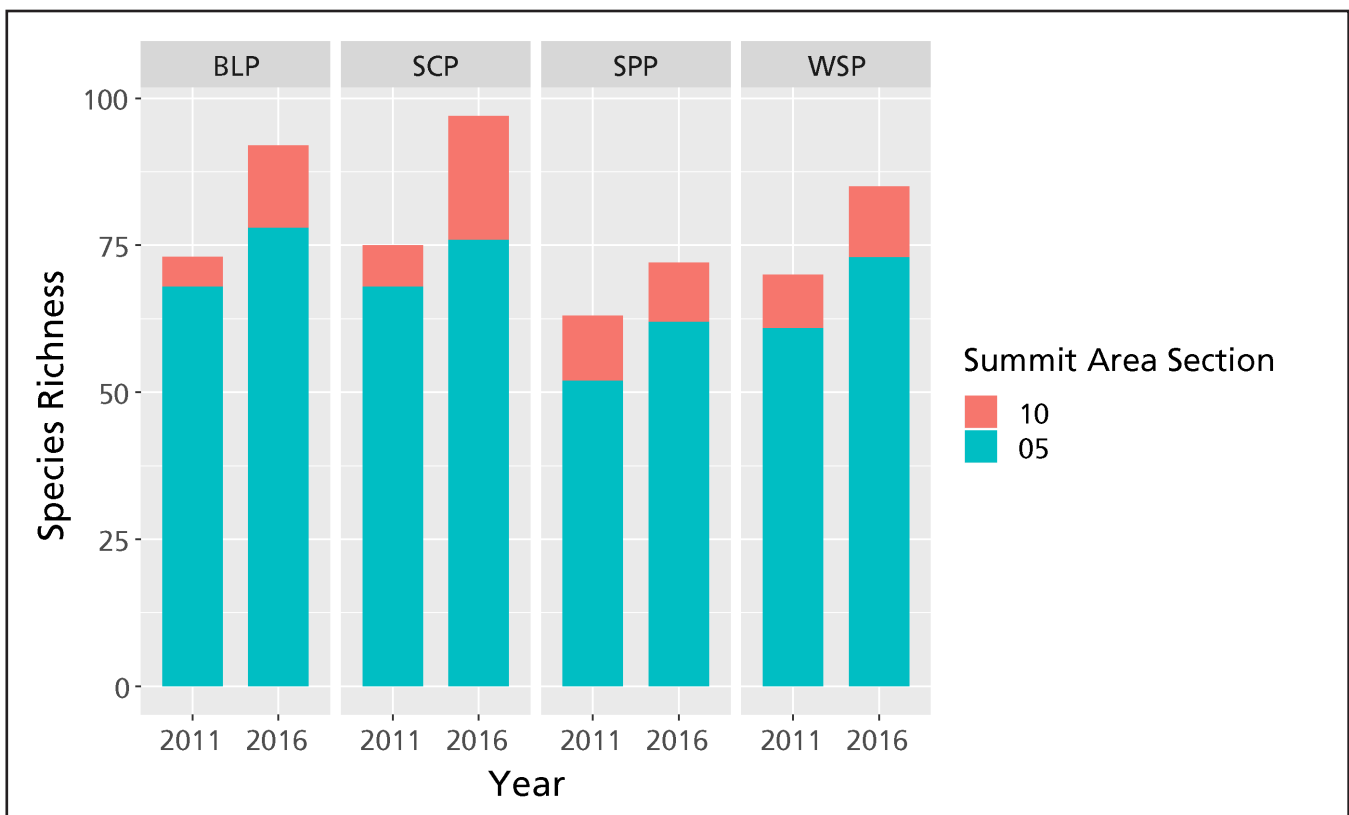


Figure 4. Number of vascular plant species present on four alpine monitoring sites within the GRSA GLORIA site in 2010 and 2015. Red represents the number of vascular plant species in upper summit area sections from the highest point to 5 m below the highest point. Blue represents the number of additional vascular plant species in lower summit area sections from 5 m to 10 m below the highest point. Note: comparisons between 2010 and 2015 should be interpreted with caution (see text).

Frequency and Cover Quadrats

The ten most abundant species were consistent in the 2010 and 2015 sampling efforts (Table 3). In both sample years, *Kobresia myosuroides* was the most dominant species across the GRSA monitoring summits. Summit vegetation consisted primarily of graminoids and forbs, with a few shrubs and tree species. Shrub species included *Potentilla fruticosa*, *Vaccinium caespitosum*, and *Vaccinium scoparium* from the lower two summits (HUK and MUD), and two tree species, *Populus tremuloides* and *Pinus arizata*, were identified from the lowest summit (HUK).

Percent cover of vegetation, rock/scree, litter, and bare ground varied slightly between monitoring years and summits (Figure 5). In 2015, vegetative cover, including vascular plants, lichens, and bryophytes, increased by 12% on PAD from 2010, while vegetative cover on HUK decreased by 12%. Vegetative cover on MUD and SIX remained relatively constant between sampling years. Percent cover of litter and bare ground increased on the four summits, however these patterns were not statistically significant ($p = 0.4$, $df = 35$).

Invasive/Exotic Plants

In addition to 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). Of the 96 plant species identified from the GRSA target region, only one non-native species was documented: *Taraxacum officinale* (common dandelion). *T. officinale* was present on the lower two peaks with a scattering of individuals on the north, south, and east aspect of MUD and the east aspect of HUK. There were no exotic species present on SIX or PAD. *T. officinale* was not documented on the south aspect of MUD during the 2010 monitoring event. The 2015 abundances on the north and east aspects of MUD and the east aspect of HUK are consistent with the findings in 2010.

T. officinale originated in Eurasia and is considered naturalized throughout the United States. Work from the alpine in Chile suggests it can compete with native alpine wildflowers for pollinators and affect their reproductive potential, but only when present in high densities (Muñoz and Cavieres 2008). If temperatures warm at GRSA, we expect that sampling in future years will reveal an increase in the frequency of *T. officinale* and other exotic species.

Table 3. Top ten most abundant species in GRSA 1-m² sampling quadrats in 2010 and 2015 and percent of total vegetative cover.

Species Name	% of Total Vegetation	
	2010	2015
<i>Kobresia myosuroides</i>	27.2	18.1
<i>Selaginella densa</i>	7.5	4.0
<i>Carex rupestris</i> var. <i>drummondiana</i>	7.1	10.2
<i>Trifolium nanum</i>	7.1	4.5
<i>Minuartia obtusiloba</i>	5.9	6.5
<i>Paronychia pulvinata</i>	5.3	5.7
<i>Oreoxis alpina</i>	4.7	5.6
<i>Trifolium dasyphyllum</i>	3.4	3.3
<i>Poa glauca</i> ssp. <i>rupicola</i>	3.3	3.7
<i>Arenaria fendleri</i> var. <i>fendleri</i>	3.1	5.5

