



Alpine Vegetation and Soils Monitoring in Yellowstone National Park

2011–2016 Data Report

Natural Resource Data Series NPS/ROMN/NRDS—2019/1233



ON THE COVER

Field worker, D. Gannon, on a GLORIA alpine vegetation monitoring site in Yellowstone National Park.
Photography by NPS

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Executive Summary

In 2011, the Rocky Mountain and Greater Yellowstone networks, in cooperation with the Colorado Natural Heritage Program and Yellowstone National Park (NP), identified and installed long-term alpine vegetation and soils monitoring sites on four summits in Yellowstone NP following a protocol developed by the Global Observation Research Initiative in Alpine Environments (GLORIA). The goals of monitoring the Yellowstone NP summit sites are to determine the status and trends in vegetation composition and structure, soil condition, and soil temperature; to predict and assess community vulnerabilities; and to inform possible management actions. The Yellowstone NP summit sites cover a small area of alpine habitat within the park, and therefore monitoring does not necessarily reflect alpine vegetation across the park. However, a broader goal is to provide alpine monitoring data that provides context and comparisons to other alpine monitoring efforts in the Rocky Mountains, western North America, and to the GLORIA network worldwide. The Yellowstone NP alpine monitoring sites were installed and monitored according to an adapted version of the GLORIA protocol in 2011, and they were resurveyed according to the same protocol in 2016. In this report, we present a summary of 2016 monitoring efforts and compare vegetation and soils data between the 2011 and 2016 monitoring years. We found the following:

- In 2016, a total of about 127 vascular plant species were documented on the four Yellowstone NP monitoring summits. This includes 54 species that were not documented during the 2011 sampling effort. Recorded species richness increased on all summits between 2011 and 2016. However, future monitoring at these sites will help us understand whether species richness really is increasing or whether the increase was due (or partially due) to our increased understanding of what taxa to expect at these sites.
- Vegetative cover and dominant species in 1-m² quadrats remained nearly constant between 2011 and 2016.
- In both years, the impact of non-native species within the monitoring sites was low with only one species (*Taraxacum officinale*) observed. Since the native *T. officinale ceratophorum* may occur in the area, a goal for future monitoring is to collect voucher specimens of *T. officinale* at the park to determine whether these are the native or exotic species, or a combination of both. Similarly in 2016, the field crew identified *Bromus inermis* in some plots. This may be the non-native or native taxon; this brome should be accurately identified before or during the next monitoring event to resolve the issue.
- Anthropogenic and natural disturbances were qualitatively assessed for all peaks in both years. We found little evidence of natural or anthropogenic disturbances within the monitoring sites during either monitoring cycle.
- There was no statistically significant change in soil temperature during the monitoring period. There was a statistically significant increase in some soil nutrients, including phosphorus, nitrogen, and potassium, which could be a result of regional deposition.

In 2011 and 2016, we found the alpine tundra at the four alpine monitoring sites in Yellowstone NP to be a system little impacted by natural and human disturbances. The current extent of exotic species within the Yellowstone NP target region is minimal. Thus, climate change and increased atmospheric deposition of nutrients are likely the greatest threats to alpine systems in the park. While we noted an increase in species richness at the monitoring sites, continued monitoring of vegetation structure and composition and soil temperature at Yellowstone NP GLORIA sites is needed to assess whether climate change or other stressors correlate with changes in biodiversity and community composition in the alpine.

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- The field crew included Dustin Gannon (Colorado Natural Heritage Program [CNHP] field technician), Lydia Fahrenkrug and Alyssa Meier (CNHP interns), Heidi Anderson (Yellowstone NP botanist), and Monica Lomahukluh (Yellowstone NP field botany technician)
- Meade and Andrea Dominick and the staff of the 7D Ranch packed field work and crew supplies into our remote camp site;
- Members of the Yellowstone NP dispatch coordinated our safety check-ins and aided with our backcountry itinerary;
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- Kristin Long (Asst. Data Manager for the Rocky Mountain Network) coordinated data management among the CNHP, the Rocky Mountain Network, and the GLORIA program central database;
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Introduction

Alpine ecosystems are an important monitoring target for a number of reasons, including their value to park visitors, wildlife, and water resources in the western U.S., and because the alpine is particularly vulnerable to climate change (Beniston 1994; Harte and Shaw 1995; Seastedt et al. 2004; Pauchard et al. 2009; Gonzalez et al. 2010). Predicted climate-induced changes in alpine and sub-alpine ecosystems include trees and forests shifting upslope, increases in shrubs and graminoids, increases in invasive exotic plants, and decreases in alpine wildlife such as pika and ptarmigan (Figure 1; Ashton et al. 2010a).

Annual air temperatures have been increasing in the western United States by an average of 0.5 to 0.2°C over the last century (Diaz and Eischeid 2007; Peder-son et al. 2010). 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 limits of some alpine species in the Alps in response to warming temperatures (Grabherr et al. 1994; Pauli et al. 2012). Such changes are likely to occur in other mountainous regions as species migrate upslope 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.

In 2010, for these and other reasons, the Rocky Mountain and Greater Yellowstone networks identified alpine vegetation and soils as a high priority vital sign in high elevation parks relative to potential changes due to a rapidly changing climate (Bingham et al. 2011). We monitor alpine vegetation and soils using adapted protocols developed by the Global Observation Research Initiative in Alpine Environments (GLORIA). 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).

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 disturbances** 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** periods of four alpine peak communities at a range of elevations.

In 2011, the Rocky Mountain and Greater Yellowstone networks, in cooperation with the Colorado Natural Heritage Program (CNHP) and Yellowstone National Park (NP), established a GLORIA target region composed of four summits within Yellowstone NP. That year we conducted baseline monitoring of alpine vegetation, soils and other parameters defined in the GLORIA and NPS protocols (Ashton et al. 2010b). A summary report of those efforts was published and provides details on the specifics of the protocol, site selection, characteristics of the summits, and initial results from the first monitoring cycle (Kuhn et al. 2015).

In 2016, the Yellowstone NP summits were fully re-surveyed according to the Rocky Mountain Network-adapted GLORIA protocol (Ashton et al. 2010b). In this report, we present a summary of the 2016 monitoring efforts and compare vegetation and soils data between the 2011 and 2016 survey years. Future statistical analysis and more detailed assessments of these data will be possible following a more thorough quality control review of the data, verification, and data reduction.



Figure 1. A conceptual diagram of 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).

Methods

The four Yellowstone NP summit survey sites established and monitored in 2011 were located and resurveyed in 2016 according to a Rocky Mountain Network adapted version of the GLORIA alpine monitoring protocol. The Rocky Mountain Network Alpine Vegetation Composition, Structure, and Soils Protocol follows established GLORIA methods while adding components for soil condition and human disturbance (Ashton et al. 2010b). The specific details on the installation of the sites are provided in Ashton et al. 2010b. The methods, results, and complete site description from the initial survey completed in 2011 are presented in Kuhn et al. 2015.

Sample design

In 2011, four summits within Absaroka Range in eastern Yellowstone NP were established as alpine vegetation and soils monitoring sites (Figure 2; Table 1). The four summits were chosen to best fit the GLORIA guidelines (Grabherr et al. 2000). They are located within close proximity of one another in the Upper Lamar River area on a ridgeline that runs north of Lamar Mountain. The four peaks have similar geology, similar land-use history and disturbance levels, and a similar climate. The elevation range of the Yellowstone NP GLORIA summits is 71 m, which is small in comparison to the alpine elevation ranges at Rocky Mountain NP (442 m) and Great

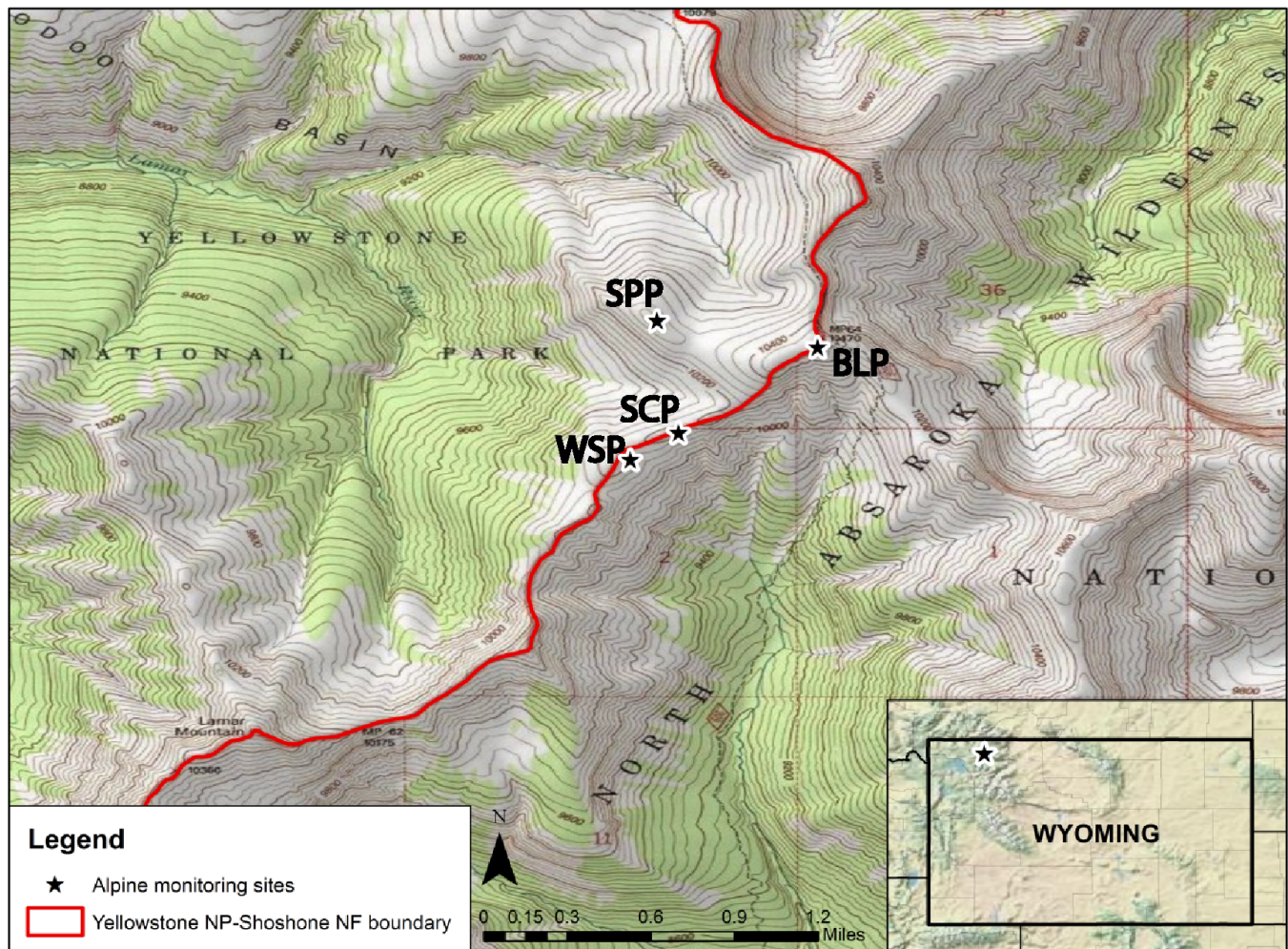


Figure 2. Location of the four alpine monitoring/sentinel sites (identified by their GLORIA site codes - BLP, SCP, SPP, and WSP) in Yellowstone NP.

