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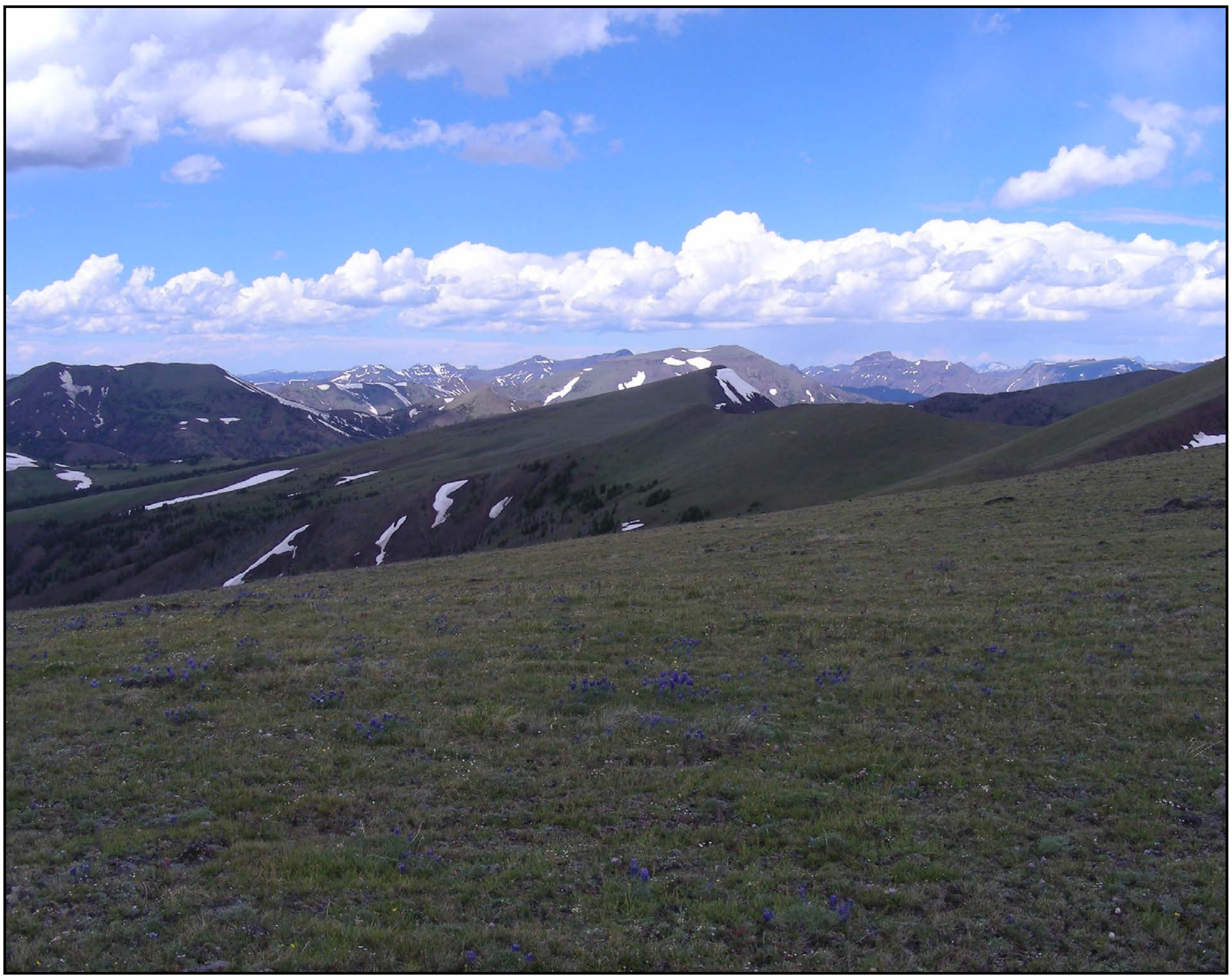
Alpine Vegetation Composition, Structure, and Soils Monitoring for Yellowstone National Park

2011 Summary Report

Natural Resource Data Series NPS/ROMN/NRDS—2015/777



ON THE COVER

Looking westward from Boundary Line Peak, on the eastern border of Yellowstone National Park. Boundary Line Peak is one of four selected GLORIA summits in the Absaroka Mountains Yellowstone National Park, Wyoming, August 2011. Photograph by: Bernadette Kuhn

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The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols. This report received peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Executive Summary

Alpine ecosystems are important monitoring targets for the Rocky Mountain (ROMN) and Greater Yellowstone (GRYN) Inventory and Monitoring networks for a number of reasons, including their value to park visitors, wildlife, and water resources in the West and because alpine ecosystems are particularly vulnerable to climate change. Here we present a summary of our efforts in 2011 to monitor vegetation composition, structure, and soils in the alpine of Yellowstone National Park (NP). We found the following:

- In 2011, an alpine monitoring site was established at Yellowstone NP 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 alpine ecosystems.
- Four GLORIA sentinel sites were established at four unnamed peaks in the upper Lamar River area, northeast of Lamar Mountain. The peaks ranged in elevation from 3,195 m to 3,122 m.
- There were 108 taxa of vascular plants identified from the four peaks, including grasses forbs, sedges, shrubs, and two tree species. In addition, 22 species of lichens were identified among the four GLORIA sites.
- The four peaks are generally characterized by erosive volcanic soils, high vegetation cover, low exotic species cover, and minimal human and herbivore disturbance.

In 2011, we found the alpine tundra at the four sentinel sites in Yellowstone NP to be a system little impacted by human disturbance or exotic species. One exception was on Boundary Line Peak that had a pre-established trail and some related signage covering a small portion of the peak. Climate change and increased atmospheric deposition of nutrients are the greatest threats to alpine systems in Yellowstone NP. Continued monitoring of the vegetation and temperature at sentinel sites will allow us to determine whether climate change correlates with changes in biodiversity in alpine ecosystems. Warmer temperatures may contribute to the extinction of some plant species while simultaneously increasing the elevation and latitudinal limitations of other species.