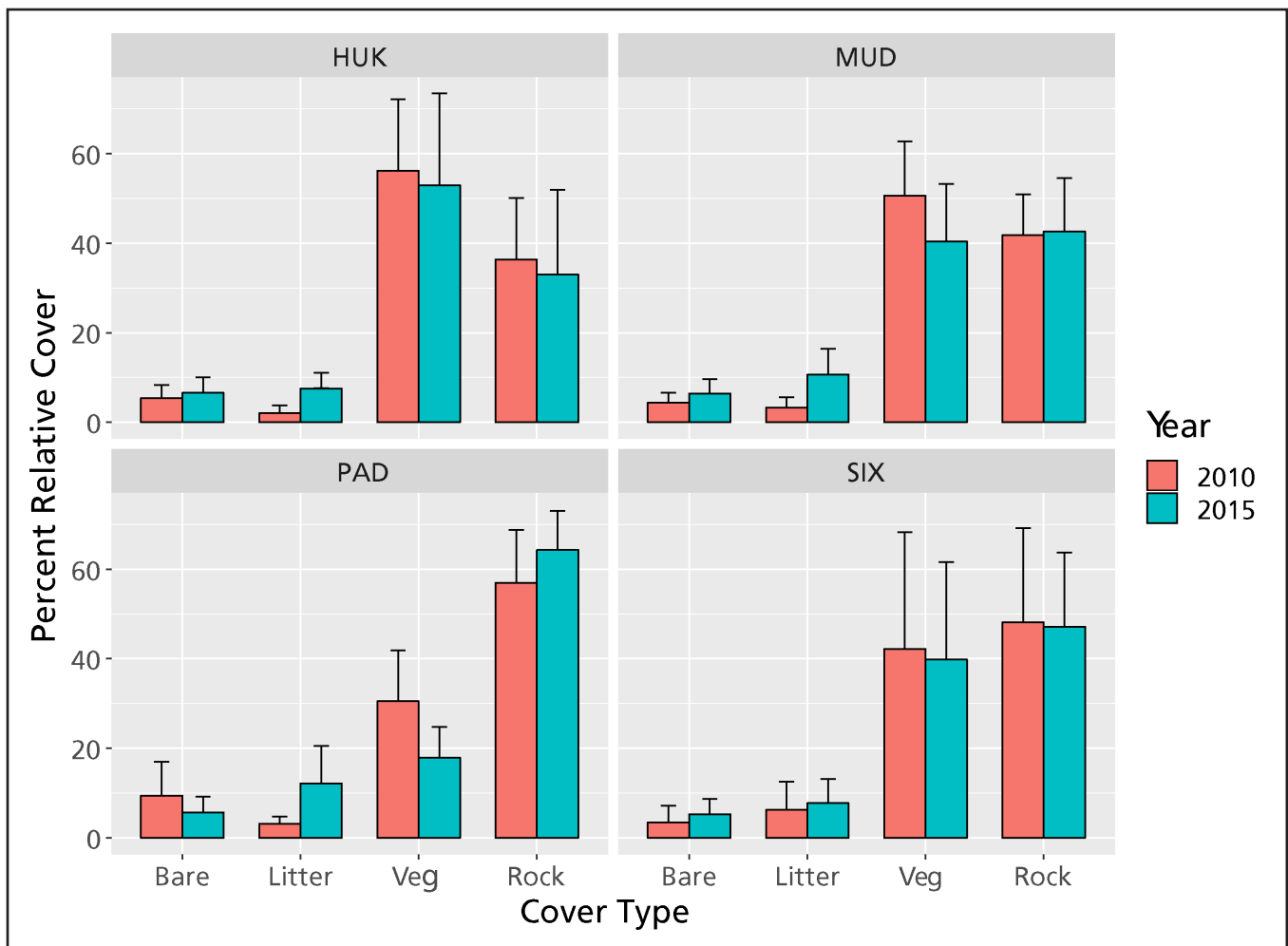


Figure 5. Mean percent cover of vegetation (vascular and non-vascular), solid rock/scree, litter, and bare ground as recorded from the 1-m² quadrats on GRSA summits in 2010 (red) and 2015 (blue). Error bars represent standard deviation. Nearly half of the quadrat data were missing from 2010; only quadrats measured in both 2010 and 2015 are compared here.

Soil chemistry

The soil textures on all four peaks are mostly sandy clay loam, with some aspects having sandy loam or clay loam. Soil pH on all peaks is slightly acidic with values ranging from 4.39 to 6.00. Soil pH has been known to decrease with an increase in elevation (Hanawald and Whittaker 1976); soils monitored at other Rocky Mountain Network alpine sites and non-Rocky Mountain Network sites like the Niwot Ridge Long Term Ecological Research station have been as or more acidic than those found here (NPS data, unpublished; Fisk 2017).

Several soil parameters had statistically significant ($p < 0.05$) increases from 2010 to 2015 including ammonium ($\text{NH}_4\text{-N}$), cation exchange capacity (CEC), and phosphorus (P). Potassium (K) and soil sulfur

($\text{SO}_4\text{-S}$) significantly decreased in 2015. Calcium (Ca), pH, and nitrate as nitrogen ($\text{NO}_3\text{-N}$) showed no significant change between years (Figure 6).

Cation exchange capacity (CEC) can describe the soil's nutrient holding capacity. Its increase from 2009 to 2015 could have been a result of the change in any of the base cations that comprise it, like calcium (non-significant increase), sodium (not measured), magnesium (non-significant increase), potassium (decrease), or aluminum (not measured). It can also be influenced by variation in weathering and pH (O'Neill et al. 2005). The increase in ammonium ($\text{NH}_4\text{-N}$) and phosphorus (P) could be a result of deposition. Stoddard et al. (2016) found an increase in phosphorus in minimally disturbed watersheds nationwide, likely in part from dry

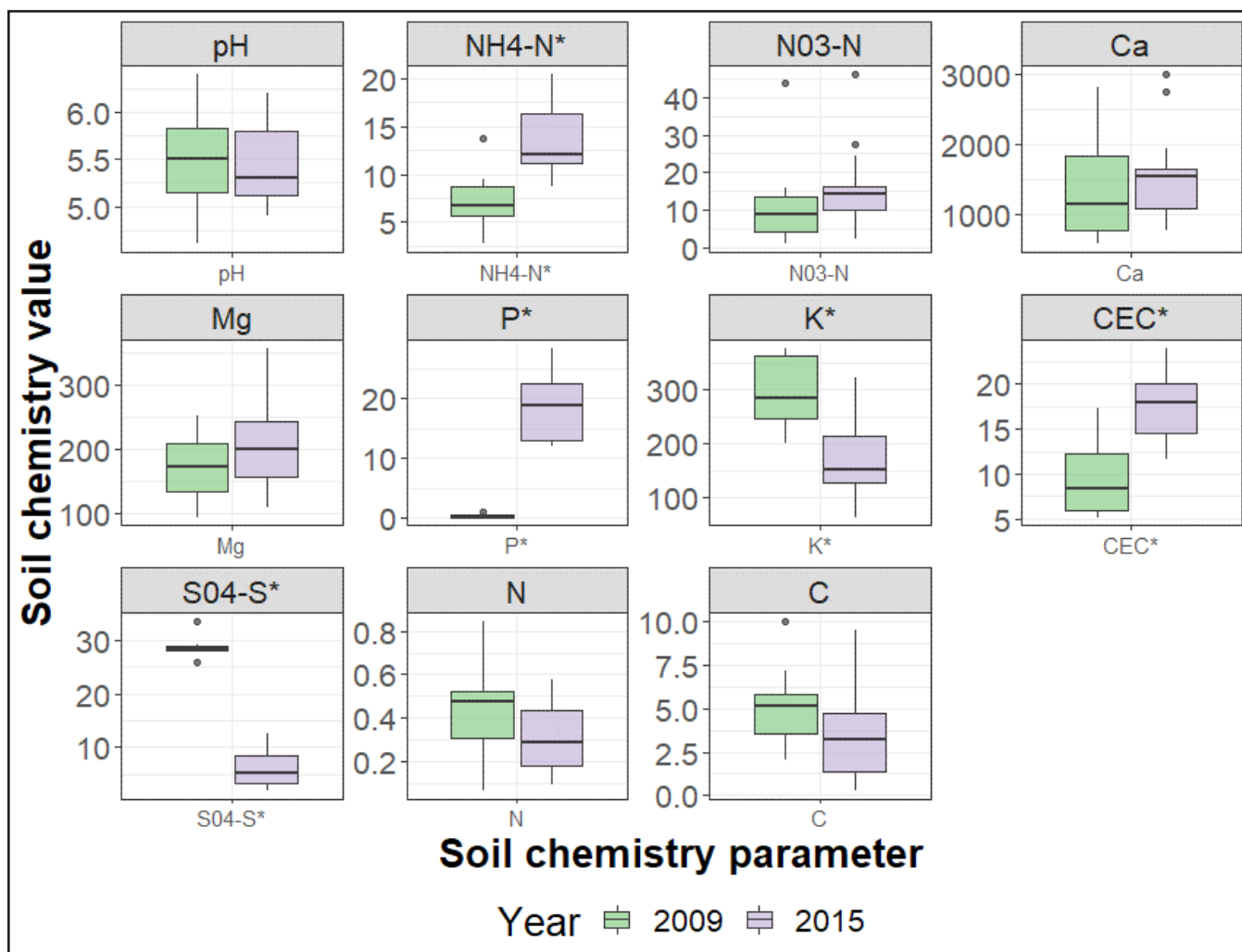


Figure 6. Mean soil chemistry values for 2010 (green) and 2015 (purple) for pH, ammonium (NH₄-N), nitrate as nitrogen (NO₃-N), calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), cation exchange capacity (CEC), and sulphate-sulfur (SO₄-S). Parameters with an asterisk next to the name indicate a significant (p < 0.05) difference between years.

phosphorus deposition from such sources as wind erosion, forest fires, and fossil fuel combustion. The National Atmospheric Deposition Program (NADP) station CO00 in Alamosa recorded an increase in NH₄-N from 2009 to 2015, though levels were quite variable month-to-month (NADP 2017).

Though there was a significant decrease in potassium, the levels in 2015 were still adequate for plant growth (Amacher et al. 2007) and were not alarming. The decrease in sulfate-sulfur (SO₄-S, the type of sulfur absorbable by plants) does not match any regional patterns picked up by the NADP station in Alamosa (NADP 2017). Future monitoring will help contribute to our understanding of these potential trends in soil chemistry.

Soil Temperature

Soil temperature is a strong indicator of growing season in the alpine. As temperatures warm and snow accumulation decreases, alpine growing seasons may extend, thus altering plant and wildlife community dynamics. Determining peak growing season in the alpine also serves as an indication of the most effective monitoring period during which the largest portion of alpine plants are productive.

Soil temperatures ranged from -23.3 to 51.7°C. The east and south aspects on all peaks had the highest average soil temperatures. Average soil temperature ranged by almost 3°C between the warmest (HUK) and coolest (SIX) peak. There were no statistical trends in soil temperature on the peaks over the time period measured (Figure 7).