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

GLORIA summit code	Summit name	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Vegetation zone
BLP	Unnamed	44.700184	-109.826731	3195	lower alpine
SCP	Unnamed	44.695765	-109.w	3122	lower alpine
SPP	Unnamed	44.701613	-109.835067	3169	lower alpine
WSP	Unnamed	44.694275	-109.837219	3124	lower alpine

Sand Dunes National Park and Preserve (450 m). The relatively narrow elevational range at Yellowstone NP does not meet the ideal inter-summit elevation range; ideally the lowest summit is close to the treeline ecotone while the highest summit is near the limit of vascular plant life (Grabherr et al. 2000).

Since the four Yellowstone NP summits were subjectively selected and are close to each other, the data and information from the Yellowstone NP target region is not statistically representative of the alpine across the park. However, the information from these sites contributes insight and data to research efforts on potential changes in alpine habitats in the Rocky Mountains, in the western U.S., and globally.

Field methods

The sites were marked during the initial set-up in 2011 to ensure accurate relocation. At each peak (identified by their GLORIA codes as BLP, SCP, SPP, and WSP), one marker (an approximately 1-ft long rebar with a labeled aluminum cap) was installed at the highest point on the summit, and 9-m² quadrat clusters in each cardinal direction at exactly 5 m in elevation below the summit were installed and marked (all four corners of the quadrat cluster were marked—one with capped rebar and three with small nails; Figure 3). Preliminary vascular plant species lists for the four sites were drafted.

HOBOnset pendant temperature loggers (UA-001-64) were buried 5 cm on the north, east, south and west sides of all peaks to acquire hourly soil temperature data. Greater Yellowstone Network and Colorado Natural Heritage Program (CNHP) staff, recognizing the concern for battery life, replaced temperature loggers in September 2013, in September 2015, and on July 20 and 21, 2016. The logger on the south aspect of SCP was not found during the 2013 visit and the east aspect logger on SPP was

not found in 2015. The loggers on the south and west aspects of WSP were left in place in 2013 to test battery duration. Periods without temperature data are as follows: SCP south aspect from August 2011 to September 2013 (logger not relocated), SPP east aspect from September 2013 to September 2015 (logger not relocated), WSP south aspect from February 2015 to September 2015 (battery failure), and WSP west aspect from December 2013 to September 2015 (battery failure).

In 2016, CNHP and park staff revisited the Yellowstone NP target region and relocated the initial monitoring plots using GPS. The vegetation resampling event was completed by a field crew consisting of two botanists and two interns from CNHP and two Yellowstone NP botanists over an eight day period. On each of the four target region summits, we completed vascular plant surveys in all of the summit area sections and all of the quadrat clusters according to the Rocky Mountain Network-adapted GLORIA protocol (Ashton et al. 2010b). Roughly 100 unknown species were collected and identified through comparisons with herbarium specimens housed at the Colorado State University Herbarium and the University of Wyoming Rocky Mountain Herbarium. The collected materials were labeled and shipped to the Yellowstone NP botanist, Heidi Anderson, for further analysis and incorporation into the park's herbarium. Unlike the 2011 GLORIA sampling event at the site, we did not collect species level data on lichen taxa, thus non-vascular taxa will not be considered further in this report. The crew collected soil samples from all aspects of all peaks as was done in the initial sampling.

Table 2 describes the types of plots present and data available on each summit within the target region. A trip report documenting the timing, logistics, and other specifics of the field effort is provided in Appendix B.

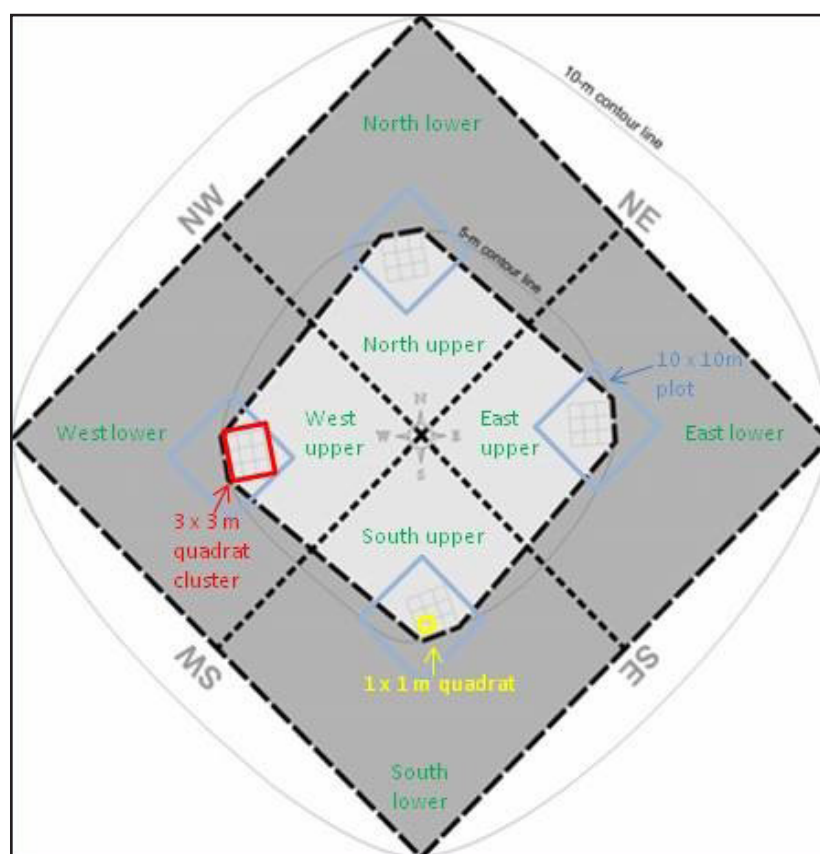


Figure 3. Field plot design used for alpine monitoring that was replicated on four summits varying in elevation. The design is centered on the highest point on the summit and extends to 10 m in elevation below the highest point. The corner 1-m² quadrats were used to measure changes in plant frequency 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 Yellowstone NP	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 parameters
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; the Rocky Mountain and Greater Yellowstone networks plan 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 graminoid, tree, shrub, and non-native species richness. Taxa not identified to species level were only included as unique taxa if the genus was not recorded from the previous monitoring cycle. Species abundances were compared based on percent of the total vegetative cover within the 1-m² quadrats across all Yellowstone NP summit sites for each monitoring year.

Additionally, we compared ground cover (percent cover of vegetation, rock/scree, bare ground, and litter) within the 64 1-m² quadrats between the two monitoring efforts. We used paired t-tests to determine whether there were statistically significant differences between 2011 and 2016 data. Taxonomy follows the USDA PLANTS database (USDA NRCS 2014).

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, Water and Plant Testing Laboratory.

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). We used the monthly median value of the soil temperature on each peak to obtain one observation per season. Missing data were omitted from the model. 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) during the monitoring period (2011–2016) across years, elevations, and aspects. Although tolerance of low soil temperatures is highly variable among species (Bliss 1962), a standardized growing season soil temperature threshold allows comparison of growing season length across elevations and years. For the purpose 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 temperature above 5°C and the number of days with a mean daily 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 2011 and 2016 at Yellowstone NP. They have not been peer-reviewed and should be interpreted with caution. We structure the results by indicator classes.

Vegetation Composition and Structure

Vegetation comparisons are preliminary. Some identifications may be problematic because (1) plants in the field or voucher specimens may not have well developed reproductive parts (often critical for accurate identification), and/or (2) there may be errors by field crew or botanists when reviewing specimens (especially inadequate specimens). It is important for future monitoring crews (in consultation with the Yellowstone NP Botanist) to focus efforts on documenting unverified or otherwise problematic identifications (and collecting voucher specimens as appropriate). In particular, future monitoring crews should clarify whether *Kobresia myosuroides*, *Carex*

filifolia, and/or *C. elymoides* occur in Yellowstone NP GLORIA plots and at what cover values. One or both of these taxa were important species in terms of percent cover in both 2011 and 2016 surveys. Crews should also carefully document (and take specimens if permitted) any *Taraxacum officinale* observed to document whether they are actually *T. officinale* ssp. *ceratophorum*, the native dandelion.

Summit Area

In 2011, a total of 108 vascular plant species were identified across the four summits of the Yellowstone NP target region. During the 2016 sampling effort, a total of approximately 127 vascular plant species were identified on these summits (see Appendix A for the complete vascular species list recorded for Yellowstone NP summit sites in 2011 and 2016). Approximately 53 taxa identified in 2016 were not documented in 2011 while about 20 taxa identified in 2011 were not documented in 2016 (Tables 3 and 4).



Blue pin flags mark summit area sections on a GLORIA alpine vegetation monitoring site within Yellowstone NP, July 2016.

Table 3. Taxa recorded from 2016 summit area sections in Yellowstone NP that were not recorded in 2011.