Acknowledgments

The Colorado Natural Heritage Program (CNHP) would like to thank all who assisted with field work, training and preparation, and gave knowledge and insight necessary for the GLORIA study, particularly Isabel Ashton, Mike Britten, Erin Shanahan, Kristen Long, Laura O'Gan, Jennifer Whipple, and Christie Hendrix. Special thanks goes out to Meade and Andrea Dominick and the staff of the 7D Ranch for packing field supplies into our remote camp site and to the members of Yellowstone National Park Dispatch for coordinating our safety check-ins and aiding with our backcountry itinerary. CNHP would also like to thank Andrew Pills and Julie Lyon with the Shoshone National Forest for input regarding logistics and for the use of the Sunlight Ranger Cabin as a crew base during off time. Flights over our study area were coordinated by Project Lighthawk staff member Shannon Rochelle, and generously donated by pilots Lisa Robertson and Richard Spencer. Special thanks also go to Kristin Legg and other employees of the Greater Yellowstone Inventory and Monitoring Network for supporting and facilitating this monitoring project.

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 Network (ROMN) selected alpine communities, defined as vegetation communities that exist above treeline, as a high-priority vital sign (Britten 2007) for a number of reasons, including their value to park visitors, wildlife, and water systems in the West and because alpine ecosystems are particularly vulnerable to climate change. The ROMN published a monitoring protocol in 2010 (Ashton 2011). The Greater Yellowstone Network (GRYN) and ROMN identified alpine communities as high priorities for enhanced monitoring to address rapid climate change in high-elevation parks in the Rocky Mountain region (Bingham et al. 2011).

The ROMN and GRYN partnered with the Colorado Natural Heritage Program (CNHP) to monitor alpine ecosystems in Yellowstone National Park (NP). Here, we present a summary of activities conducted under this partnership in 2011. The objective of this project was to measure vegetation composition, structure, and soils in the alpine regions of Yellowstone NP.

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

- Determine the status and trend in vegetation composition and structure of four sentinel alpine peak communities at a range of elevations.
- Determine status and trend in cover of invasive exotic plant species at four sentinel alpine peak communities at a range of elevations.
- 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 in four sentinel alpine peak communities.
- Determine the status and trend of anthropogenic and natural disturbance in 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.
- 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 and CNHP, 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 (CNHP) followed the GLORIA monitoring design (Grabherr et al. 2000), which calls for the establishment of four sentinel sites on alpine peaks representing an elevation gradient within a target region (e.g., the Absaroka Range in eastern Yellowstone NP, Wyoming). One GLORIA region includes four sites. 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.

In 2011, we established monitoring sites at four summits within Yellowstone NP (US-YNP). The sites were selected from an evaluation of all potential sites within the park. Potential sites were identified from a combination of topographic maps, satellite and aerial imagery, and maps of facilities and transportation corridors, such as roads and trails.

The sites were established and sampled by a CNHP field crew over three visits: one reconnaissance visit July 20-24 by Joe Stevens and Bernadette Kuhn, and two sampling trips (July 31-August 7 and August 14-21). The sampling trips involved six crew members: Bernadette Kuhn (Ecologist/Leader), Travis Talbot (Botanist), Betsy Harbert (Botanist), Monica Kopp (Botanist), and Daniel Shryock (Botanist). Joe Stevens (Ecologist/Principle Investigator) and Vinamra Mathur (International Student Intern) accompanied the sampling crew from July 31 through August 3, 2011.

To identify target summits, we examined topographic maps and photographs, discussed options with park managers, took a reconnaissance flight over the area, and hiked to potential sites to select the best summits. The summits we chose are within close proximity of one another and are located in the Upper Lamar River area on a ridgeline that runs north of Lamar Mountain (Figure 1 and Table 1).

The four peaks have similar geology, land-use history and disturbance levels, and 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 sides of all peaks to acquire hourly temperature data for the winter of 2011-2012, and drafted preliminary species lists for the four sites.

Figure 1. Location of four alpine sentinel sites in Yellowstone National Park.

Table 1. Name, location, elevation, and life zone of the four alpine sites within the target region of Yellowstone NP.

Summit Code	Unofficial Summit Name	Latitude (dec. degrees)	Longitude (dec. degrees)	Elevation (m)	Vegetation Zone
BLP	Boundary Line Peak	44.70028	-109.8267	3,195	lower alpine
SCP	Stone Crop Peak	44.69584	-109.8339	3,122	lower alpine
SPP	Snow Pipit Peak	44.70167	-109.835	3,169	lower alpine
WSP	Wolf Scat Peak	44.69444	-109.8364	3,124	lower alpine

Plot Layout

Once the summits were selected, we established a long-term monitoring plot at each of the summit sites. On each summit we:

- placed one marker (a rebar with a labeled aluminum cap) at the highest point on the summit (HSP);
- identified and marked a 3x3 m quadrat cluster on each cardinal direction at exactly 5 m in elevation below the summit (Figure 2), all four corners of each quadrat cluster are marked: one with capped rebar and three with nails;
- identified four upper and four lower summit area sections that describe each aspect to a distance of 10 m of elevation below the summit (Figure 3). That is, the upper north section was the north side from the summit (HSP) to 5 m below the summit, and the lower section was from 5 to 10 m below the summit.