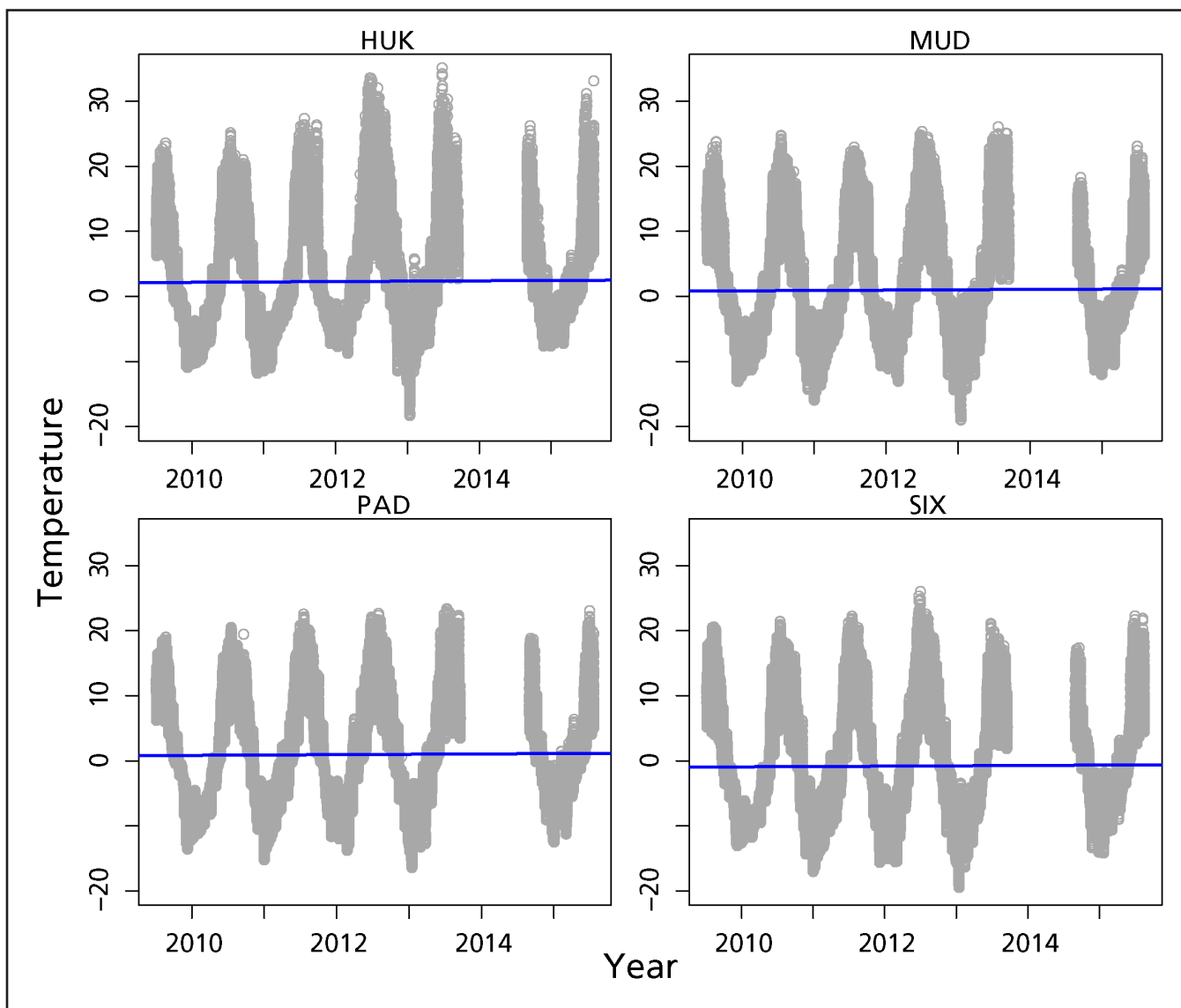


Figure 7. Monthly soil temperatures for each peak, averaged across all aspects, from 2009 to 2015 (grey circles) showing a LOWESS (locally weighted scatterplot smoothing) fit (blue line). There was no statistically significant trend for any peak. Analysis was also run for the time period prior to the break in data, 2009 to 2013, to ensure the gap in data did not change the result; it did not.

Average monthly soil temperatures and soil diurnal temperature ranges (DTRs) varied by aspect, although variations were not consistent across the four peaks (Figure 8). Periods with no daily soil temperature fluctuations suggest snow cover insulated the soil from low winter air temperatures and daily air temperature fluctuations. The extreme fluctuations on HUK's south aspect in the spring and summer of 2012 could be a result of the logger being too close to the soil surface and the sun warming it

more than usual. Soil DTRs were greatest during July through September.

Across the period of record, August 2011 to September 2015, the average growing season (period where mean daily soil temperatures were consistently above 5°C) occurred from early-June to late-September (Figure 9). The period of continuous days above the designated soil temperature threshold (5°C) decreased as the peaks increased in elevation.

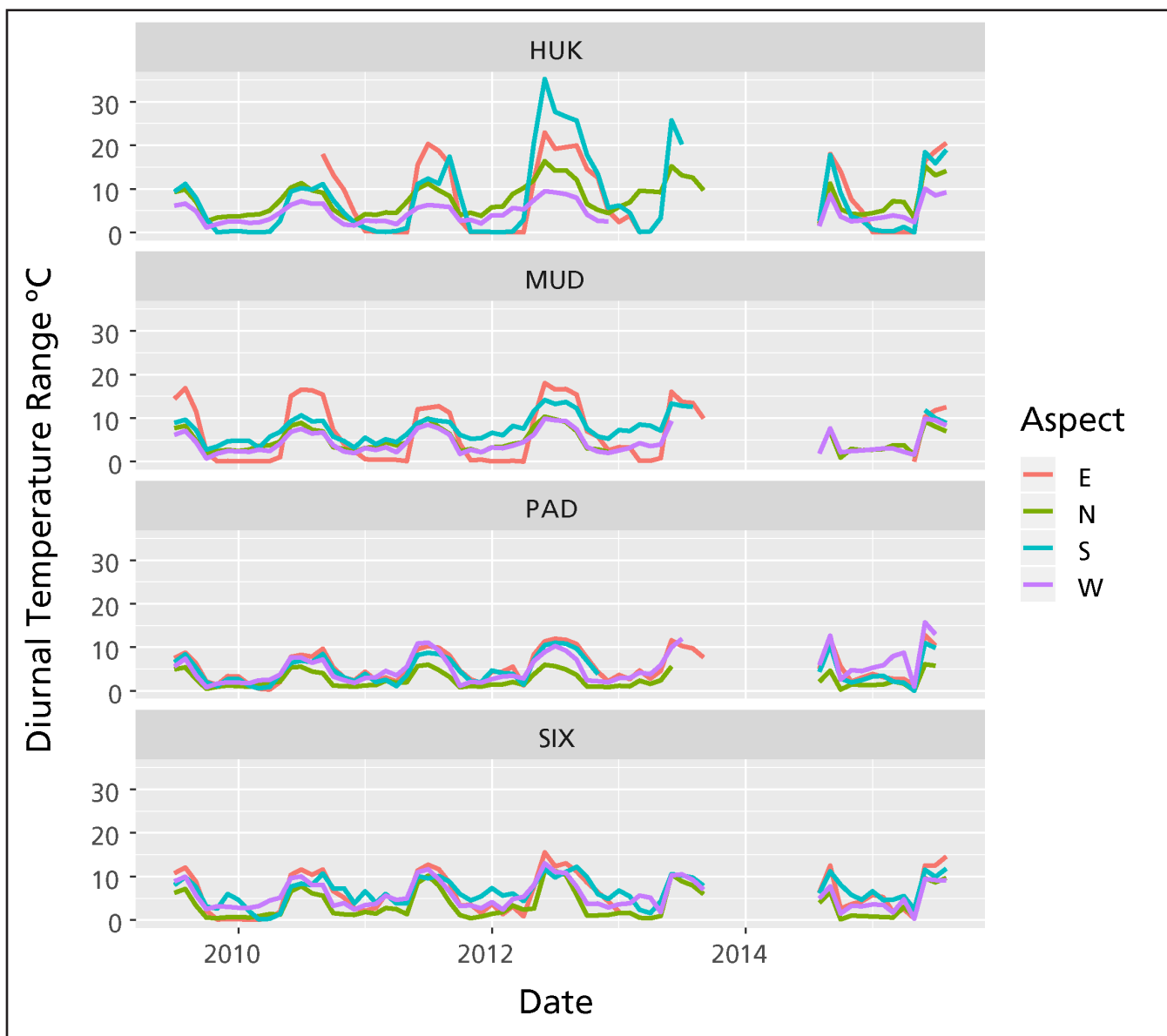


Figure 8. Diurnal temperature range (DTR) on all GRSA monitoring peaks and all aspects from July 2009 through August 2015. The DTR is the monthly average of the maximum and minimum daily temperatures. Lapses in data occurred when loggers were not replaced prior to battery failure or when loggers failed or could not be recovered.