Genus	Species	New taxon for Yellowstone NP?	ID designation*	Note
<i>Agrostis</i>	<i>humilis</i>	No	Verified	–
<i>Antennaria</i>	<i>media</i>	No	Accepted	–
<i>Antennaria</i>	<i>microphylla</i>	No	Accepted	–
<i>Antennaria</i>	<i>rosea</i>	No	Accepted	–
<i>Antennaria</i>	<i>umbrinella</i>	No	Accepted	–
<i>Boechera</i>	<i>pendulina</i>	Yes	Unverified	–
<i>Botrychium</i>	<i>simplex</i>	No	Unverified	New high elevation report for this taxa in Yellowstone NP
<i>Bromus</i>	<i>inermis</i>	No	Un-verified	Taxon not identified to ssp. level, likely <i>B. inermis</i> ssp. <i>purpurescens</i> , the native species
<i>Carex</i>	<i>albonigra</i>	No	Accepted	–
<i>Carex</i>	<i>atrosquama</i>	Yes	Unverified	–
<i>Carex</i>	<i>microptera</i>	No	Accepted	–
<i>Carex</i>	<i>rossii</i>	No	Accepted	–
<i>Castilleja</i>	<i>pulchella</i>	No	Accepted	–
<i>Cerastium</i>	<i>arvense</i>	No	Accepted	–
<i>Chaenactis</i>	<i>douglasii</i>	No	Accepted	–
<i>Draba</i>	<i>aurea</i>	No	Accepted	–
<i>Draba</i>	<i>crassa</i>	No	Accepted	–
<i>Dryas</i>	<i>octopetala</i>	No	Accepted	–
<i>Elymus</i>	<i>trachycaulus</i>	No	Accepted	–
<i>Epilobium</i>	sp.	No	Accepted	–
<i>Erigeron</i>	<i>concinus</i>	Yes	Accepted	–
<i>Erigeron</i>	<i>strigosus</i>	No	Unverified	Rare in Yellowstone NP (known from 1 low elevation location)
<i>Erigeron</i>	<i>ursinus</i>	No	Accepted	–
<i>Eriogonum</i>	<i>hookeri</i>	Yes	Un-verified	–
<i>Juncus</i>	<i>drummondii</i>	No	Accepted	–
<i>Kobresia</i>	<i>myosuroides</i>	Yes	Unverified	May be <i>Carex elymoides</i> ; both <i>K. myosuroides</i> and <i>C. elymoides</i> may exist in plots
<i>Lewisia</i>	<i>pygmaea</i>	No	Accepted	–
<i>Lomatium</i>	<i>cous</i>	No	Accepted	–
<i>Lupinus</i>	<i>x alpestris</i>	Yes	Unverified	Clarify identification
<i>Minuartia</i>	<i>rubella</i>	No	Accepted	–
<i>Oreoxis</i>	<i>alpina</i>	Yes	Unverified	Potentially <i>Ivesia gordonii</i>
<i>Oxytropis</i>	<i>campestris</i>	No	Accepted	–

* ID designations:

Verified – uncommon to rare and/or unexpected in Yellowstone NP alpine; plant identified from a specimen adequate for identification;

Unverified – Uncommon to rare and/or unexpected in Yellowstone NP alpine; plant identified without a specimen (i.e., in the field) or with a specimen inadequate for identification;

Accepted – Common or expected in Yellowstone NP alpine; identification is straightforward.

Table 3 (continued). Taxa recorded from 2016 summit area sections in Yellowstone NP that were not recorded in 2011.

Genus	Species	New taxon for Yellowstone NP?	ID designation*	Note
<i>Oxytropis</i>	<i>lagopus</i>	No	Accepted	–
<i>Packera</i>	<i>dimorphophylla</i>	No	Accepted	–
<i>Packera</i>	<i>multilobata</i>	Yes	Unverified	–
<i>Pedicularis</i>	<i>groenlandica</i>	No	Accepted	–
<i>Penstemon</i>	<i>procerus</i>	No	Accepted	–
<i>Phleum</i>	<i>alpinum</i>	No	Accepted	–
<i>Phlox</i>	<i>condensata</i>	Yes	Unverified	Potentially <i>Townsendia condensata</i>
<i>Pinus</i>	<i>contorta</i>	No	Accepted	–
<i>Poa</i>	<i>alpina</i>	No	Accepted	–
<i>Polygonum</i>	<i>viviparum</i>	No	Accepted	–
<i>Potentilla</i>	<i>ovina</i>	No	Accepted	–
<i>Ranunculus</i>	<i>eschschooltzii</i>	No	Accepted	–
<i>Salix</i>	<i>glauca</i>	No	Accepted	–
<i>Senecio</i>	<i>integerrimus</i>	No	Accepted	–
<i>Senecio</i>	<i>lugens</i>	No	Accepted	–
<i>Symphyotrichum</i>	<i>foliaceum</i>	No	Accepted	–
<i>Taraxacum</i>	<i>officinale</i> ssp. <i>ceratophorum</i>	No	Accepted	<i>T. officinale ceratosporum</i> is the native ssp.
<i>Tephrosieris</i>	<i>lindstroemii</i>	No	Accepted	–
<i>Townsendia</i>	<i>parryi</i>	No	Accepted	–
<i>Trisetum</i>	<i>wolfii</i>	No	Accepted	–
<i>Veronica</i>	<i>wormskjoldii</i>	No	Accepted	–

* ID designations:

Verified – uncommon to rare and/or unexpected in Yellowstone NP alpine; plant identified from a specimen adequate for identification;

Unverified – Uncommon to rare and/or unexpected in Yellowstone NP alpine; plant identified without a specimen (i.e., in the field) or with a specimen inadequate for identification;

Accepted – Common or expected in Yellowstone NP alpine; identification is straightforward.

Table 4. Taxa recorded from 2011 summit area sections in Yellowstone NP that were not recorded in 2016.

Genus	Species	New taxon for Yellowstone NP?	ID designation*	Note
<i>Antennaria</i>	<i>monocephala</i>	No	Unverified	Very rare in Yellowstone NP, only known from Cutoff Mt.
<i>Arabis</i>	<i>pyncocarpa</i>	No	Unverified	–
<i>Carex</i>	<i>haydeniana</i>	No	Verified	Common species in Yellowstone NP and likely in GLORIA plots
<i>Carex</i>	<i>nelsonii</i>	Yes	Unverified	New report for Yellowstone NP
<i>Carex</i>	<i>rupestris</i>	No	Unverified	Known from two sites in Yellowstone NP
<i>Carex</i>	<i>vernacular</i>	Yes	Unverified	–
<i>Claytonia</i>	<i>megarrhiza</i>	No	Accepted	–
<i>Dodecatheon</i>	<i>pulchellum</i>	No	Accepted	–
<i>Elymus</i>	<i>alaskanus</i>	Yes	Unverified	–
<i>Eurybia</i>	<i>merita</i>	No	Accepted	–
<i>Juncus</i>	<i>hallii</i>	No	Accepted	–
<i>Melica</i>	<i>bulbosa</i>	No	Accepted	–
<i>Penstemon</i>	<i>aridus</i>	No	Unverified	Might be <i>P. procerus</i>
<i>Phacelia</i>	<i>sericea</i>	No	Accepted	–
<i>Pinus</i>	<i>albicaulis</i>	No	Accepted	–
<i>Poa</i>	<i>arctica</i>	No	Unverified	Rare in Yellowstone NP (known from 4 locations)
<i>Pseudocymopterus</i>	<i>montanus</i>	No	Accepted	–
<i>Senecio</i>	<i>serra</i>	No	Accepted	–
<i>Silene</i>	sp.	No	Accepted	Collect identifiable specimens during next visit to identify to species level
<i>Viola</i>	<i>praemorsa</i>	No	Accepted	–

* ID designations:

Verified – uncommon to rare and/or unexpected in Yellowstone NP alpine; plant identified from a specimen adequate for identification;

Unverified – Uncommon to rare and/or unexpected in Yellowstone NP alpine; plant identified without a specimen (i.e., in the field) or with a specimen inadequate for identification;

Accepted – Common or expected in Yellowstone NP alpine; identification is straightforward.

Many of the 53 unique species documented in 2016 were inconspicuous forbs, late season forbs, or graminoids (which are difficult to distinguish before flowering structures have developed) typical to alpine habitats. It is likely that these species were present during 2011, but went undocumented during the monitoring event due to either human or environmental variables. Many taxa including Cyperaceae, Asteraceae, Poaceae and Brassicaceae are particularly difficult to identify to species. This may have resulted in some of the unique species from 2011 and 2016 being misidentifications of the same species. This is likely the case for the most dominant species across the four summits, which was identified as *Carex filifolia* in 2011 and *Kobresia myosuroides* in 2016. It is likely that both species are present within the target region. Further analysis of specimens from both monitoring events would be necessary to clear up these possible misidentifications. Field crews should be alerted to this issue before the next monitoring cycle in 2021.

Some newly documented species, such as *Pinus contorta* and *Salix glauca* would be more difficult to overlook during a monitoring event as they are easily

identifiable and less dependent upon phenological stage for detection. Thus, these species are likely to have established in the last five years. In 2016, we took GPS points at all of the trees established within the monitoring plots. No GPS points were taken in 2011, thus we were not able to compare tree data further than recorded richness from the sampling efforts. Future field crews may consider taking additional data on woody species recorded within the monitoring plot including photographs, GPS exact location, height, and diameter to further document and monitor woody species encroachment into the alpine.

Species richness within the summit area sections on all summits differed between monitoring years (Figure 4), although this trend was not statistically significant ($p = 2.36$, $df = 7$). During the 2016 sampling effort, higher species richness was recorded from all summits in both the 5-m and 10-m summit area sections.