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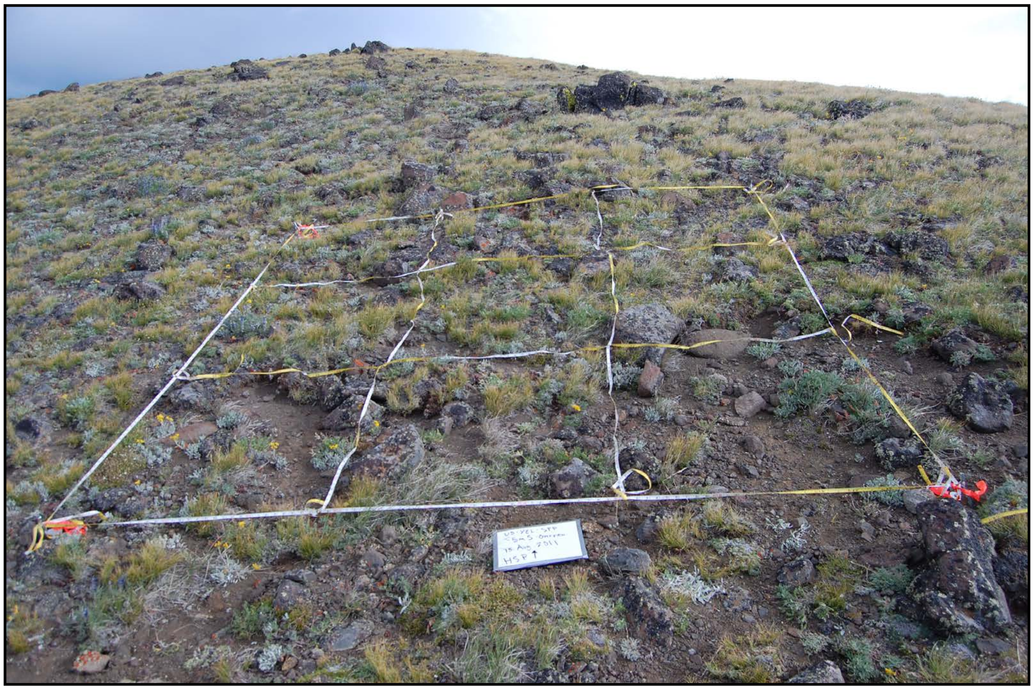

Figure 2. A divided meter tape outlines a 3x3 m quadrat cluster on the south side of the peak, August 2011.

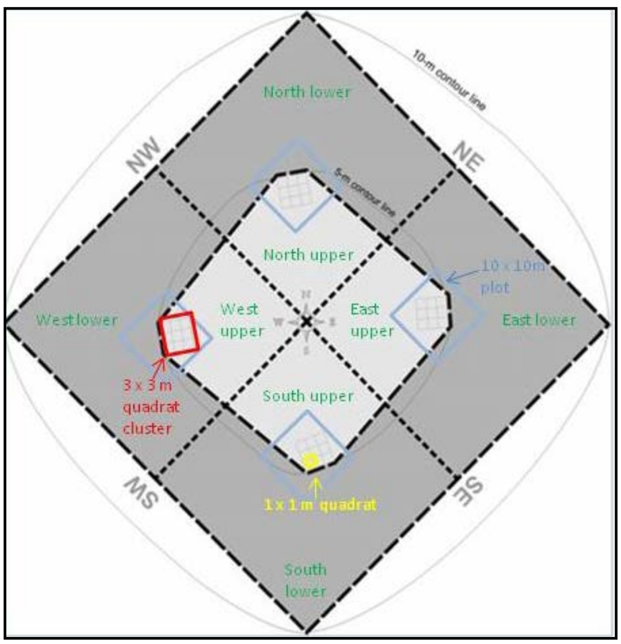

Figure 3. Field plot design used for alpine monitoring, which was replicated on four summits varying in elevation. The design is centered by the high summit point (HSP) and extends to 10 m in elevation below the highest point.

Vegetation, Soils, Temperature, and Disturbance Monitoring

The quadrat clusters each contain 9-1 m^2 quadrats (Figures 2 and 3) that are used to measure fine changes in vegetation cover and frequency. In addition, one temperature data logger is buried at a depth of 10 cm in the center of each quadrat cluster to measure changes in soil temperature over time and variation in temperature associated with aspect. The 1 m^2 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 (seven 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 (Table 2).

After establishing and photographing the quadrats on all peaks, we installed four temperature loggers per peak buried 10 cm in the soil, measured plant cover and frequency in at least eight 1 m^2 quadrats per peak, and surveyed all summit area sections to determine changes 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 any one of 100 10x10 cm grid cells within the quadrat. We installed HOBO Onset pendant temperature loggers (UA-001-64) that are programmed to measure and

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

Plot Type	Size	# of Plots/ Peak	# of Plots in US-YNP	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/ absence; 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

record temperature every hour. To aid in identification, some plant specimens were collected, identified using regional floras, and compared to herbarium specimens.

We also collected a bulk soil sample (an aggregate of three cores to 20 cm depth) 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. 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 CNHP (Rocchio 2007) and the California Rapid Assessment Method for Wetlands (Collins et al. 2008), we recorded a condition score for each site that ranges from 0 (pristine) to 100 (highly disturbed).

In total, the field work for 2011 took 17 days, four of which were used for travel and access to and from backcountry campsites. All four peaks are within close proximity of one another, and could be accessed from one campsite, cutting down on travel time. Initial set-up and establishment of the four peaks took five people (Bultema, Kopp, Kuhn, Shryock, and Talbot) roughly six days to complete. This included the data logger installation and soil sampling for the four peaks. The remaining seven days of field work were spent acquiring vegetation data, identifying plant species, photographing the summits and obtaining locational data, and sampling lichens and mosses. 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.

Results

Vegetation Composition and Structure

Summit Area

The four sentinel GLORIA summits varied in percent cover of vegetation, rock, and bare ground (Figure 4). Snow Pipit Peak (SPP) had the lowest cover of vascular and nonvascular plants, particularly on the east and west sides of the summit. This peak, unlike the other three, is oriented east to west and was notably rockier than the other three. All four peaks were well vegetated, with vascular and nonvascular plant cover between 43-69% cover.