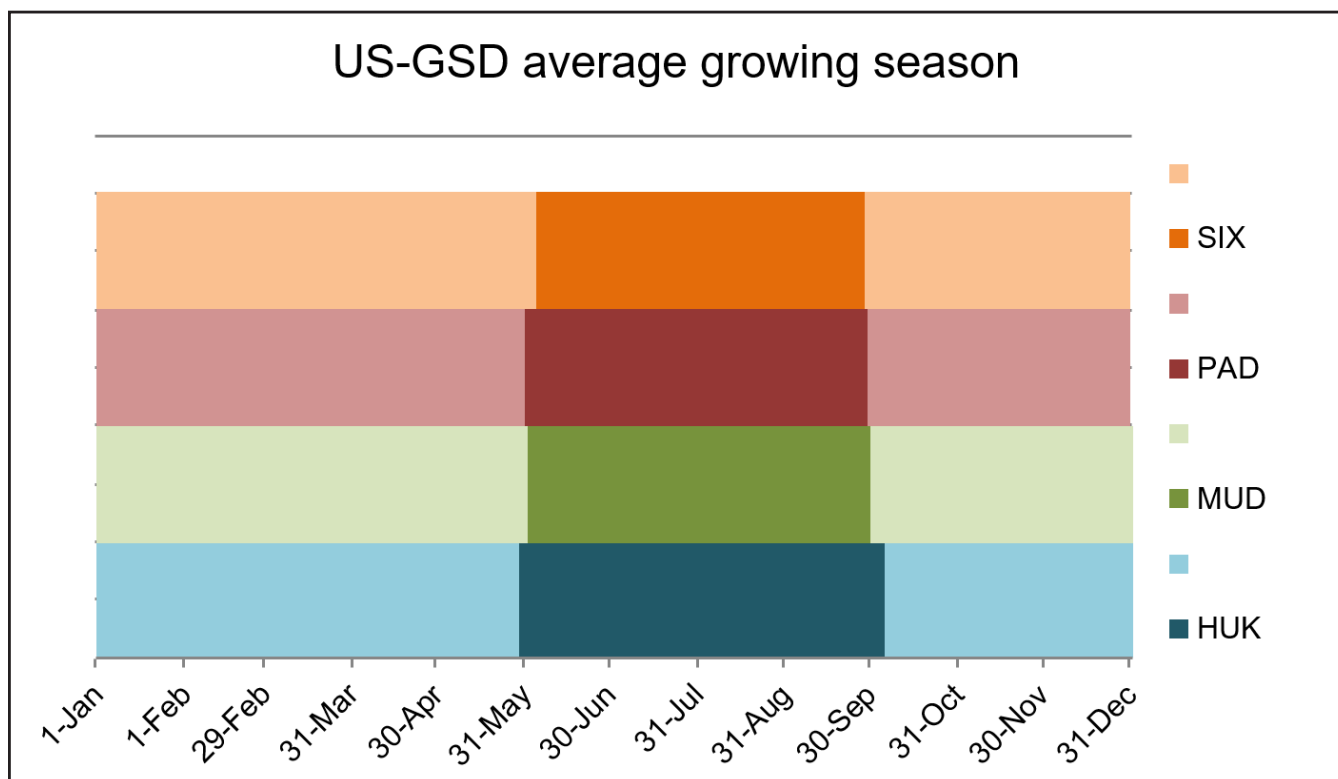


Figure 9. Period of continuous days with mean daily soil temperature above 5°C (42.8°F) are represented in dark colors. This period of average daily soil temperatures above freezing suggests the length of the growing season for each of the four GRSA monitoring peaks. Light colors represent continuous days where mean daily temperature equals or does not exceed 5°C. Dates are averaged across data from September 2010 to August 2015.

Disturbance

Observing and documenting land use and natural episodic events can provide insight into understanding status and trends in vegetation composition, structure, and soils. Disturbance can act as a strong driver of change and can cause direct alterations in community composition. Disturbances may be of particular interest to park staff because they may be able to reduce disturbances through changes in land management (e.g., reroute trails, reduce elk populations).

We conducted a qualitative assessment of anthropogenic and natural disturbances on the GRSA summits to approximately 1 km around the summits. As in 2010, we found all four summits to be pristine. There was no evidence of major 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 to the landscape. Some evidence of natural disturbances including impacts from native ungulates and rodents was present. Burrows and disturbed soil indicated rodent disturbance. Browsed and trampled vegetation indicated native herbivory. There was little to no natural disturbance visible at HUK, and the two middle peaks, PAD and MUD, showed some evidence of rodents and native ungulates. A rock cairn and hiker log on the summit of SIX provided evidence of some recreational activity, however the summit had no visible user trails and appeared to be seldom visited by recreationalists. Evidence of abandoned two-tracks and seldom used hunting campsites were noted in the surrounding lowlands. However, these disturbances did not have visible impacts on vegetation above tree line.

Suggestions for Future Monitoring

Although the GLORIA protocol is designed to maximize repeatability and consistency between surveys, inconsistencies between monitoring years and field crews are unavoidable. For example, despite hiring qualified botanists familiar with alpine flora, each botanist compares cover estimates slightly differently, and this adds to inconsistencies in data collection between years. Also, the 2010 monitoring crew created a species list for each summit from scratch, a very time-intensive task. The list may not be complete because finding every taxa is highly dependent on sampling during peak productive phenologic stage for every species. The 2015 field crew had access to the list which helped them to confirm identifications and look for additional taxa. Other data comparison challenges occurred because the summit area sections were not installed according to the GLORIA protocol during 2010. When they were reinstalled according to protocol in 2015, the area of each summit area section was slightly decreased.

Inconsistencies between sampling years could be minimized with additional efforts. As the overall GRSA target region species list becomes more comprehensive, subsequent field botanists will be more prepared to make confident identifications in the field resulting in fewer data collection inconsistencies between crews and years. Collecting voucher specimens while in the field and saving collections from all monitoring cycles could help solve future species identification complications as well. Steps to reduce variation in human data collection could include providing all future field crews with a standardized training, including cover estimate training, and familiarizing the crew with the current GRSA target region species list. Also, with subsequent sampling efforts and more available data, these inconsistencies will likely become less statistically important to analyzing vegetation structure and composition trends.

Lapses in soil temperature data series caused when soil temperature loggers were not replaced prior to battery failure could be avoided by collecting and replacing soil temperature loggers more frequently. The newly installed HOBO® TidBit Data Loggers are rated to last five years, compared to HOBO pendant loggers used prior to 2015, which are rated to last only two years. Installing back-up soil temperature loggers on each summit would make it possible to cross reference missing data and outliers.

Despite data collection variation, some GLORIA sampling methods, such as the 1-m² quadrat vegetation data proved highly consistent between the 2010 and 2015 monitoring events. The ten most commonly encountered species and percent cover of vegetation, rock/scree, litter and bare ground were relatively constant between 2010 and 2015 across all summits. This consistency highlights the repeatability of the GLORIA 1-m² sampling method between survey years.

Another suggestion for future monitoring is to record more information on tree species to more accurately document any change in tree presence or abundance, including noting exact locations and including photos of trees that are saplings or larger.

This report contains a limited analysis of the available data, and further analysis may expose interesting patterns. Additional analyses could include comparisons of historical elevation ranges with the 2010 and 2015 ranges, as done in Gottfried et al. 2012, to calculate rates of increase in plant species adapted to warmer sub-alpine environments (“thermophilization” rate) on GRSA summits.

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Appendix A. GRSA Vascular Plant Taxa List

Table A-1. GRSA target region species list for each summit (HUK, MUD, PAD, and SIX) by summit area section (05 and 10). "x" indicates the species was present.

Species	HUK				MUD				PAD				SIX			
	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)
<i>Achillea millefolium</i> L. var. <i>occidentalis</i> DC.	x	x	x	x	x	x	x	x	x	x	x	x	–	–	x	x
<i>Agoseris aurantiaca</i> (Hook.) Greene var. <i>purpurea</i> (A. Gray) Cronquist	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
<i>Agoseris glauca</i> (Pursh) Raf. var. <i>dasycephala</i> (Torr. & Gray) Jepson	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Allium geyseri</i> S. Watson	–	–	–	–	–	–	–	–	x	x	x	x	–	–	–	–
<i>Androsace chamaejasme</i> Wulfen	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Androsace septentrionalis</i> L.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Antennaria rosea</i> Greene	x	x	x	x	x	x	x	x	x	x	x	x	–	–	–	–
<i>Antennaria</i> sp. in GRSA	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–
<i>Arabis drummondii</i> Gray	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Arenaria fendleri</i> A. Gray var. <i>fendleri</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Arenaria</i> sp. in GRSA	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Artemisia scopulorum</i> Gray	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Besseyia alpina</i> (Gray) Rydb.	–	–	–	–	–	–	–	x	x	–	x	–	–	–	–	–
<i>Calamagrostis purpurascens</i> R. Br.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Campanula rotundifolia</i> L.	x	–	x	x	x	x	–	–	x	x	–	–	–	–	–	x
<i>Campanula uniflora</i> L.	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	–
<i>Carex albonigra</i> Mack.	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	x
<i>Carex heteroneura</i> W. Boott var. <i>chalciolepis</i> (Holm) F.J. Herm.	–	–	–	x	–	–	–	–	–	–	–	–	–	–	x	x
<i>Carex obtusata</i> Lilj.	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
<i>Carex rupestris</i> All. var. <i>drummondiana</i> (Dewey) Bailey	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Castilleja haydenii</i> (A. Gray) Cockerell	x	x	x	x	x	x	x	x	x	x	x	x	–	x	–	–
<i>Castilleja occidentalis</i> Torr.	–	–	–	–	–	–	–	–	x	x	x	x	–	–	x	x
<i>Cerastium arvense</i> L.	–	–	–	–	–	–	–	x	–	–	x	x	–	–	–	x

Table A-1 (continued). GRSA target region species list for each summit (HUK, MUD, PAD, and SIX) by summit area section (05 and 10). "x" indicates the species was present.