The slight increase in species richness could be an indication of increasing vascular plant richness across the Yellowstone NP summits, however many

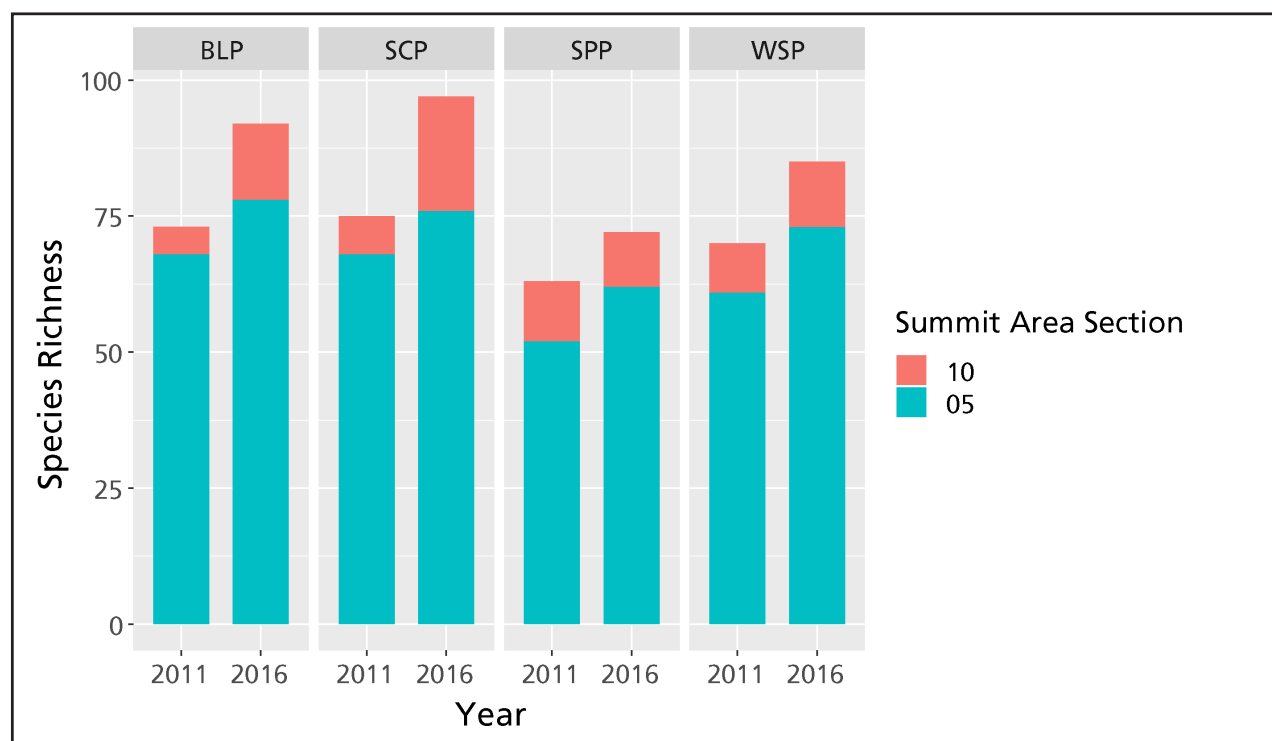


Figure 4. Number of vascular plant species present on the four GLORIA alpine monitoring/sentinel sites within Yellowstone NP in 2011 and 2016. Blue represents the number of vascular plant species in upper summit area sections from the highest point to 5 m below the highest point. Red represents the number of additional vascular plant species in lower summit area section from 5 m to 10 m below the highest point. Note: comparisons between 2011 and 2016 should be interpreted with caution (see text).

human and environmentally controlled variables during monitoring events must be considered when analyzing recorded inter-annual fluctuations of species richness and abundance. There may also be a bias in the species richness data because the 2016 field crews had access to the 2011 plant list, potentially causing them to search for those species. It is possible that increased species richness across all four summits is wholly or partly due to this. 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. The 2011 sampling event took place after a winter with an uncommonly high snow pack. Not only did this

prevent sampling of some areas which were buried under snowfields, but this also likely delayed the phenology of certain alpine species preventing them from being detected at the time of monitoring.

Frequency and Cover Quadrats

The twenty species with the highest percent cover within the 1-m² sampling quadrats were nearly consistent from the 2011 and 2016 sampling efforts (Table 5). In 2011, *Carex filifolia* was the most dominant species across the Yellowstone NP monitoring/sentinel summits and *Kobresia myosuroides* was not identified as present. In 2016, both species were identified and *K. myosuroides* was recorded as the most dominant species. These two species are very similar in appearance and difficult to identify when growing together. It is likely that the dominant cover is a mix

Table 5. Top twenty most abundant vascular plant species in the Yellowstone NP 1-m² sampling quadrats in 2011 and 2016 and percent of total vegetative cover.

Species name	2011	2016
<i>Carex filifolia</i> / <i>Kobresia myosuroides</i>	7.0	8.5*
<i>Selaginella densa</i>	6.8	2.3
<i>Minuartia obtusiloba</i>	5.5	5.1
<i>Phlox multiflora</i>	5.4	3.9
<i>Carex rupestris</i> / <i>Carex</i> sp.	4.5	3.9*
<i>Poa glauca</i>	4.4	3.7
<i>Lupinus depressus</i>	4.0	3.4
<i>Potentilla diversifolia</i>	3.8	3.4
<i>Geum rossii</i>	3.2	3.3
<i>Agoseris glauca</i>	3.1	3.6
<i>Polemonium</i>	2.9	3.6
<i>Eurybia merita</i> / <i>Symphyotrichum foliaceum</i>	2.8	3.3*
<i>Elymus scribneri</i>	2.8	3.2
<i>Erigeron ochroleucus</i>	2.8	0.1
<i>Arenaria congesta</i>	2.6	0.5
<i>Phlox pulvinata</i>	2.5	2.4
<i>Carex paysonis</i>	2.3	2.6
<i>Solidago multiradiata</i>	2.2	3.2
<i>Carex phaeocephala</i>	2.1	2.2
<i>Oreostemma alpigenum</i>	1.9	1.0

* Identified as a different species in the field, but are likely misidentifications of the same species. *Carex filifolia* was paired with species identified to *Kobresia myosuroides*, *C. rupestris* was paired with cover identified as *Carex* sp. due to lack of perigynia, and *Eurybia merita* was paired with species identified as *Symphyotrichum foliaceum* during the 2016 monitoring event.

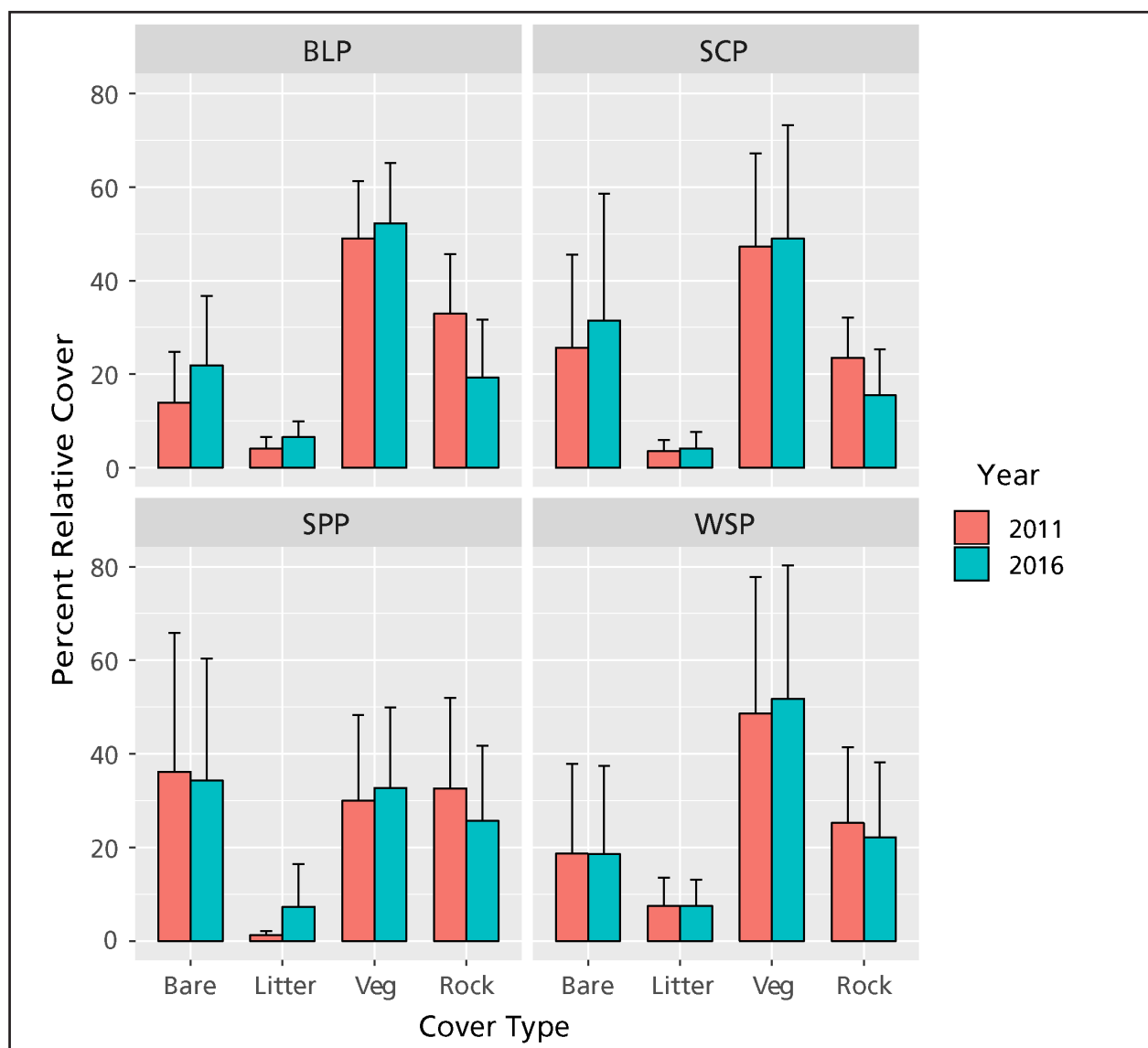


Figure 5. Mean percent relative cover of vascular and non-vascular plants, solid rock/ scree, litter, and bare ground recorded from 1-m² quadrats of Yellowstone NP summits in 2011 (red) and 2016 (blue). Error bars represent standard deviation.

of the two species. Further investigation is required to separate these species as few samples were taken for herbarium identification, and some of these specimens were identified to both species.

Vegetation across the four summits consisted primarily of graminoids and forbs with a few shrubs and tree species in both years. Not all species were found in each sample period (Tables 3 and 4). Shrub species included *Salix glauca*, *S. nivalis*, and *S. petrophila* from three of the four summits, BLP, SCP, and WSP. Three tree species were documented: *Picea engelmannii* from BLP and SCP (documented in 2011 and 2016), *Pinus albicaulis* from SCP and SPP (only

documented in 2011), and *Pinus contorta* from WSP (only documented in 2016).