A total of 108 vascular plant taxa and 22 lichen taxa were found on the four summits (Appendix 1). The number of taxa varied only slightly among peaks, with summit SPP containing the lowest diversity (Table 3). Forbs and graminoids dominated all four peaks, although a few woody species were documented. One peak, Stone Cap Peak (SCP), contained the tree species Engelmann spruce (*Picea engelmanii*). The only other tree species that was documented was whitebark pine (*Pinus albicaulis*), which was found on SCP and SPP summits. Two diminutive willow species, snow willow (*Salix nivalis*) and alpine willow (*Salix petrophila*), were found at Wolf Scat Peak (WSP) and Boundary Line Peak (BLP), and at SCP and WSP, respectively.

The three dominant species recorded on BLP were *Carex filifolia*, *Geum rossii*, and

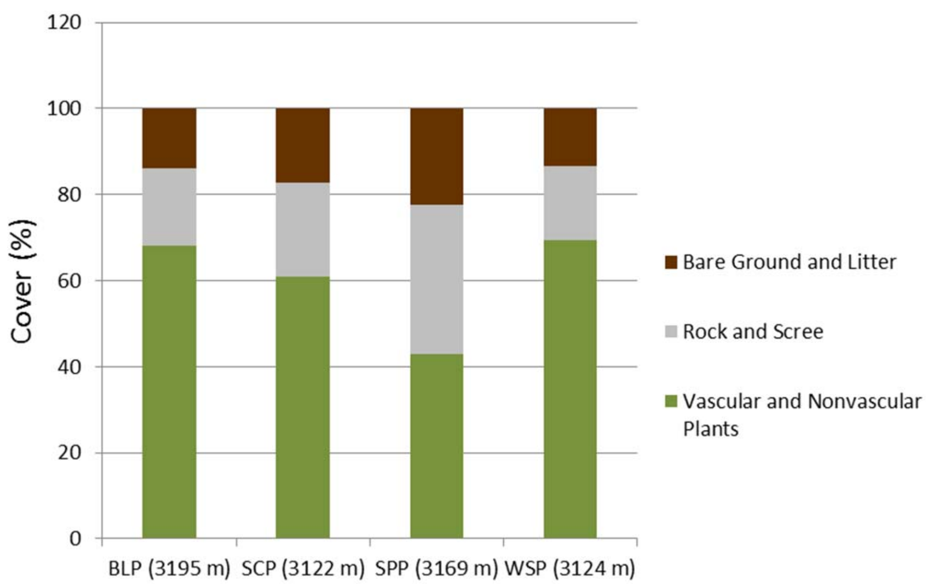

Figure 4. Mean bare ground, rock, and vegetation for each of the four GLORIA peaks at Yellowstone NP. Values were averaged for each cover class from the summit to 10 meters below the summit. Averages include all four aspects of each peak.

Table 3. Number of vascular plant (VP) taxa present on four alpine sentinel sites within the Yellowstone NP GLORIA site.

GLORIA Summit Code	Elevation (m)	# of VP Taxa (to 5 m below summit)	Additional VP Taxa (from 5-10 m below summit)	Total # of VP Taxa (entire summit area)
BLP	3,195	69	9	78
SCP	3,122	70	8	78
SPP	3,169	54	13	67
WSP	3,124	62	9	71

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Figure 5. A 1 m² quadrat on the south side of summit Snow Pipit Peak used to measure fine -scale changes in species cover and frequency.

Minuartia obtusiloba. At SCP, dominants were *Geum rossii*, followed by *Lupinus depressus* and *Minuartia obtusiloba*. At SPP, *Carex rupestris* and *Astragalus australis* were dominant. On WSP, two sedge species, *Carex filifolia* and *Carex elynoides*, were dominant, along with *Geum rossii*.

Frequency and Cover Quadrats

We measured plant cover and frequency on each aspect of all four peaks using 16 1 m^2 quadrats on each peak, for a total of 64 quadrats (Figure 5). A one-way analysis of the variance (ANOVA) was calculated to compare total vegetation cover among peaks. The results were not significant ($F3, 15=1.76$, $p=0.16$) at a $\alpha=0.05$ level. Differences among aspects were significant ($F3, 15=1.76$, $p=1.46E-08$) at a $\alpha=0.05$ level. North, South, and West aspects all contained higher cover than the East aspect.

Figure 6 shows examples of various plants and lichen documented in the plots.

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Figure 6. Alpine species found in US-YNP: *Lupinus depressus* (top), *Townsendia condensata* (middle), and lichens (lower; orange=*Xanthoria elegans*, foliose dark-grey brown=*Umbilicaria virginis*, pale green growing on smaller rock=*Rhizoplaca melanopthalma)*.

Invasive Exotic Plants

Of the 108 vascular plant taxa identified from US-YNP, dandelion (*Taraxacum officinale*) was the only exotic species found. It was documented from BLP, SCP, and WSP. At SPP, we documented a *Taraxacum* sp. lacking flowers and achenes, and was therefore unidentifiable to species (Appendix 1). We suspect it is a native, alpine member of this genus.

Temperature

Temperatures recorded 15 cm below the soil surface ranged from approximately -20 to +20 degrees Celsius and colder temperatures generally were correlated with higher elevations (Figure 7). In 2011-2012, freezing temperatures on all the summits generally began in mid-to late-October and ended in early May. During 2012-2013, freezing temperatures generally began in September and lasted into mid- to late-May. Two exceptions were documented: (1) on SPP, freezing temperatures started in late October; (2) on SCP, freezing temperatures ended earlier. Temperatures for the E aspects of SCP, WSP, and SPP and the N aspect of SPP hovered near freezing with little variability from fall and into the spring suggesting snow cover insulated the soils on these aspects and summits and kept them relatively warm.