Species	HUK				MUD				PAD				SIX			
	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)
<i>Cerastium beeringianum</i> Chamisso & Schlechtendal	x	x	–	–	–	–	–	–	–	–	–	–	x	–	x	x
<i>Cirsium scopulorum</i> (Greene) Cockerell ex Daniels	–	–	–	–	–	–	–	–	–	x	–	–	–	x	x	x
<i>Claytonia megarhiza</i> (Gray) Parry ex S. Wats.	–	–	–	–	–	–	–	–	–	x	–	–	x	x	x	x
<i>Cruciferae</i> in GRSA	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
<i>Cystopteris fragilis</i> (L.) Bernh.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	x
<i>Danthonia intermedia</i> Vasey	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
<i>Danthonia parryi</i> Scribn.	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Deschampsia cespitosa</i> (L.) P. Beauv.	–	–	–	–	–	–	–	–	–	–	–	–	x	x	x	x
<i>Draba aurea</i> Vahl ex Hornem.	x	x	x	x	x	x	x	x	x	x	x	x	x	–	x	x
<i>Draba breweri</i> S. Watson var. <i>cana</i> (Rydb.) Rollins	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–
<i>Draba crassa</i> Rydb.	–	–	x	x	–	–	x	x	–	–	x	x	–	–	–	x
<i>Draba fladnizensis</i> Wulfen	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
<i>Draba grayana</i> (Rydb.) C.L. Hitchc.	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
<i>Draba</i> sp. in GRSA	–	–	–	–	–	–	x	x	–	–	x	–	–	–	x	x
<i>Draba streptocarpa</i> A. Gray	x	x	x	x	x	x	x	x	x	x	x	x	x	–	x	x
<i>Elymus scribneri</i> (Vasey) M.E. Jones	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Erigeron formosissimus</i> Greene	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Erigeron pinnatisectus</i> (Gray) A. Nels.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Erigeron simplex</i> Greene	x	x	–	x	x	x	–	x	x	x	x	x	x	x	–	x
<i>Erigeron</i> sp. in GRSA	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Eriogonum flavum</i> Nutt.	x	x	–	–	x	x	–	–	x	x	x	–	–	–	–	–
<i>Eriogonum jamesii</i> Benth. var. <i>flavescens</i> S. Watson	–	–	x	x	–	–	x	x	–	–	x	x	–	–	–	–
<i>Eritrichium nanum</i> (L.) Schrad. ex Gaudin	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Erysimum capitatum</i> (Dougl. ex Hook.) Greene	x	x	–	x	x	x	x	x	x	x	x	x	–	–	–	–
<i>Festuca brachyphylla</i> Schult.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Festuca minutiflora</i> Rydb.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	x

Table A-1 (continued). GRSA target region species list for each summit (HUK, MUD, PAD, and SIX) by summit area section (05 and 10). "x" indicates the species was present.

Species	HUK				MUD				PAD				SIX			
	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)
<i>Frasera speciosa</i> Dougl. ex Griseb.	—	x	x	x	—	—	—	—	x	—	—	—	—	—	—	—
<i>Gentiana algida</i> Pall.	—	—	—	—	—	—	—	—	—	—	x	—	—	—	x	x
<i>Gentianella amarella</i> (L.) Borner ssp. <i>acuta</i> (Michx.) J.M. Gillett	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—
<i>Gentianella tenella</i> (Rottb.) Börner ssp. <i>tenella</i>	—	—	x	x	—	—	—	—	—	—	x	—	—	—	—	—
<i>Geum rossii</i> (R. Br.) Ser. var. <i>turbinatum</i> (Rydb.) C.L. Hitchc.	—	x	—	x	—	x	x	x	x	x	x	x	x	x	x	x
<i>Heterotheca pumila</i> (Greene) Semple	x	x	x	x	x	x	x	x	—	x	x	x	—	—	—	—
<i>Heuchera parvifolia</i> Nutt. ex Torr. & Gray	x	x	x	x	x	x	x	x	x	x	—	x	x	x	x	x
<i>Kobresia myosuroides</i> (Vill.) Fiori	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Lewisia pygmaea</i> (Gray) B.L. Robins.	—	x	—	—	—	—	—	x	—	—	—	—	—	—	—	—
<i>Lloydia serotina</i> (L.) Rchb.	x	—	—	x	x	x	—	—	x	x	—	—	x	x	—	—
<i>Luzula spicata</i> (L.) DC.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Mertensia lanceolata</i> (Pursh) DC.	x	x	—	x	x	x	x	x	x	x	x	x	—	x	x	x
<i>Minuartia macrantha</i> (Rydb.) House	x	x	—	—	x	x	—	—	x	x	x	x	—	—	x	x
<i>Minuartia obtusiloba</i> (Rydb.) House	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Minuartia rubella</i> (Wahlenb.) Hiern	—	—	—	x	—	—	x	x	—	—	x	x	—	—	x	x
<i>Muhlenbergia tricholepis</i> (Torr.) Columbus	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—
<i>Oreoxis alpina</i> (Gray) Coult. & Rose	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Osmorhiza</i> sp. in GRSA	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—
<i>Oxyria digyna</i> (L.) Hill	—	—	—	—	—	—	—	—	—	—	—	—	x	x	x	x
<i>Packera werneriiifolia</i> (Gray) W.A. Weber & A. Löve	—	—	—	—	—	—	—	x	—	—	—	x	—	—	—	x
<i>Paronychia pulvinata</i> A. Gray	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Pedicularis parryi</i> A. Gray	x	x	x	x	x	—	—	—	x	x	x	x	—	—	—	x
<i>Penstemon hallii</i> Gray	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	x
<i>Penstemon</i> sp. in GRSA	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
<i>Penstemon whippleanus</i> Gray	—	x	—	—	—	x	—	—	—	—	x	—	—	—	—	—
<i>Phacelia hastata</i> Dougl. ex Lehm.	x	x	—	x	—	—	—	—	—	—	—	—	—	—	—	—

Table A-1 (continued). GRSA target region species list for each summit (HUK, MUD, PAD, and SIX) by summit area section (05 and 10). "x" indicates the species was present.

Species	HUK				MUD				PAD				SIX			
	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)
<i>Phleum alpinum</i> L.	–	x	–	–	–	–	–	x	–	–	–	–	x	x	–	–
<i>Phlox condensata</i> (Gray) E. Nels.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Phlox multiflora</i> A. Nelson	x	x	x	x	x	x	x	x	–	–	–	–	–	–	–	–
<i>Pinus aristata</i> Engelm.	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Poa alpina</i> L.	–	–	–	x	–	–	x	–	x	x	x	–	–	–	x	x
<i>Poa fendleriana</i> (Steud.) Vasey	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–
<i>Poa glauca</i> Vahl ssp. <i>rupicola</i> (Nash ex Rydb.) W.A. Weber	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Poa leptocoma</i> Trin.	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Poa</i> sp. in GRSA	x	x	x	x	x	x	x	x	–	–	x	–	–	–	x	–
Poaceae in GRSA	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Polemonium viscosum</i> Nutt.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	–	x
<i>Polygonum bistortoides</i> Pursh	x	x	x	x	x	x	x	x	x	x	x	x	–	–	–	–
<i>Populus tremuloides</i> Michx.	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
<i>Potentilla concinna</i> Richards.	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	x
<i>Potentilla diversifolia</i> Lehm.	–	x	–	x	–	x	–	–	x	x	–	–	x	x	x	x
<i>Potentilla fruticosa</i> L.	x	x	x	x	x	–	x	–	–	–	–	–	–	–	–	–
<i>Potentilla hippiana</i> Lehm.	–	–	–	–	–	–	x	x	–	–	–	–	–	–	x	x
<i>Potentilla nivea</i> L.	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	x
<i>Potentilla ovina</i> Macoun	x	–	x	x	–	–	x	x	x	–	x	x	x	x	–	–
<i>Potentilla pulcherrima</i> Lehm.	x	x	–	–	x	x	–	–	x	x	–	–	x	x	–	–
<i>Potentilla rubricaulis</i> Lehm.	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	x
<i>Potentilla</i> sp. in GRSA	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
<i>Potentilla subjuga</i> Rydb.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Primula angustifolia</i> Torr.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Primula parryi</i> A. Gray	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
<i>Pseudocymopterus montanus</i> (A. Gray) J.M. Coult. & Rose	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–

Table A-1 (continued). GRSA target region species list for each summit (HUK, MUD, PAD, and SIX) by summit area section (05 and 10). "x" indicates the species was present.

Species	HUK				MUD				PAD				SIX			
	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)
<i>Pulsatilla patens</i> (L.) Mill. ssp. <i>multifida</i> (Pritz.) Zämelis	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
<i>Rhodiola integrifolia</i> Raf.	–	x	–	x	–	–	–	–	x	x	–	–	x	x	–	–
<i>Rhodiola rhodantha</i> (A. Gray) H. Jacobsen	–	–	–	–	–	–	–	–	–	–	x	x	–	–	x	x
<i>Saxifraga bronchialis</i> L. ssp. <i>austromontana</i> (Wieg.) Piper	–	–	–	–	x	x	–	x	–	–	–	–	x	x	x	x
<i>Saxifraga chrysantha</i> Gray	–	–	–	–	–	–	–	–	x	x	–	–	x	–	–	x
<i>Saxifraga flagellaris</i> Willd. ex Sternb.	x	–	–	–	x	x	–	x	x	x	x	x	x	x	x	x
<i>Saxifraga rhomboidea</i> Greene	–	x	–	x	–	x	–	x	x	x	x	x	x	x	x	x
<i>Sedum lanceolatum</i> Torr.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Selaginella densa</i> Rydb.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Senecio amplexans</i> A. Gray	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	x
<i>Senecio soldanella</i> Gray	–	–	–	–	–	–	–	–	–	x	–	–	x	x	–	–
<i>Senecio</i> sp. in GRSA	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–
<i>Silene acaulis</i> (L.) Jacq.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Silene drummondii</i> Hook.	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Solidago multiradiata</i>	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
<i>Solidago nana</i> Nutt.	x	x	x	x	x	x	x	x	x	x	x	x	–	–	–	x
<i>Taraxacum eriophorum</i> Rydb.	–	x	–	–	x	x	–	–	–	–	–	–	–	–	–	–
<i>Taraxacum officinale</i> Weber	–	x	–	x	x	x	x	x	–	–	–	–	–	–	–	–
<i>Tetraneuris acaulis</i> (Pursh) Greene var. <i>caespitosa</i> A. Nelson	x	x	x	x	x	x	x	x	x	x	x	x	–	x	x	x
<i>Tetraneuris brandegeei</i> (Porter ex A. Gray) K.F. Parker	x	x	x	x	x	x	x	x	x	x	x	x	–	x	x	x
<i>Thlaspi montanum</i> L. var. <i>montanum</i>	–	x	–	–	–	–	–	–	–	–	–	–	x	–	x	x
<i>Tonestus pygmaeus</i> (Torr. & Gray) A. Nels.	–	–	x	x	x	–	x	x	x	x	x	x	–	–	x	x
<i>Trifolium dasyphyllum</i> Torr. & Gray	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Trifolium nanum</i> Torr.	x	x	–	x	x	x	x	x	x	x	x	x	x	x	x	x

Table A-1 (continued). GRSA target region species list for each summit (HUK, MUD, PAD, and SIX) by summit area section (05 and 10). "x" indicates the species was present.