Percent cover of vegetation, rock/scree, litter, and bare ground from 1-m² sampling quadrats varied slightly between monitoring years and summits (Figure 5). In 2016, vegetative cover, including cover of vascular plants, lichens, and bryophytes, increased slightly on all peaks, although when data from 2011 and 2016 were compared using a paired t-test, this trend was not statistically significant ($p = 0.07$, $df = 63$). When we compared reference photographs of the 1-m² sample plots, there was no noticeable increase in plant cover between years.

Invasive/Exotic Plants

In addition to the upward migration of species, climate change may allow for the spread of exotic/invasive species into the alpine where they are typically limited by the harsh environment (Pauchard et al. 2009). Recorded frequency and abundance of non-native species increased in twenty of the 64 Yellowstone NP summit area sections (Table 6), however common exotic species found in 2016 are closely related to native subspecies (Heidi Anderson, pers. comm.), so caution is necessary before interpreting this as invasion of the alpine by exotic species.

Of the 108 vascular plant taxa identified from the Yellowstone NP region in 2011 and the 127 plant taxa identified in 2016, *Taraxacum officinale* (common dandelion) was the only non-native species confirmed. In 2011, *T. officinale* was documented

from BLP, SCP, and WSP, and an unidentifiable *Taraxacum* was documented on SPP, although it was suspected to be a native member of the genus (*T. officinale* ssp. *ceratophorum*). In 2016, *T. officinale* was documented from the 5-m and 10-m summit area sections from all four of the target summits. During the next monitoring cycle, field crews should review key characteristics of these species to ensure accurate identification.

Bromus inermis was identified from SPP in 2016, however these specimens were not identified to subspecies. The native status of *B. inermis* relies on subspecies identification; *B. inermis* ssp. *pumpellianus* occurs in Yellowstone NP and is a native varietal while *B. inermis* ssp. *inermis* is exotic. Further analysis must be conducted before a status can be assigned.

Table 6. Abundance of *Taraxacum officinale* as recorded from 2011 and 2016 summit area sections (SAS) in Yellowstone NP. "—" indicates that *T. officinale* was not recorded from that SAS (abundance estimations/categories are qualitative).

Summit-SAS	2011	2016
BLP-E05	very rare	scattered
BLP-E10	rare	rare
BLP-N05	very rare	—
BLP-N10	—	rare
BLP-S05	present- abundance not recorded	rare
BLP-S10	very rare	scattered
BLP-W05	—	scattered
BLP-W10	—	scattered
SCP-E10	—	very rare
SCP-W05	—	rare
SCP-W10	very rare	rare
SPP-N05	—	rare
SPP-N10	—	rare
SPP-W10	—	scattered
WSP-E05	very rare	common
WSP-E10	—	rare
WSP-N05	—	scattered
WSP-S05	very rare	scattered
WSP-S10	very rare	rare
WSP-W05	—	scattered
WSP-W10	—	common

Soil Chemistry

Soils from the four summits in Yellowstone NP were well-drained sandy loams. Levels of pH were near neutral to slightly acidic, with a mean pH of 6.65 (± 0.5 standard deviation; Table 7), which is optimal for many plant species (Amacher et al. 2007). The carbon to nitrogen ratio (a measure of litter quality) was comparable to Rocky Mountain Network monitoring at alpine sites in Rocky Mountain National Park (NPS data, unpublished) and is about average for mineral soil (O'Neill et al. 2005). It averaged 9.4 (± 1.9) across all peaks at Yellowstone NP in 2016.

Between 2011 and 2016 there were significant differences in several soil chemistry parameters. Phosphorus, pH, potassium, nitrogen, and carbon increased, while zinc and copper decreased. Manganese and

nitrate-nitrogen remained level (Figure 6). The increase in major nutrients (N, P, K) may be a result of atmospheric deposition. Stoddard et al. (2016) found an increase in phosphorus in minimally disturbed watersheds nationwide, likely in part from dry phosphorus deposition from such sources as wind erosion, forest fires, and fossil fuel combustion. The National Atmospheric Deposition Program (NADP) station WY08 at Yellowstone recorded an increase in pH, total N deposition, and potassium from 2011 to 2016, though the potassium levels were quite variable month-to-month (NADP 2017). The decrease in micronutrients (Zn, Cu) may be a result of the change in pH; the availability of most micronutrients decreases as pH increases (Brady and Weil 1996).

Table 7. Mean and standard deviation of soil chemistry parameters measured in 2011 and 2016 for each of the four summits at Yellowstone NP.

Year	Summit	pH	NO ₃ -N (mg/kg)	P (mk/kg)	K (mg/kg)	Total N (%)	Total C (%)	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)
2011	BLP	6.00 ± 0.68	2.48 ± 2.22	2.40 ± 1.30	96.60 ± 39.20	0.14 ± 0.09	1.11 ± 0.84	0.58 ± 0.19	0.88 ± 0.17	3.43 ± 0.42
2011	SCP	6.40 ± 0.75	1.55 ± 0.51	1.50 ± 0.77	37.98 ± 13.50	0.06 ± 0.05	0.44 ± 0.05	0.30 ± 0.12	0.78 ± 0.21	4.60 ± 1.34
2011	SPP	5.90 ± 0.14	1.10 ± 0.66	2.25 ± 1.42	59.65 ± 23.74	0.06 ± 0.02	0.31 ± 0.16	0.35 ± 0.10	0.68 ± 0.37	4.60 ± 0.61
2011	WSP	5.85 ± 0.30	2.60 ± 0.96	1.95 ± 1.14	38.70 ± 9.33	0.10 ± 0.08	0.95 ± 0.73	0.35 ± 0.13	1.03 ± 0.50	5.25 ± 2.27
2016	BLP	6.58 ± 0.59	4.23 ± 2.93	5.68 ± 2.50	91.58 ± 47.91	0.14 ± 0.11	1.46 ± 1.27	0.28 ± 0.17	0.65 ± 0.17	1.95 ± 0.44
2016	SCP	6.33 ± 0.17	5.28 ± 3.85	5.38 ± 0.50	117.08 ± 35.50	0.14 ± 0.07	1.50 ± 0.85	0.33 ± 0.10	0.90 ± 0.41	1.38 ± 0.57
2016	SPP	7.08 ± 0.33	1.25 ± 0.55	3.23 ± 0.71	88.00 ± 63.12	0.10 ± 0.01	0.75 ± 0.17	0.15 ± 0.06	0.58 ± 0.36	1.68 ± 0.21
2016	WSP	6.63 ± 0.44	4.70 ± 5.40	8.48 ± 4.80	146.48 ± 128.11	0.28 ± 0.23	2.93 ± 2.86	0.88 ± 0.90	1.45 ± 0.37	2.18 ± 0.39

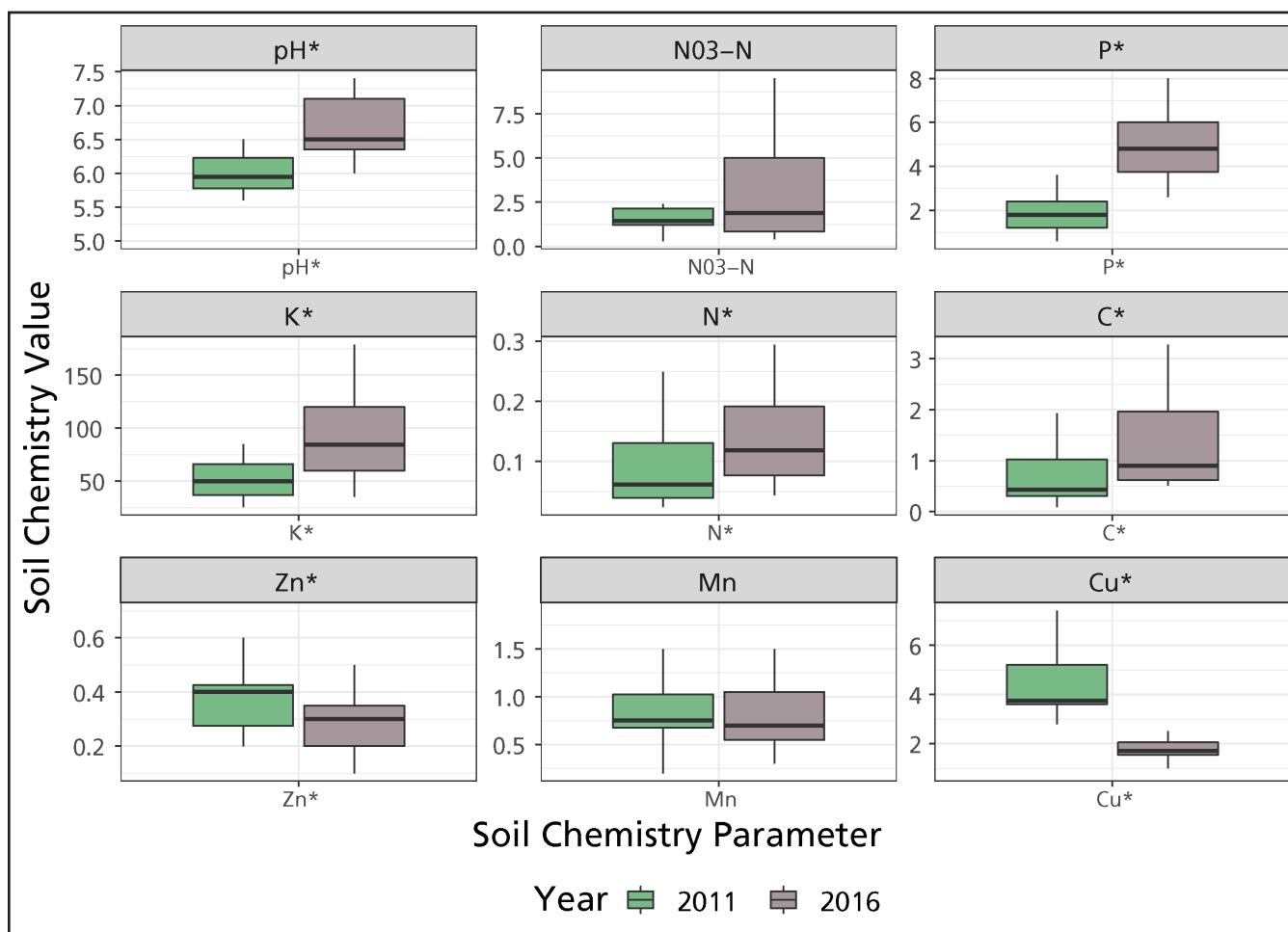


Figure 6. Boxplots of soil chemistry values in Yellowstone NP across all aspects and summits for 2011 (green) and 2016 (purple), showing pH, nitrate as nitrogen (NO₃-N), phosphorus (P), potassium (K), nitrogen (N), carbon (C), zinc (Zn), manganese (Mn), and copper (Cu). Parameters with an asterisk next to the name indicate a significant (p < 0.05) difference between years.