Table 4 records the first day of Fall and Spring on GLORIA summits. Fall is defined as the first day when average minimum temperatures are below 0°C, and Spring is defined as the first day when average minimum temperatures are above 0°C. Note that estimates for WSP do not include the record from the west or south sides of the peak. Also note the estimates

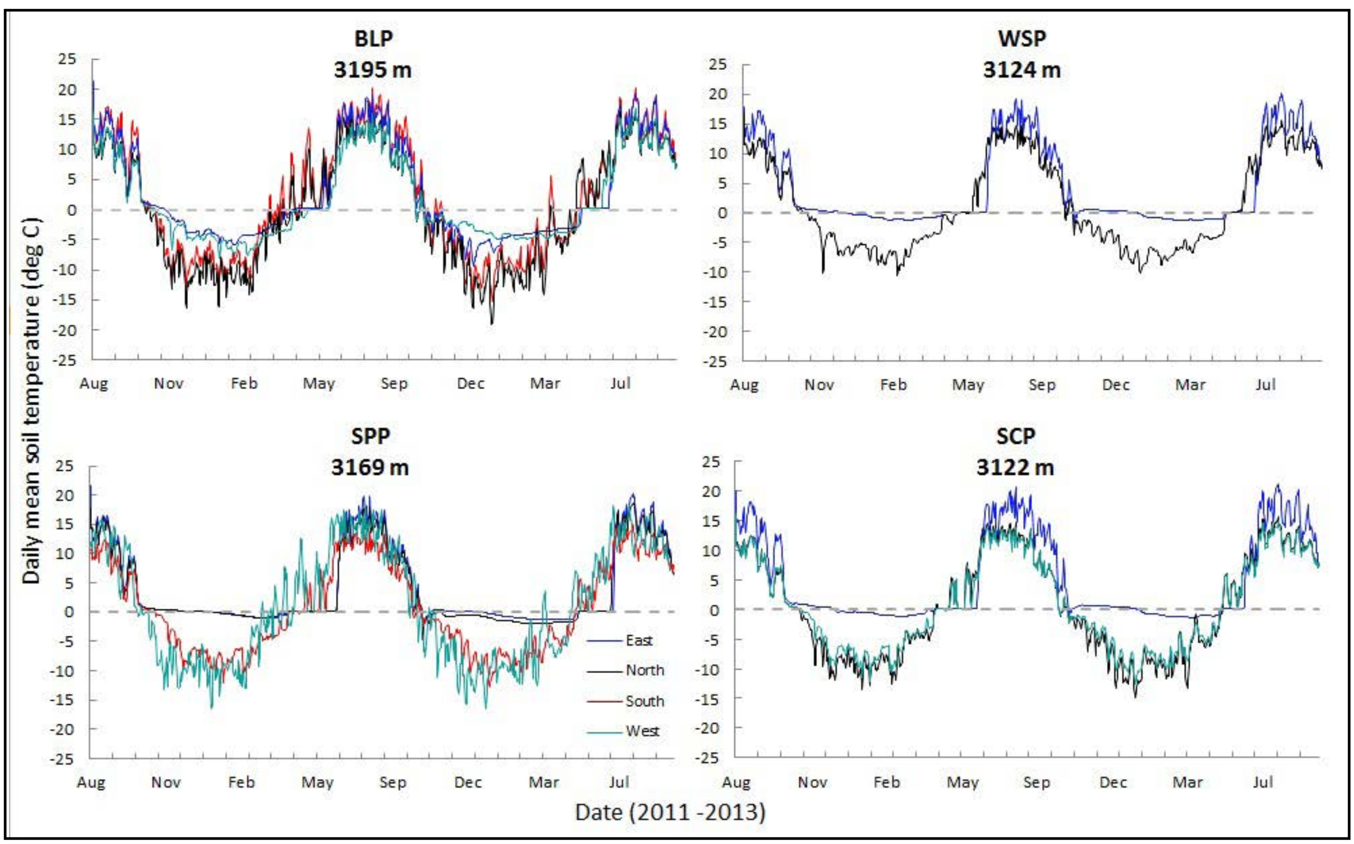

Figure 7. Daily soil temperatures from July 2011-September 2013 on the north, east, south, and west sides of Boundary Line Peak (BLP), Stone Crop Peak (SCP), Snow Pipit Peak (SPP), and Wolf Scat Peak (WSP) summits in Yellowstone National Park. The dataloggers on the west and south sides of WSP were left to test battery duration, so we do not report data for this time period. The datalogger on the south side of SCP was not recovered and the data logger on the E aspect of SPP did not record data from September 2011 to June 2012.

Table 4. The first days of Fall and Spring for each summit.

	BLP	SCP	SPP	WSP
2011 Fall	Oct-11	Oct-11	Oct-11	Oct-11
2012 Spring	Apr-12	Apr-12	Apr-12	May-12
2012 Fall	Oct-12	Oct-12	Oct-12	Oct-12
2013 Spring	May-13	May-13	May-13	May-13

Table 5. Soil properties from four alpine summits in Yellowstone National Park, Wyoming. Each row in the table contains soil chemistry values from a unique soil sample taken in 2011.

Summit Code	Aspect	pH	EC (mmhos/cm)	Organic Matter (%)	NH_4 (mg/kg)	NO_3 (mg/kg)	P (mg/kg)	Fe (mg/kg)	Total N (%)	C:N Ratio
BLP	N	6.3	0.1	4.4	0.2	2	1.2	44.56	0.249	7.76
BLP	E	6.2	0.1	4.3	0.3	1	1.8	79.47	0.1869	9.25
BLP	S	6.5	0.1	5.1	0.1	1	2.4	11.83	0.0416	7.35
BLP	W	5	0.2	1.8	1	6	4.2	35.72	0.0962	5.05
SCP	N	7.1	0.1	4.1	0.1	2	0.6	6.243	0.0247	17.68
SCP	E	7	0.2	2.2	0.1	1	1.8	6.211	0.0242	13.72
SCP	S	5.7	0.1	4.2	1.2	1	1.2	61.15	0.0595	1.77
SCP	W	5.8	0.1	5.7	0.1	1	2.4	77.6	0.1223	7.19
SPP	N	5.8	0.1	3.4	0.9	0	1.2	30.85	0.0637	6.54
SPP	E	5.8	0.1	4.4	0.8	1	1.2	31.02	0.0839	5.41
SPP	S	6.1	0.1	3	0.5	2	2.4	31.39	0.0501	1.77
SPP	W	5.9	0.1	2.9	0.7	1	4.2	37.02	0.0454	6.44
WSP	N	6.2	0.1	2.2	1.4	2	1.8	24.3	0.0299	12.68
WSP	E	6	0.1	2.4	2	2	3.6	28.39	0.0333	8.18
WSP	S	5.6	0.1	6.6	1.6	4	1.2	36.4	0.1554	9.4
WSP	W	5.6	0.2	7.2	1.1	2	1.2	42.01	0.1816	9.26

for SCP do not include the record from the south side of the peak.