Species	HUK				MUD				PAD				SIX			
	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)	2010 (05)	2010 (10)	2015 (05)	2015 (10)
<i>Trisetum spicatum</i> (L.) K. Richt.	x	x	–	x	x	x	x	x	x	x	x	x	x	–	x	x
<i>Umbelliferae</i> in GRSA	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Vaccinium caespitosum</i> Michx.	–	x	–	–	–	x	–	–	–	–	–	–	–	–	–	–
<i>Vaccinium scoparium</i> Leiberg ex Coville	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–

Appendix B. GRSA 2015 Trip Report

Alpine vegetation monitoring in Great Sand Dunes National Park and Preserve 2015 Trip Report

February 2, 2017

Colorado Natural Heritage Program
Colorado State University
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Fort Collins, CO 80523-1475

Introduction

In 2010, Rocky Mountain Inventory and Monitoring Network established a Global Observation Research Initiative in Alpine Environments (GLORIA) target region composed of four summits within Great Sand Dunes National Park and Preserve (GRSA). GLORIA was established in 2001 as an international monitoring network designed to assess and predict biodiversity and temperature changes in alpine communities in response to drivers such as climate (Pauli et al. 2004). In 2009 and 2010, baseline monitoring of alpine vegetation, soils and other parameters defined in the GLORIA and NPS protocols were monitored on the GRSA target region summits. Summary reports of those efforts were produced and provide details on the specifics of the protocols, the site selection, the characteristics of the summits, and the initial results from those first monitoring exercises (Ashton 2010a). In July and August 2015, the Colorado Natural Heritage Program (CNHP) field crew completed a full GLORIA resample which consists of four primary activities: replacing temperature

loggers, sampling all 96 vegetation plots, sampling soils for bulk density, and photo documenting vegetation plots at four GRSA GLORIA summits. The purpose of this report is to outline the basic timeline of sampling, any irregularities or errors in surveying and miscellaneous details that may be beneficial for future survey crews.

Sample design

In 2010, Rocky Mountain Network and the CNHP established monitoring sites on four alpine summits in the Sangre de Cristo Mountains of Great Sand Dunes National Park and Preserve according to the GLORIA monitoring protocol (Grabherr et al. 2000). The four summits are situated along an elevational gradient, varying from just above timber line to the altitudinal limit for plants of the area (Table B-1; Figure B-1). The summits share qualitatively similar local climates, geologic substrates, land-use history, and levels of anthropogenic disturbance as required by the GLORIA monitoring design (Grabherr et al. 2000).

Table B-1. Name, location, elevation, and vegetation zone of the four alpine monitoring/sentinel sites within the GRSA target region.

GLORIA summit code	Summit name	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Vegetation zone
SIX	Unnamed	37.861501	-105.492034	4000	alpine/nival ecotone
PAD	Unnamed	37.87965	-105.478217	3870	upper alpine
MUD	Unnamed	37.887517	-105.47665	3700	lower alpine
HUK	Unnamed	37.89615	-105.473733	3550	lower alpine/subalpine ecotone

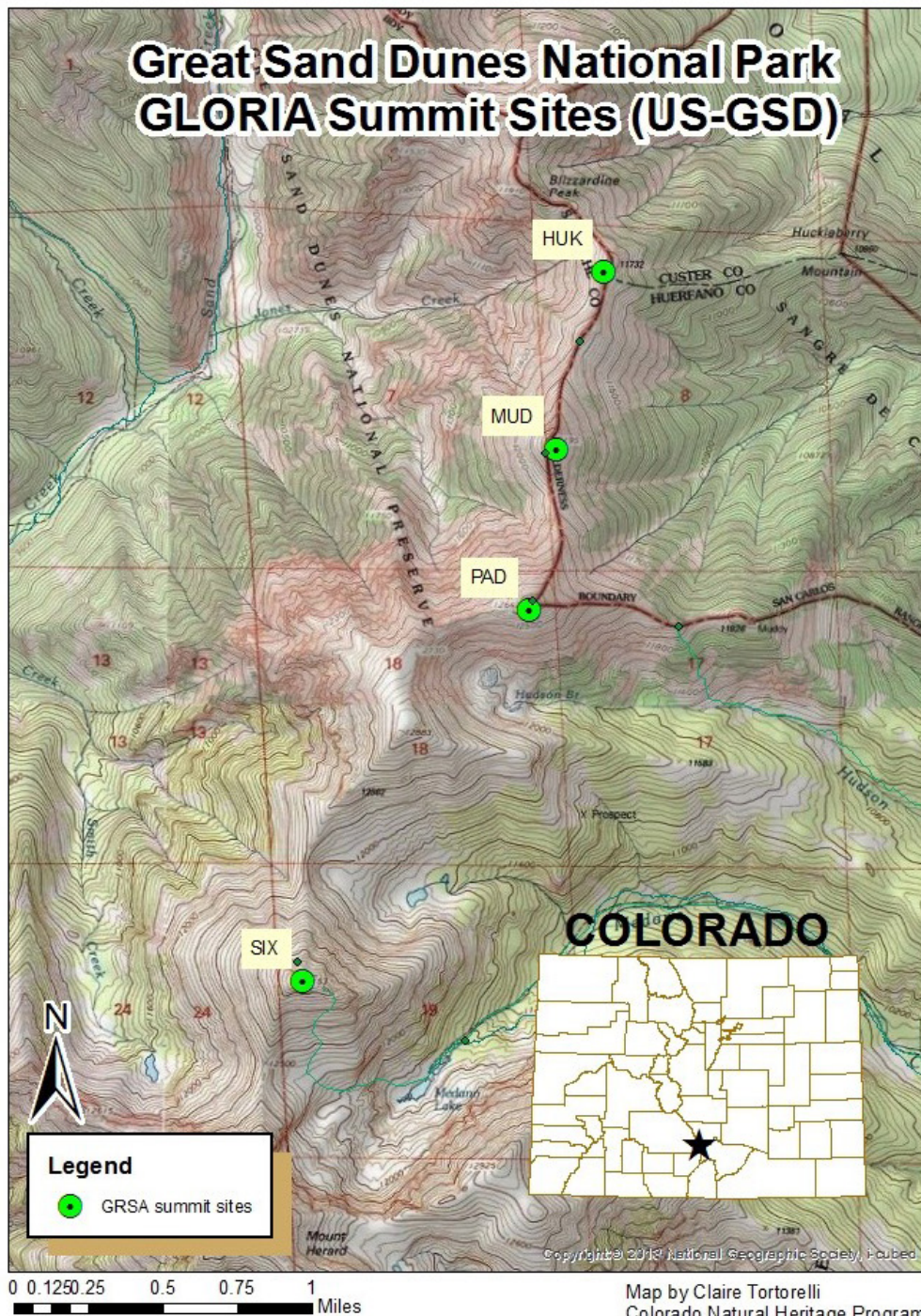


Figure B-1. Locations of the four monitoring peaks (HUK, MUD, PAD, and SIX) at GRSA, CO.

The summit sites were permanently marked during the initial set-up to ensure accurate relocation. At each peak, one marker (a rebar with a labeled aluminum cap) was installed at the highest point on the summit, and 9-m² quadrat clusters (made of nine 1-m² quadrats and also called 3 x 3-m quadrat clusters in this field report) in each cardinal direction at exactly 5 m in elevation below the summit were installed and marked. HOBO Onset pendant temperature loggers (UA-001-64) were buried on the north, east, south and west side of all peaks to acquire hourly temperature data. Preliminary species lists for the four sites were drafted.

In 2015, we revisited the GRSA target region and relocated the initial survey plots using GPS devices and measurement data describing the locations of hardware installed during the initial survey. On each of the four target region summits we completed the vascular plant surveys in all of the summit area sections and all of the 1-m² quadrats according to the GLORIA protocol applied during the initial survey (see Ashton 2010b). To aid in species identification, some plant specimens were collected, identified using regional floras, and compared to herbarium specimens.

The CNHP crew collected soil samples from all aspects of all peaks as was done in the initial sampling. Field work on the four GRSA summits was completed during three field trips in 2015: July 21–23 (PAD), August 3–8 (PAD, MUD, and HUK), and August 17–19 (SIX).