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. Soil temperatures ranged from -22.9 to 32.6°C (-9.2 to 90.7°F). The east aspect on all peaks recorded the highest average temperatures. Average soil temperature ranged by only 0.8°C (1.5°F) between the peaks across the period of record. There was no statistical trend in soil temperature on each peak over the time period measured (Figure 7).

Monitoring the difference between daily maximum and minimum temperature can reflect variations in climate change that mean daily temperatures do not

capture (Qu et al. 2014). Increases in daily mean air temperatures at a faster rate than daily maximum air temperatures has led to a steady decrease of air diurnal temperature range (DTR) nationwide (Karl et al. 1991). Monitoring soil DTR in Yellowstone NP summit sites can act as an early indicator of warming climates in alpine environments. Additionally, soil DTR provides an indication of snow loading, with periods of zero soil DTR likely being periods during which the soil is buried under snow. If snow cover duration decreases over time it could initiate an earlier start to the growing season and an earlier start of senescence later in the season. There may also be an increased probability of dry soil conditions later in the growing season if snow melts earlier.

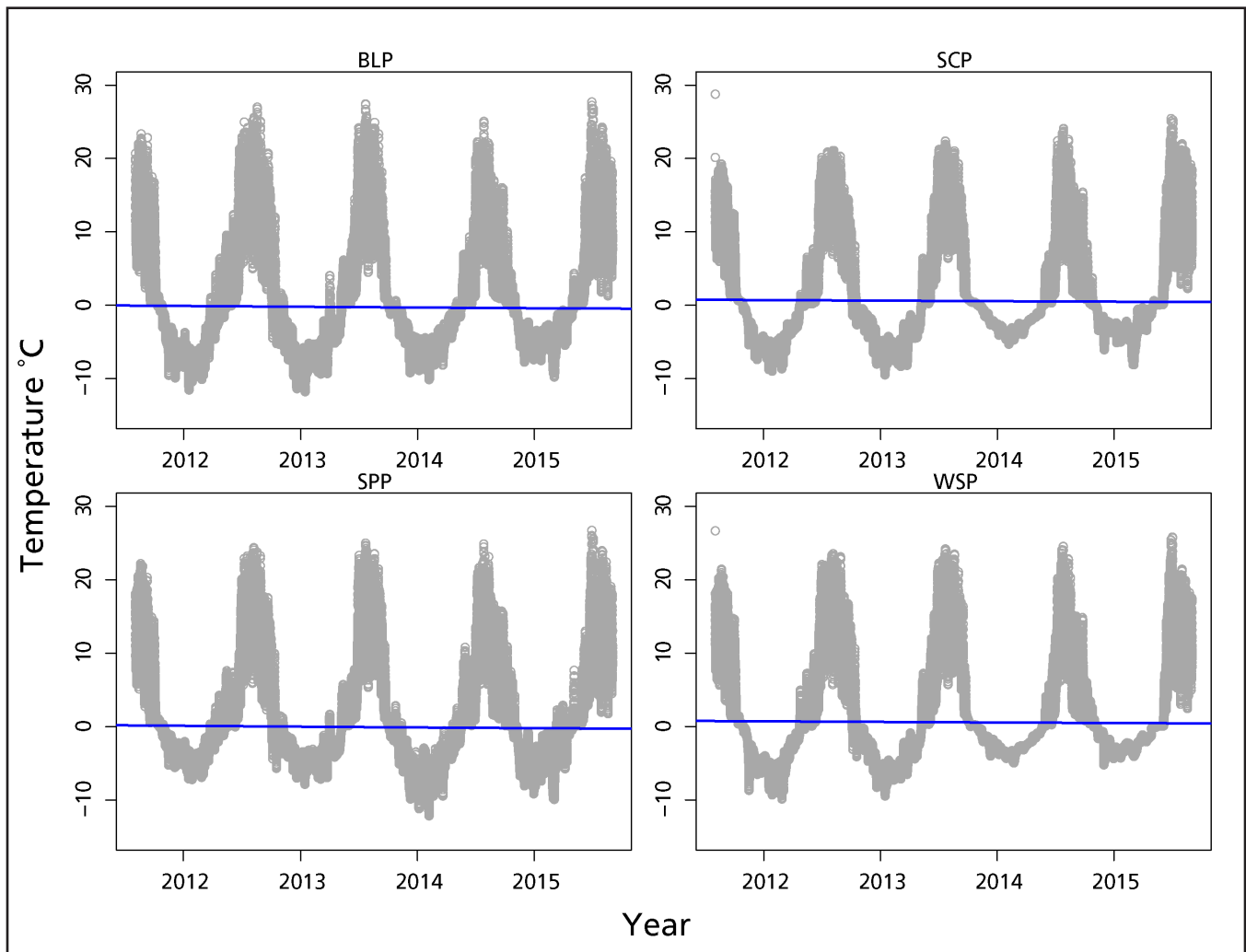


Figure 7. Mean monthly soil temperatures for each of the four peaks monitored at Yellowstone NP, averaged across aspects, from fall 2011 to summer 2016. There was no statistically significant trend for any peak.

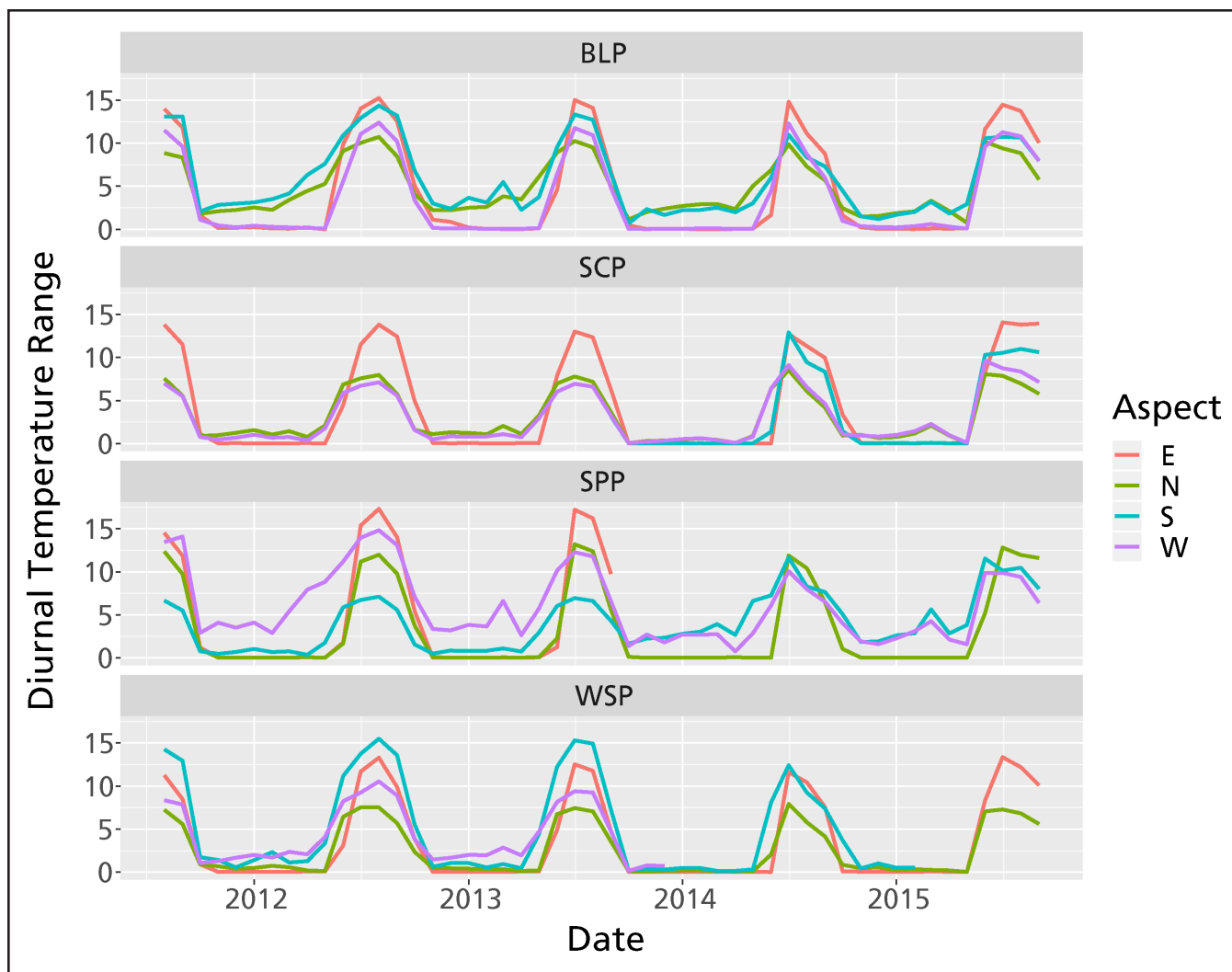


Figure 8. Soil diurnal temperature range (DTR) on all peaks and all aspects of Yellowstone NP summit sites from August 2011 through August 2015. The soil DTR is the monthly average of the maximum and minimum daily temperatures. Lapses in data occurred when loggers were not replaced prior to battery failure or when loggers failed or could not be recovered.

Average monthly soil temperatures and soil DTR varied by aspect, although the variations were not consistent across the four peaks (Figure 8). Periods with no daily temperature fluctuations (WSP north and east aspects, SPP north aspect, SCP east and south aspects, and BLP east and west aspects) suggest snow cover insulated the soil from low winter air temperatures and daily temperature fluctuations. Soil DTRs were greatest during August on all peaks with August soil DTRs ranging between 10.4 and 17.3°C. Assuming snow cover when soil DTR equals zero, snow fields melted out between May and June. While no significant patterns were identified in the Yellowstone NP alpine soil DTR data across the period of record, long-term collection of soil temperature data

will continue to improve our understanding of the effects of climate warming on Yellowstone NP alpine summits.