Soils

Soils from Yellowstone NP were well-drained gravelly loams, with pH ranges of 5.0-7.1, and a mean pH of 6.0 (Table 5). Mean organic matter content is 3.99. The US-YNP GLORIA site straddles the Yellowstone NP/Shoshone National Forest boundary. No soil maps have been created for this area of the park. The adjacent soils on Shoshone National Forest are classified as Eutrocryepts. Parent material consists of colluviums derived from acidic volcanic breccias (NRCS 2013). All soil samples were analyzed at Colorado State University Soil Testing Lab and results are on file at ROMN.

Anthropogenic and Natural Disturbance

Human disturbance was measured qualitatively at all four summits. All were located in the remote backcountry of the Absaroka Range, so disturbance levels were extremely low. Light recreation impacts were noted along the edge of summit BLP, including a rock cairn (Figure 8). The hiking trail that connects Yellowstone NP to the Shoshone National Forest lies a few hundred feet north of BLP, and is marked by a wooden sign. All other impacts documented on the summits were from wildlife. Bear, wolf, and elk scat were present at BLP, SPP, and WSP, and elk were observed grazing near SPP (Figure 9).

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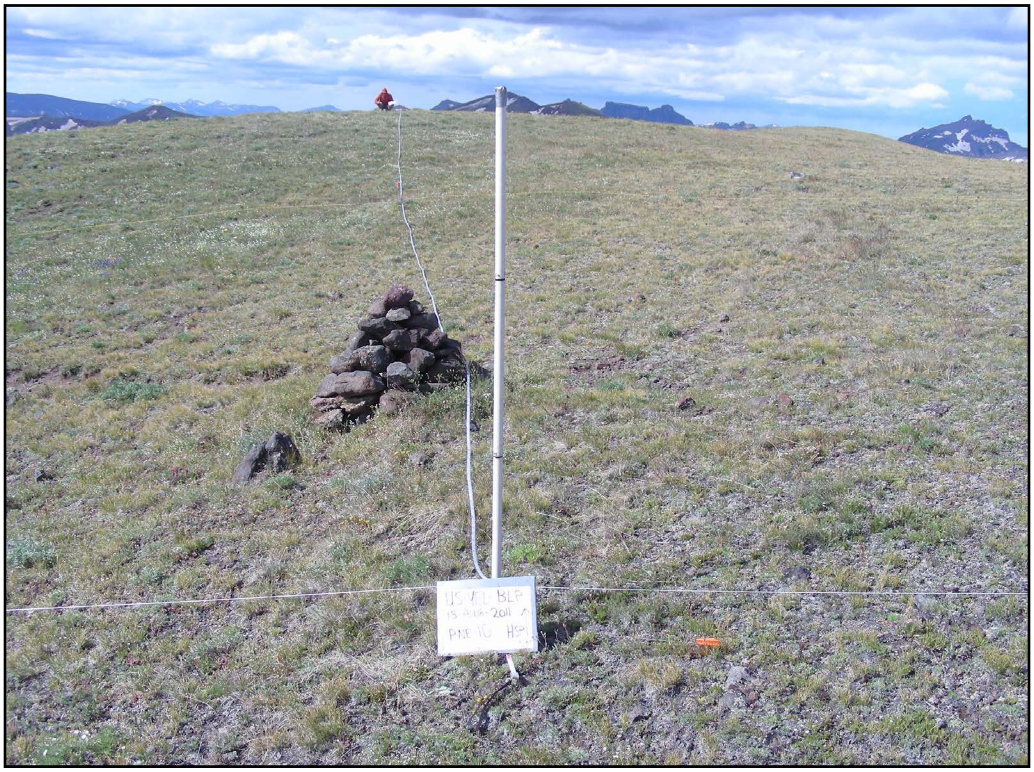

Figure 8. Rock cairn at the High Summit Point on Boundary Line Peak.

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Figure 9. Elk browsing in meadow below summit Snow Pipit Peak.

Discussion

The goal of our alpine monitoring efforts in Yellowstone NP is to examine status and trends of the following parameters: vegetation composition and structure, invasive/exotic cover, soil condition, soil temperature, and disturbance. To this end, we established a US-YNP GLORIA sentinel site at four unnamed peaks in the upper Lamar River area, northeast of Lamar Mountain. As of 2013, the site has not been re-sampled, so we cannot describe trends; however, the paragraph below summarizes notable details of the vegetation sampling effort.

Vegetation Sampling

There were 108 taxa of vascular plants identified from the four peaks, including grasses forbs, sedges, shrubs, and two tree species. In addition, 22 species of lichens were identified among the four summit sites. Future sampling efforts will likely reveal additional taxa of vascular plants, especially members of Poaceae and Cyperaceae. The lichen diversity at the site was low, but several taxa were encountered that could not be removed from boulders for identification.

In the winter of 2010-2011, precipitation was above average in Yellowstone NP (WRCC 2013). Our field crew encountered deep snowpack and deep, swift water at stream crossings, as well as persistent snowfields at the summits during the reconnaissance visit (July 20-24) and the first sampling event (July 31-August 7). Due to record amounts of snow from the winter and spring of 2011, the identification of late blooming members of Cyperaceae and Poaceae was difficult, if not impossible. We completed the sampling event using six well-trained field botanists comfortable working in rugged and remote backcountry environments. Future parties conducting vegetation sampling should ensure that all crew members are familiar with Wyoming flora in order to maximize time efficiency and are comfortable working in a rugged backcountry setting. Due to the complex logistics involved in accessing the area and transporting sampling equipment, maximum time efficiency is required for completing sampling at the site.