Training

Prior to conducting field surveys at the GRSA site, members of the field crew, Claire Tortorelli, and Dustin Gannon, met for a half day of office and field training at the CNHP office with Joe Stevens and Bernadette Kuhn to become familiarized with survey protocols and the purpose and need of using the GLORIA research methods. A site was selected on the Colorado State University campus on a small hill top to familiarize the crew with the methodology and to practice setting up the 3 x 3-m quadrat clusters, the 1-m² quadrats, and the summit area sections.

Driving Access

The crew convened in Westcliffe, Colorado to access the GRSA summits from the east side of the Sangre de Cristo Mountain Range (Note: As of 2015, Westcliffe does not have cell service which makes

convening here more difficult). From Westcliffe, to access PAD, HUK, and MUD, take CO-69 S/S 6th St. south for 16.2 miles, turn right at Pass Peak Rd. and follow for 6.4 miles, then turn right on an unnamed road to the Trailhead parking. This road is well maintained and accessible by a low clearance vehicle. It leads to a large field where we parked the truck to access the north campsite below MUD. The trail began as a well-defined two-track and became more overgrown the closer the crew got to the campsite.

To access SIX from Westcliffe, take CO-69 S/S 6th St. south for 16.2 miles, then turn right at Pass Peak Rd. and follow for 6.4 miles, turn left and follow for 2.6 miles, then turn right onto CO Rd 559.1 and follow for 1.8 miles, turn left at the fork and follow for .6 miles, then turn right into the Medano Lake trail head (campsite 5.6/7) parking lot, leave vehicles here. This trail leads to Medano Lake and campsite from which SIX is easily accessible. A 4-wheel drive, high clearance vehicle was necessary to access the Medano Lake trailhead from the Westcliffe side. The crew accessed the trailhead in a Ford® F-150 and nearly high centered on exposed rock in the road when heading over the pass. Total access time from Westcliffe to the trail access for all peaks was just over an hour.

Camp and Summit Access

During the July trip, the CNHP crew camped at the South Basecamp as recommended by GRSA staff while sampling PAD. Due to the difficulty in accessing the South Basecamp and the lack of water near this site, the crew did not return to this site, and instead staged out of the North Basecamp during the second trip on August 3–8. The North Basecamp near HUK provided trail access to a flat campsite with easy access to water. This campsite and the route shown in Figure B-2 are recommended for use in future resampling events of PAD, HUK, and MUD. From the road, it took the crew three hours to reach the North Basecamp.

Although there are no defined trails to the summits of PAD, HUK, and MUD, game trails and abandoned hunting trails allow for easy hiking through the forest and up the slopes to gain access to the ridge and the three summits (Figure B-2). From North Basecamp, it took the crew between 1.5 and 3 hours to reach the summits of PAD, MUD, and HUK, with PAD having the longest approach, and HUK the shortest.

Great Sand Dunes National Park: GLORIA Summits, Routes, and Campsites

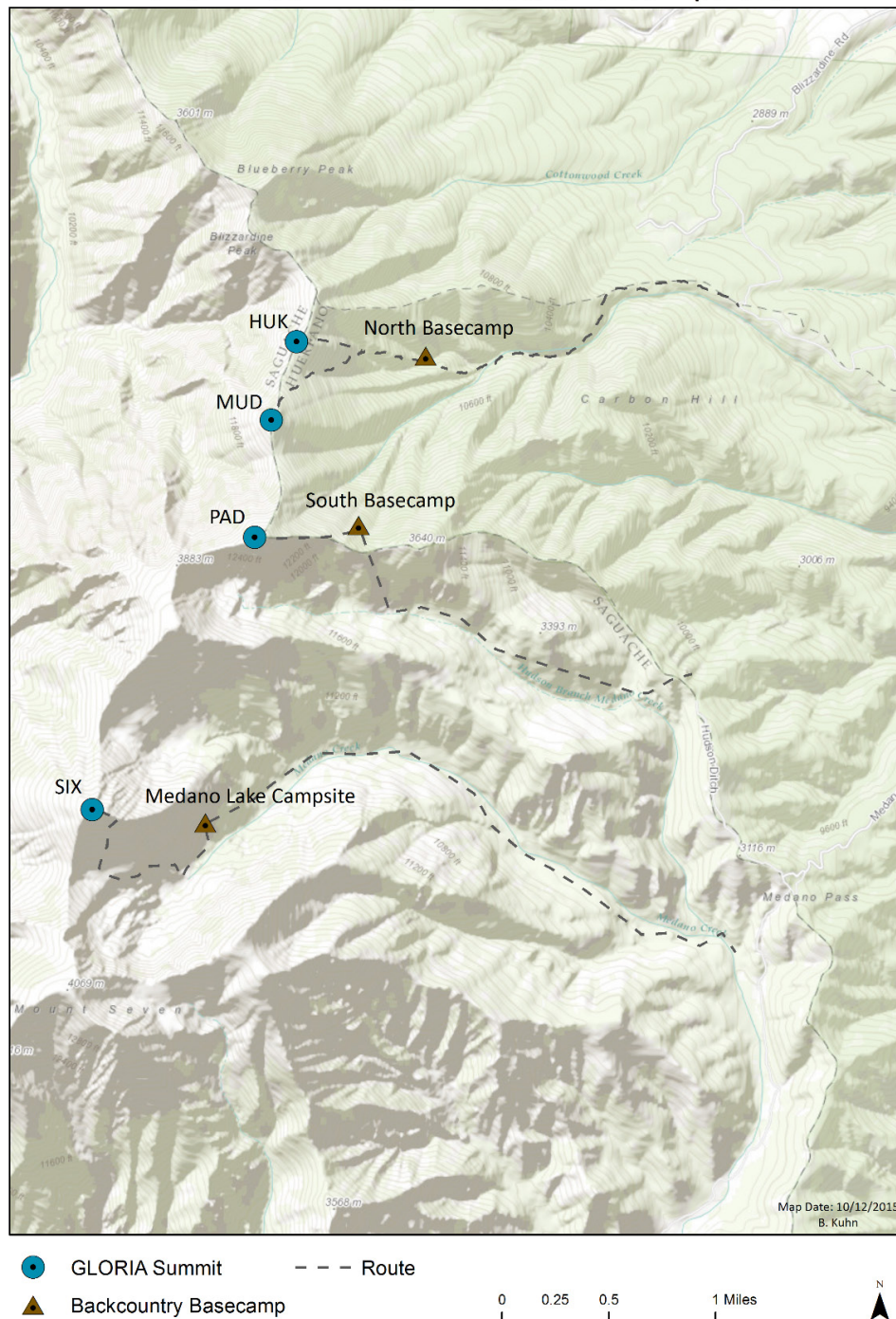


Figure B-2. Map of key locations (summit sites, campsites, and access trails) at GRSA GLORIA target region. August 2015.

The highest summit, SIX, was accessed using the well-established Medano Lake trail (Figure B-2). The crew camped at the established Medano Lake Campsite (Figure B-3). This site is located just below Medano Lake and has easy access to water and flat ground for camping. The crew accessed the summit of SIX using a trail which passes Medano Lake, and follows cairns to climb the southeast ridge of SIX.

Camp sites were chosen for proximity to GLORIA summits, access to water, and available flat ground. Ropes were attached to dry bags and slung over tree branches as a precaution from bears, although no notable wildlife was encountered during this sampling effort.

Field Sampling

The first sampling trip, July 21–23, involved four crew members camped at the south basecamp. One crew member became ill after the first sampling day and the crew hiked out the following morning. During the sampling day, the crew relocated the original survey markers, replaced all soil temperature loggers,

and sampled the PAD E 3 x 3-m plot, and the E and S 5-m summit area sections. The gear was stashed at the south basecamp to make a quick descent and lighter approach during the subsequent trip.

The second sampling trip, August 3–8, involved six field members camped at the north basecamp. From the north basecamp, the crew was able to easily access the ridge and sample the remainder of PAD, MUD, and HUK, respectively. The gear left at the South Basecamp during the first trip was gathered, and all of the gear was hiked out of the field and reorganized for the final trip to SIX.

The final sampling trip, August 17–19, involved five field members. Two marked the GLORIA plot configuration using compasses and pin flags and the remaining three botanists completed the summit area sections and 1-m² sampling quadrats. The crew completed the sampling at SIX in one day, and the crew hiked out of the park the next day. Future resampling efforts should consider using five or six crew members to complete field work in a timely manner.



Figure B-3. Medano Lake Campsite below summit SIX.

Conclusion

Excluding the first sampling day, during which the field crew was becoming familiarized with the sampling protocol, the plot set-up took approximately two hours. Sampling the 1-m² quadrats required two field crew members, one calling species and the other recording for 20 to 35 minutes. The summit area sections required one field botanist and took from 30 minutes to 70 minutes to complete depending on the area of the section and the density of vegetation.

No problems were encountered in relocating the sampling hardware, locating and replacing the temperature loggers, and surveying vegetation. However, the initial summit area sections were not laid out according to the GLORIA protocol, and these were re-delimited and sampled according to the protocol. Additionally, within the 1-m² quadrats, the GLORIA manual specifies that all layers of vascular plant cover should be noted per hit. The crew recorded only the top cover hit at this site (refer to section 4.1.1 in the GLORIA manual for further guidance). Overall, the CNHP crew experienced sunny, clear, and very windy weather while working on the

four peaks (Figure B-4). Inclement weather would significantly slow the sampling process, and should be accounted for in future sampling efforts.

Literature Cited

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- Grabherr, G., M. Gottfried, and H. Pauli. 2000. GLORIA: A global observation research initiative in alpine environments. *Mountain research and development* 20:190-191.



Figure B-4. CNHP field crew members use blue and green flags to mark the GLORIA plot configuration on the summit of PAD. July 2015.