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 mid-June to late-September (Figure 9). The period of continuous days above the designated soil temperature threshold (5°C) was nearly equal on all peaks, excluding a five-day lag in the start of the growing season on SPP. The average number of days with mean daily soil temperature above the temperature threshold was 100 across the four monitoring/sentinel peaks over the period of record.

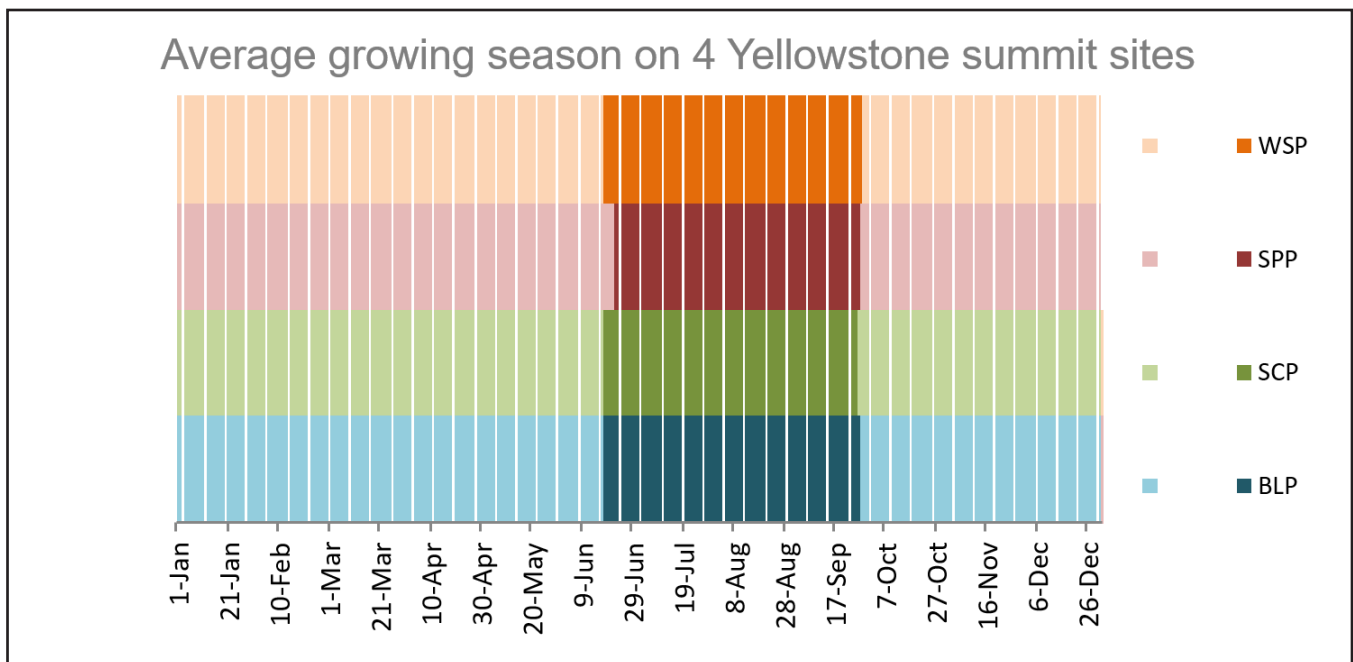


Figure 9. Period of continuous days with mean daily soil temperature above 5°C (42.8°F) are represented in dark colors. This period of average daily temperatures above freezing suggests the length of the growing season for each of the four Yellowstone NP monitoring/sentinel peaks. Light colors represent continuous days where mean daily temperature equals or does not exceed 5°C. Dates are averaged across data from August 2011 to September 2015.

Anthropogenic and Natural 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 cause direct alterations in community composition and disturbances may be of particular interest to park staff because they may be able to reduce disturbances through changes in land management.

Human disturbance was estimated qualitatively at the four summits. All summits were located in the remote backcountry of the Absaroka Range resulting

in extremely low disturbances levels. Light recreation impacts were noted along the edge of BLP including a rock cairn. 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 native wildlife. Elk were visible grazing in the alpine near the target summits and bear prints were present in snowfields near the summits.

Apparent natural erosion was noted on the east aspect of SPP and the south aspect of SCP. Coincidentally, there are the two locations where temperature loggers were lost.

Suggestions for Future Fieldwork

Below are several things for future field crews to follow or be aware of prior to conducting fieldwork.

- Study species list to gain familiarity with common species prior to fieldwork.
- Practice techniques to standardize cover estimates among field personnel during training.
- Collect voucher specimens of difficult species including Cyperaceae, Poaceae, Asteraceae, and Brassicaceae while in the field and save collections from all monitoring cycles.
- Clarify whether *Kobresia myosuroides*, *Carex filifolia*, and/or *C. elymoides* occur in Yellowstone NP GLORIA plots (and at what cover values). One or both of these taxa were important species in terms of percent cover in both 2011 and 2016 sampling efforts.
- Carefully document any *Taraxacum officinale* observed (and take specimens if permitted) to document whether they are actually *T. officinale* ssp. *ceratophorum*, the native dandelion.
- Identify *Bromus inermis* to the subspecies level to clarify whether the native or the non-native varietal is present and in what abundance.

- Consider taking additional data on woody species recorded within the monitoring plot, including photographs, GPS exact locations, heights, and diameters to further document and monitor woody species encroachment into the alpine.
- Note that 1-m² quadrat vegetation data was the most consistent and easily comparable between the 2 monitoring events.
- It may be necessary to replace soil temperature logger batteries every one to two years to prevent future loss of soil temperature data.

This report contains a limited analysis of the available data, and further monitoring and analyses may reveal patterns. Additional analyses could include comparing historical elevational ranges of species to documented occurrences in 2011 and 2016 on Yellowstone NP summits, as done in Gottfried et al. (2012) to calculate thermophilization rates (increasing dominance of warm-adapted species). An analysis and comparison of alpine vegetation and soils data across all GLORIA sites in the Rocky Mountains could be especially informative.

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Appendix A. Yellowstone National Park Target Region Species List

Table A-1. Yellowstone NP target region species list for each summit (BLP, SCP, SPP, and WSP) by summit area section (05 and 10) and by year. “x” indicates the species was present.

Species	BLP				SCP				SPP				WSP			
	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)
<i>Achillea millefolium</i> L.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Agoseris glauca</i> (Pursh) Raf.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Agrostis humilis</i> Vasey	–	–	–	–	–	–	x	x	–	–	–	–	–	–	x	x
<i>Allium geyeri</i> S. Watson	–	–	–	–	–	–	–	–	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 media</i> Greene	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	x
<i>Antennaria microphylla</i> Rydb.	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	x
<i>Antennaria monocephala</i> DC.	x	x	–	–	x	x	–	–	x	x	–	–	x	x	–	–
<i>Antennaria rosea</i> Greene	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
<i>Antennaria umbrinella</i> Rydb.	–	–	x	–	–	–	x	x	–	–	x	x	–	–	x	x
<i>Arabis lemmonii</i> S. Watson var. <i>lemmonii</i>	x	x	–	x	–	x	–	x	x	x	–	–	–	x	–	x
<i>Arabis lyallii</i> S. Watson var. <i>lyallii</i>	x	x	x	x	x	x	x	x	–	x	x	x	x	x	x	x
<i>Arabis pycnocarpa</i> M. Hopkins var. <i>pycnocarpa</i>	–	–	–	–	x	x	–	–	x	x	–	–	–	–	–	–
<i>Arenaria congesta</i> Nutt.	x	x	x	–	x	x	–	–	x	x	–	–	x	x	–	–
<i>Arnica rydbergii</i> Greene	–	–	–	–	–	x	–	x	–	–	x	–	–	–	–	–
<i>Artemisia scopulorum</i> Gray	x	x	x	x	x	x	x	x	–	–	–	–	x	x	x	x
<i>Astragalus alpinus</i> L.	x	x	x	x	–	–	–	x	x	x	x	x	x	x	x	x
<i>Astragalus australis</i> (L.) Lam.	x	x	x	x	x	x	–	x	x	x	x	x	–	x	x	x
<i>Astragalus kentrophyta</i> Gray	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Besseyia wyomingensis</i> (A. Nels.) Rydb.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Boechera pendulina</i> (Greene) W.A. Weber	–	–	–	–	–	–	x	x	–	–	x	x	–	–	x	x
<i>Botrychium</i> sp. in Yellowstone NP	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
<i>Bromus inermis</i> Leyss.	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–
<i>Calamagrostis</i> in Yellowstone NP	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
<i>Calamagrostis purpurascens</i> R. Br.	–	–	x	–	–	–	–	–	x	x	x	x	–	–	–	–

Table A-1 (continued). Yellowstone NP target region species list for each summit (BLP, SCP, SPP, and WSP) by summit area section (05 and 10) and by year. "x" indicates the species was present.