The elevation gradient of the four selected peaks is smaller than we would have liked and may be less than ideal for identifying climate change effects across the alpine zone. The alpine elevation gradient is small throughout the park, however, and the selected peaks were chosen after an extensive evaluation of all peaks determining that these provided the best combination of suitability with the protocol and logistical feasibility. As logistically difficult as these sites were to sample, there were many other areas that presented far greater logistical challenges with similarly narrow elevation gradients.

Temperature

The alpine ecosystems in Yellowstone NP are characterized by cold temperatures and a short growing season. When the sites were established, we assumed they were all in the same climate region (a prerequisite of a GLORIA target region). The very similar patterns in the temperature data across the summits suggest that this is the case. Soil temperature patterns suggest that snow cover varied by summit and aspect. Future analyses are needed to derive an index based on soil temperature that can be used to estimate the length of the snow cover season on all peaks. Over time, the temperature records collected at these sites will greatly add to our understanding and documentation of climate change in the alpine ecosystems of Yellowstone NP.

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Appendix A: US-YNP Target Region Species List

Table A1. Vascular Plants.

Species	BLP 5 m	BLP 10 m	SCP 5 m	SCP 10 m	SPP 5 m	SPP 10 m	WSP 5 m	WSP 10 m
Achillea millefolium L. var. *occidentalis* DC.	x	x	x	x	x	x	x	x
Agoseris glauca (Pursh) Raf. var. *dasycephala* (Torr. & Gray) Jepson	x	x	x	x	x	x	x	x
Allium sp.					x			
Androsace septentrionalis L. ssp. *subulifera* (Gray) G.T. Robbins	x	x	x	x	x	x	x	x
Antennaria monocephala DC.	x	x	x	x	x	x	x	x
Arabis lemmonii S. Watson var. *lemmonii*	x	x		x	x	x		x
Arabis lyallii S. Watson var. *lyallii*	x	x	x	x		x	x	x
Arabis pycnocarpa M. Hopkins var. *pycnocarpa*			x	x	x	x		
Arenaria congesta Nutt.	x	x	x	x	x	x	x	x
Arnica rydbergii Greene				x				
Artemisia scopulorum Gray	x	x	x	x			x	x
Astragalus alpinus L.	x	x			x	x	x	x
Astragalus australis (L.) Lam.	x	x	x	x	x	x		x
Astragalus kentrophyta A. Gray var. *tegetarius* (S. Watson) Dorn	x	x	x	x	x	x	x	x
Besseya wyomingensis (A. Nels.) Rydb.	x	x	x	x	x	x	x	x
Calamagrostis sp.						x		
Calamagrostis purpurascens R. Br.					x	x		
Caltha leptosepala DC.	x	x						
Carex elynoides Holm.			x	x		x	x	
Carex filifolia Nutt.	x	x	x		x		x	x
Carex haydeniana Olney	x	x	x	x			x	x
Carex sp.		x	x					
Carex nelsonii Mackenzie	x							
Carex paysonis Clokey	x		x	x			x	x
Carex phaeocephala Piper	x	x	x	x			x	x
Carex rupestris All.	x	x	x		x	x	x	x
Carex scopulorum T. Holm			x		x			
Carex vernacula L.H. Bailey		x				x		
Castilleja nivea Pennell & Ownbey	x	x	x	x	x	x	x	x
Cerastium beeringianum Chamisso & Schlechtendal	x	x	x	x	x	x	x	x
Chaenactis douglasii (Hook.) Hook. & Arn. var. *alpina* Gray		x						
Cirsium eatonii (Gray) B.L. Robins.		x						
Cistanthe umbellata (Torr.) Hershkovitz				x				
Claytonia megarhiza (Gray) Parry ex S. Wats.	x	x				x	x	
Deschampsia cespitosa (L.) P. Beauv.	x	x	x	x			x	x

Table A1. Vascular Plants (continued).								
Species	**BLP 5 m**	**BLP 10 m**	**SCP 5 m**	**SCP 10 m**	**SPP 5 m**	**SPP 10 m**	**WSP 5 m**	**WSP 10 m**
Dodecatheon pulchellum (Raf.) Merr.		x						
Draba crassifolia R. Graham	x	x	x	x			x	
Draba incerta Pays.	x	x	x	x	x	x	x	
Draba oligosperma Hooker	x	x	x	x	x	x	x	x
Elymus alaskanus (Scribn. & Merr.) A. Löve ssp. *latiglumis* (Scribn. & J.G. Sm.) A. Löve							x	x
Elymus scribneri (Vasey) M.E. Jones	x	x	x	x	x	x	x	x
Erigeron compositus Pursh	x	x	x	x	x	x	x	x
Erigeron ochroleucus Nutt. var. *scribneri* (Canby ex Rydb.) Cronquist	x	x	x	x	x	x	x	x
Erigeron simplex Greene	x	x	x	x			x	x
Eriogonum ovalifolium Nutt. var. *purpureum* (Nutt.) Durand	x	x			x	x		
Eritrichium nanum (L.) Schrad. ex Gaudin	x	x	x	x	x	x	x	x
Eurybia merita (A. Nelson) G.L. Nesom	x	x	x	x	x	x	x	x
Festuca brachyphylla J.A. Schultes ex J.A. & J.H. Schultes ssp. *coloradensis* Frederiksen	x	x	x	x	x		x	x
Festuca idahoensis Elmer					x	x		
Festuca saximontana Rydb.							x	
Geum rossii (R. Br.) Ser.	x	x	x	x	x	x	x	x
Geum triflorum Pursh				x	x	x		
Juncus hallii Engelm.							x	
Koeleria macrantha (Ledeb.) Schult.	x	x	x				x	x
Linum lewisii Pursh			x	x	x			
Lomatium cous (Wats.) Coult. & Rose	x	x	x	x	x	x	x	x
Lupinus depressus Rydb.	x	x	x	x	x	x	x	x
Luzula spicata (L.) DC.	x	x	x				x	x
Melica bulbosa Geyer ex Porter & J.M. Coult.					x	x		
Mertensia alpina (Torr.) G. Don	x	x	x	x	x	x		
Minuartia obtusiloba (Rydb.) House	x	x	x	x	x	x	x	x
Myosotis alpestris F.W.Schmidt	x	x	x	x	x	x	x	x
Oreostemma alpigenum (Torr. & A. Gray) Greene var. *haydenii* (Porter) Nesom	x	x	x	x	x	x	x	x
Oxyria digyna (L.) Hill		x				x		
Oxytropis sericea Nutt. var. *speciosa* (Torr. & A. Gray) S.L. Welsh	x	x	x	x	x	x	x	x
Packera cana (Hook.) W.A. Weber & A. Löve	x	x	x	x	x	x	x	x
Pedicularis cystopteridifolia Rydb.	x	x	x	x			x	x
Pedicularis groenlandica Retz.								
Penstemon aridus Rydb.		x						
Penstemon procerus Dougl. ex Graham								
Phacelia hastata Dougl. ex Lehm.		x	x	x			x	x
Phacelia sericea (Grah.) Gray			x					