Appendix C. GRSA Summit Site 2015 Field Log

Table C-1. 2015 field log for GRSA summit sites.

Date	Peak	Persons	Activities	Notes
7/21/2015	PAD	Justin Unrein, Bernadette Kuhn, Claire Tortorelli, Dustin Gannon	Crew convened in Westcliffe, CO, carpooled 1.2 hours to Hudson Ditch and hiked 3 hours to South Basecamp	Westcliffe, CO: No cell service; road to Hudson Ditch is only passable with 4-wheel drive and high clearance vehicle. Would not be passable after heavy rain; hiked down old water flume and series of game trails to reach South Basecamp. No water near camp!
7/22/2015	PAD	Justin Unrein, Bernadette Kuhn, Claire Tortorelli, Dustin Gannon	Replaced temperature loggers on PAD, finished E 3 x 3 and E and S summit area sections, stashed gear for the following day	Bernadette was feeling ill and getting worse. We packed up camp and began hiking out. Stashed the remainder of the gear at the South Basecamp for the following trip.
7/23/2015		Justin Unrein, Bernadette Kuhn, Claire Tortorelli, Dustin Gannon	Broke camp, hiked back to truck, and drove back to Fort Collins	–
8/3/2015	PAD	Joe Stevens, Joe Tort, Keith Shultz, James Hunt, Claire Tortorelli, Dustin Gannon	Crew convened at intersection of 69 and 559, parked and made low camp (North basecamp)	1.5 hour drive to parking from the intersection and 3 hour hike from campsite on the road to the basecamp. Well maintained road.
8/4/2015	PAD	Joe Stevens, Joe Tort, Keith Shultz, James Hunt, Claire Tortorelli, Dustin Gannon	Hiked to timberline, retrieved gear from South basecamp, and sampled PAD	3 hour hike to PAD from North basecamp with the retrieval of the gear. Completed all sampling except the S and W 3 x 3. Redelimitate the summit area sections to follow protocol.
8/5/2015	MUD	Joe Stevens, Joe Tort, Keith Shultz, James Hunt, Claire Tortorelli, Dustin Gannon	Dusty and James hiked to PAD to finish the 3 x 3s, the rest of the crew sampled MUD	2 hour hike to the summit of MUD. Discovered a closer, flatter camp-ground GPS: "trail to camp2" 13S 0458707, 4193743. Recommend using this campsite for future access.
8/6/2015	MUD	Joe Stevens, Joe Tort, Keith Shultz, James Hunt, Claire Tortorelli, Dustin Gannon	1.5 hour hike to the summit of MUD, finished MUD and set-up summit area sections on HUK. Finished W & N 3 x 3s, photos, and soils	Saved trail to MUD on GPS as "camp to MUD". Very windy! Flags may need replacing.
8/7/2015	HUK	Joe Stevens, Joe Tort, Keith Shultz, James Hunt, Claire Tortorelli, Dustin Gannon	1.5 hour hike to HUK. Completed HUK and hiked to the truck. Drove back to Fort Collins	Took the trail across the creek from low camp and accessed a nice trail to the parking area. Route is recorded for future reference.
8/17/2015	SIX	Claire Tortorelli, Dustin Gannon, Keith Shultz, James Hunt, Kellen Keisling	convened at the Medano Lake Trailhead (campsite 5.7) hiked to Medano Lake campsite and set up camp	Access TH from eastside requires high clearance and 4-wheel drive. Trail was well maintained.
8/18/2015	SIX	Claire Tortorelli, Dustin Gannon, Keith Shultz, James Hunt, Kellen Keisling	Reached the summit of SIX in 2 hours from Medano Lake campsite. Finished sampling and hiked back to camp.	Followed cairns along the SE ridge of SIX which met up with the Medano Lake trail. Recommend taking this trail to access the summit of SIX in future sampling efforts.
8/19/2015	SIX	Claire Tortorelli, Dustin Gannon, Keith Shultz, James Hunt, Kellen Keisling	Hiked out and drove back to Fort Collins	–

Appendix D. GRSA Summit Site Access Routes and Base Camps

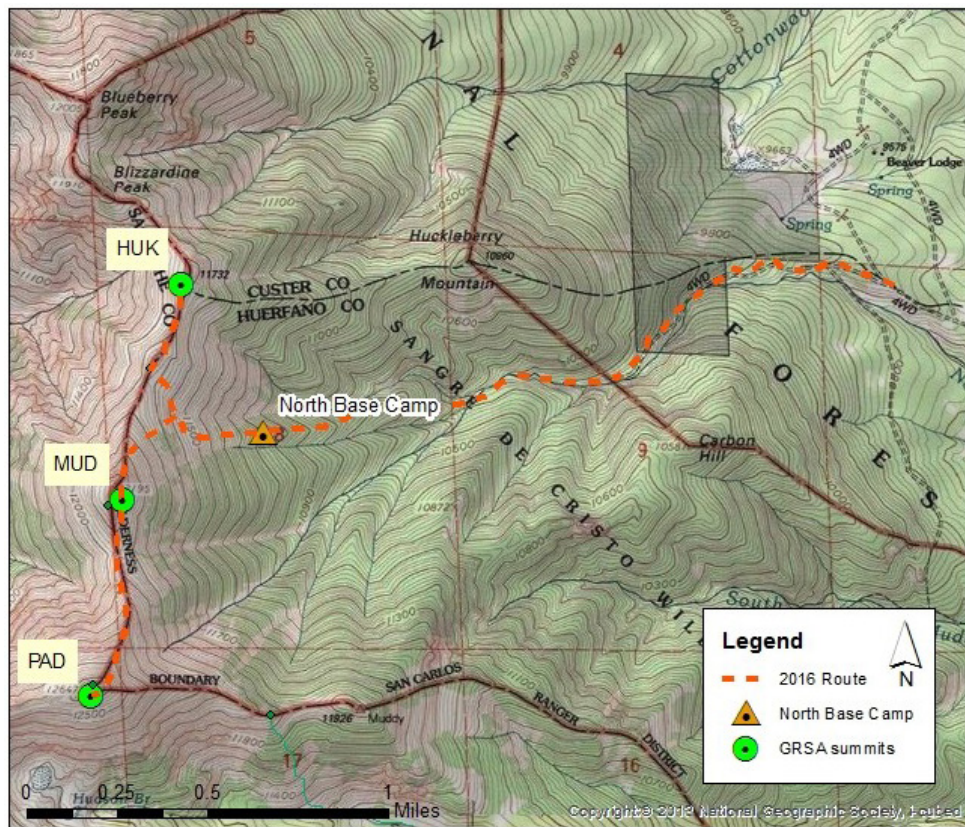


Figure D-1. HUK, MUD, and PAD access via north basecamp, GRSA 2015.

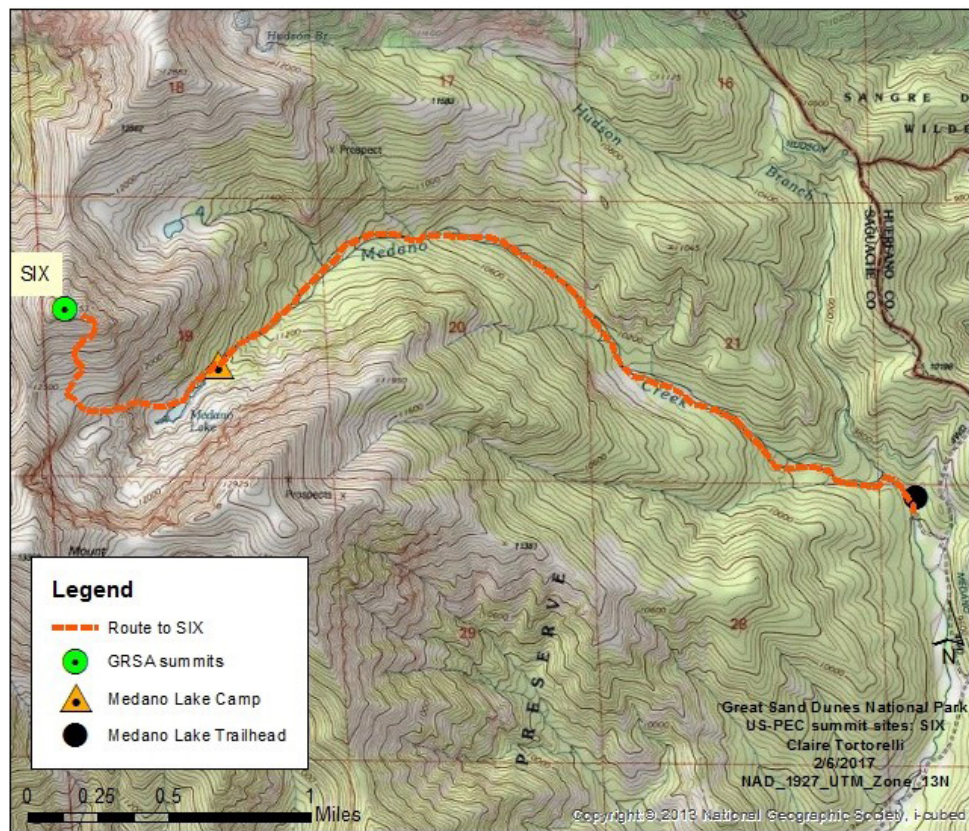


Figure D-2. SIX access via Medano Lake trail and camp, GRSA 2015.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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Natural Resource Stewardship and Science

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