Table A1. Vascular Plants (continued).

Species	BLP 5 m	BLP 10 m	SCP 5 m	SCP 10 m	SPP 5 m	SPP 10 m	WSP 5 m	WSP 10 m
Phlox multiflora A. Nelson	x	x	x	x	x	x	x	x
Phlox pulvinata (Wherry) Cronq.	x	x	x	x	x	x	x	x
Picea engelmannii Parry ex Engelm.			x	x				
Pinus albicaulis Engelm.			x	x		x		
Poa arctica R. Br. var. *arctica*	x	x	x	x	x	x	x	x
Poa cusickii Vasey. *epilis* (Scribn.) W.A. Weber	x	x	x	x	x	x	x	x
Poa cusickii Vasey ssp. *pallida* Soreng	x	x	x	x	x	x	x	x
Poa glauca Vahl ssp. *rupicola* (Nash ex Rydb.) W.A. Weber	x	x	x	x	x	x	x	x
Poa secunda J. Presl	x	x					x	x
Polemonium pulcherrimum Hook.			x	x			x	x
Polemonium viscosum Nutt.	x	x	x	x	x	x	x	x
Polygonum bistortoides Pursh	x	x	x	x		x	x	x
Potentilla diversifolia Lehm. var. *diversifolia*		x	x	x			x	x
Potentilla sp.						x		
Pulsatilla patens (L.) Mill. ssp. *multifida* (Pritz.) Zämelis	x	x	x	x			x	x
Ranunculus eximius Greene	x	x		x	x	x		x
Salix nivalis Hook.								x
Salix petrophila Rydb.	x	x	x	x				x
Saxifraga rhomboidea Greene	x	x	x	x			x	x
Sedum sp.								
Sedum lanceolatum Torr.	x	x	x	x	x	x	x	x
Selaginella densa Rydb.	x	x	x	x	x	x	x	x
Senecio crassulus A. Gray				x		x		
Senecio fremontii Torr. & A. Gray var. *fremontii*	x	x		x		x		x
Senecio serra Hook.	x	x	x					x
Sibbaldia procumbens L.						x		
Silene sp.	x							
Smelowskia calycina (Steph. ex Willd.) C.A. Mey. var. *americana* (Regel & Herder) Drury & Rollins	x	x	x	x	x	x	x	x
Solidago multiradiata Ait. var. *scopulorum* Gray	x	x	x	x			x	x
Stellaria longipes Goldie		x	x			x		
Taraxacum sp.					x	x		
Taraxacum officinale Weber	x	x		x			x	x
Townsendia condensata Parry ex Gray					x	x		
Trisetum spicatum (L.) K.Richt.	x	x	x	x	x		x	x
Viola praemorsa Douglas ex Lindl. ssp. *linguifolia* (Nutt.) M.S. Baker & J.C. Clausen ex M. Peck			x	x				

Table A2. Lichens.

Species	BLP	SCP	SPP	WSP
Aspicilia desertorum (Kremp.) Mereschk.	x	x	x	x
Caloplaca tiroliensis Zahlbr.	x	x		x
Candelariella rosulans (Müll. Arg.) Zahlbr.	x	x	x	x
Cetraria islandica (L.) Ach.		x		x
Cetraria muricata (Ach.) Eckfeldt	x	x		x
Cladonia acuminata (Ach.) Norrl.	x			
Cladonia cariosa (Ach.) Spreng.			x	
Lecanora garovaglii (Körb.) Zahlbr.	x	x		
Lecanora muralis (Schreb.) Rabenh.		x		
Lecanora polytropa (Hoffm.) Rabenh.		x		
Lecidea atrobrunnea (Ramond) Schaer.	x	x	x	x
Lecidella stigmatea (Ach.) Hertel & Leuckert	x	x		
Peltigera canina (L.) Willd.	x			
Physconia muscigena (Ach.) Poelt	x	x	x	x
Placidium squamulosum (Ach.) Breuss	x			
Rhizoplaca melanophthalma (DC) Leuckert & Poelt			x	
Silobia scabrida (H. Magn.) M. Westberg	x	x	x	x
Sporastatia testudinea (Ach.) A. Massal.	x		x	
Staurothele areolata (Ach.) Lettau	x	x	x	x
Thamnolia vermicularis (Sw.) Ach. ex Schaerer ssp. *subuliformis* (Ehrh.) Schaer.		x		x
Umbilicaria virginis Schaerer	x		x	
Xanthoria elegans (Link) Th. Fr.	x	x	x	x

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