Species	BLP				SCP				SPP				WSP			
	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)
<i>Caltha leptosepala</i> DC.	x	x	x	x	—	—	—	—	—	—	—	—	—	—	—	—
<i>Carex albonigra</i> Mack.	—	—	x	—	—	—	x	x	—	—	—	—	—	—	—	—
<i>Carex atosquama</i> Mackenzie	—	—	x	x	—	—	—	x	—	—	—	—	—	—	x	x
<i>Carex elynoides</i> Holm.	—	—	—	—	x	x	—	—	—	x	—	—	x	—	x	—
<i>Carex filifolia</i> Nutt.	x	x	x	—	x	—	—	—	x	—	—	—	x	x	—	—
<i>Carex haydeniana</i> Olney	x	x	—	—	x	x	—	—	—	—	—	—	x	x	—	—
<i>Carex</i> in Yellowstone NP	—	x	x	x	x	—	x	x	—	—	x	x	—	—	x	x
<i>Carex microptera</i> Mack.	—	—	x	x	—	—	—	x	—	—	—	—	—	—	x	x
<i>Carex nelsonii</i> Mackenzie	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Carex paysonis</i> Clokey	x	—	x	x	x	x	x	x	—	—	—	x	x	x	x	x
<i>Carex phaeocephala</i> Piper	x	x	x	x	x	x	x	x	—	—	—	—	x	x	x	x
<i>Carex rossii</i> Boott	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Carex rupestris</i> All.	x	x	—	—	x	—	—	—	x	x	—	—	x	x	—	—
<i>Carex scopulorum</i> T. Holm	—	—	—	x	x	—	—	—	x	—	—	—	—	—	—	—
<i>Carex vernacula</i> L.H. Bailey	—	x	—	—	—	—	—	—	—	x	—	—	—	—	—	—
<i>Castilleja nivea</i> Pennell & Ownbey	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—
<i>Castilleja pulchella</i> Rydb.	—	—	x	x	—	—	x	x	—	—	—	—	—	—	x	x
<i>Cerastium arvense</i> L.	—	—	x	x	—	—	x	x	—	—	x	x	—	—	x	x
<i>Cerastium beeringianum</i> Chamisso & Schlechtendal	x	x	x	x	x	x	x	—	x	x	x	—	x	x	x	—
<i>Chaenactis douglasii</i> (Hook.) Hook. & Arn.	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—
<i>Cirsium eatonii</i> (Gray) B.L. Robins.	—	x	—	x	—	—	—	—	—	—	—	—	—	—	—	—
<i>Cistanthe umbellata</i> (Torr.) Hershkovitz	—	—	—	—	—	x	—	x	—	—	—	—	—	—	—	—
<i>Claytonia megarhiza</i> (Gray) Parry ex S. Wats.	x	x	—	—	—	—	—	—	—	x	—	—	x	—	—	—
<i>Cruciferae</i> in Yellowstone NP	—	—	—	x	—	—	—	x	—	—	—	—	—	—	—	—
<i>Deschampsia cespitosa</i> (L.) P. Beauv.	x	x	—	x	x	x	x	x	—	—	x	x	x	x	x	—
<i>Dodecatheon pulchellum</i> (Raf.) Merr.	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Draba aurea</i> Vahl ex Hornem.	—	—	x	x	—	—	x	—	—	—	—	—	—	—	x	x

Table A-1 (continued). Yellowstone NP target region species list for each summit (BLP, SCP, SPP, and WSP) by summit area section (05 and 10) and by year. “x” indicates the species was present.

Species	BLP				SCP				SPP				WSP			
	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)
<i>Draba crassa</i> Rydb.	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	x
<i>Draba crassifolia</i> R. Graham	x	x	x	x	x	x	–	–	–	–	–	–	x	–	–	–
<i>Draba incerta</i> Pays.	x	x	x	x	x	x	x	x	x	x	x	x	x	–	x	x
<i>Draba oligosperma</i> Hooker	x	x	–	–	x	x	x	–	x	x	x	x	x	x	–	–
<i>Dryas octopetala</i> L.	–	–	–	x	–	–	x	x	–	–	–	–	–	–	–	–
<i>Elymus alaskanus</i> (Scribn. & Merr.) A. Löve ssp. <i>latiglumis</i> (Scribn. & J.G. Sm.) A. Löve	–	–	–	–	–	–	–	–	–	–	–	–	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>Elymus trachycaulus</i> (Link) Gould ex Shinners	–	–	x	–	–	–	–	x	–	–	–	–	–	–	x	x
<i>Epilobium</i> sp. in Yellowstone NP	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
<i>Erigeron compositus</i> Pursh	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Erigeron concinnus</i> (Hook. & Arn.) Torr. & A. Gray	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–
<i>Erigeron ochroleucus</i> Nutt. var. <i>scribneri</i> (Canby ex Rydb.) Cronquist	x	x	x	x	x	x	x	x	x	x	–	–	x	x	x	x
<i>Erigeron rydbergii</i> Cronquist	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
<i>Erigeron</i> sp. in Yellowstone NP	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
<i>Erigeron strigosus</i> Muhl. ex Willd.	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–
<i>Erigeron ursinus</i> D.C. Eaton	–	–	–	–	–	–	x	x	–	–	x	x	–	–	x	x
<i>Eriogonum hookeri</i> S. Watson	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	x
<i>Eriogonum ovalifolium</i> Nutt.	x	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	–	–
<i>Eurybia merita</i> (A. Nelson) G.L. Nesom	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
<i>Festuca idahoensis</i> Elmer	–	–	–	–	–	–	x	x	x	x	x	x	–	–	x	x
<i>Festuca saximontana</i> Rydb.	–	–	–	–	–	–	–	x	–	–	–	–	x	x	x	–
<i>Geum rossii</i> (R. Br.) Ser.	x	x	x	x	x	x	x	x	x	x	–	–	x	x	x	x
<i>Geum triflorum</i> Pursh	–	–	–	–	–	x	x	–	x	x	x	x	–	–	x	–

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<i>Juncus hallii</i> Engelm.	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–
<i>Juncus drummondii</i> E. Mey.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
<i>Kobresia myosuroides</i> (Vill.) Fiori	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	x
<i>Koeleria macrantha</i> (Ledeb.) Schult.	x	x	–	–	x	–	–	–	–	–	x	x	–	x	–	–
<i>Lewisia pygmaea</i> (Gray) B.L. Robins.	–	–	x	–	–	–	–	–	–	–	x	x	–	–	x	x
<i>Linum lewisii</i> Pursh	–	–	–	–	x	x	x	x	x	–	x	x	–	–	–	–
<i>Lomatium cous</i> (Wats.) Coult. & Rose	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	x
<i>Lupinus</i> × <i>alpestris</i> (A. Nelson) D.B. Dunn & J.M. Gillett	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–
<i>Lupinus depressus</i> Rydb.	x	x	x	x	x	x	x	x	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
<i>Melica bulbosa</i> Geyer ex Porter & J.M. Coult.	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–
<i>Mertensia alpina</i> (Torr.) G. Don	x	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
<i>Myosotis alpestris</i> F.W.Schmidt	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Oreostemma alpigenum</i> (Torr. & A. Gray) Greene var. <i>haydenii</i> (Porter) Nesom	x	x	x	x	x	x	–	–	x	x	x	x	x	x	x	x
<i>Oreoxis alpina</i> (Gray) Coult. & Rose	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
<i>Oxyria digyna</i> (L.) Hill	–	x	–	–	–	–	–	–	–	x	–	x	–	–	–	–
<i>Oxytropis campestris</i> (L.) DC.	–	–	x	x	–	–	x	x	–	–	x	x	–	–	x	x
<i>Oxytropis lagopus</i> Nutt. var. <i>atropurpurea</i> (Rydb.) Barneby	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
<i>Oxytropis sericea</i> Nutt. var. <i>speciosa</i> (Torr. & A. Gray) S.L. Welsh	x	x	–	x	x	x	–	–	x	x	–	–	x	x	–	–
<i>Packera cana</i> (Hook.) W.A. Weber & A. Löve	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	–
<i>Packera dimorphophylla</i> (Greene) W.A. Weber & A. Löve	–	–	x	x	–	–	–	x	–	–	–	x	–	–	–	x
<i>Packera multilobata</i> (Torr. & A. Gray ex A. Gray) W.A. Weber & A. Löve	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–

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	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)
<i>Pedicularis cystopteridifolia</i> Rydb.	x	x	x	x	x	x	x	x	—	—	—	x	x	x	x	x
<i>Pedicularis groenlandica</i> Retz.	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—
<i>Penstemon aridus</i> Rydb.	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Penstemon procerus</i> Dougl. ex Graham	—	—	x	x	—	—	—	—	—	—	—	—	—	—	—	—
<i>Phacelia hastata</i> Dougl. ex Lehm.	—	x	x	x	x	x	x	x	—	—	—	—	—	x	—	x
<i>Phacelia sericea</i> (Grah.) Gray	—	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—
<i>Phleum alpinum</i> L.	—	—	—	—	—	—	—	x	—	—	—	—	—	—	x	x
<i>Phlox condensata</i> (Gray) E. Nels.	—	—	x	x	—	—	—	—	—	—	—	—	—	—	—	—
<i>Phlox multiflora</i> A. Nelson	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Phlox pulvinata</i> (Wherry) Cronq.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Picea engelmannii</i> Parry ex Engelm.	—	—	—	x	x	x	x	x	—	—	—	—	—	—	—	—
<i>Pinus albicaulis</i> Engelm.	—	—	—	—	x	x	—	—	—	x	—	—	—	—	—	—
<i>Pinus contorta</i> Dougl. ex Loud.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x
<i>Poa alpina</i> L.	—	—	x	x	—	—	x	x	—	—	x	x	—	—	x	x
<i>Poa arctica</i> R. Br. var. <i>arctica</i>	x	x	—	—	x	x	—	—	x	x	—	—	x	x	—	—
<i>Poa cusickii</i> Vasey	x	x	x	—	x	x	x	x	x	x	x	x	x	x	x	x
<i>Poa glauca</i> Vahl	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Poa secunda</i> J. Presl	x	x	—	x	—	—	x	x	—	—	—	—	x	x	—	—
<i>Poa</i> sp. in Yellowstone NP	—	—	—	—	—	—	—	—	—	—	x	x	—	—	x	x
<i>Polemonium pulcherrimum</i> Hook.	—	—	—	—	x	x	x	x	—	—	x	—	x	x	x	—
<i>Polemonium viscosum</i> Nutt.	x	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	x	x
<i>Polygonum viviparum</i> L.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x
<i>Potentilla diversifolia</i> Lehm.	x	x	x	x	x	x	x	x	—	—	x	x	x	x	x	x
<i>Potentilla</i> in Yellowstone NP	—	—	—	x	—	—	—	—	—	x	—	—	—	—	—	—
<i>Potentilla ovina</i> Macoun	—	—	x	x	—	—	x	—	—	—	x	x	—	—	x	x
<i>Pseudocymopterus montanus</i> (Gray) Coult. & Rose	x	x	—	—	x	x	—	—	x	x	—	—	x	x	—	—

Table A-1 (continued). Yellowstone NP target region species list for each summit (BLP, SCP, SPP, and WSP) by summit area section (05 and 10) and by year. "x" indicates the species was present.

Species	BLP				SCP				SPP				WSP			
	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)
<i>Pulsatilla patens</i> (L.) Mill. ssp. <i>multifida</i> (Pritz.) Zämelis	x	x	x	x	x	x	x	x	—	—	—	—	x	x	x	x
<i>Ranunculus eschscholtzii</i> Schlecht.	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—
<i>Ranunculus eximius</i> Greene	x	x	x	x	—	x	—	x	x	x	—	x	—	x	—	x
<i>Salix glauca</i> L.	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—
<i>Salix nivalis</i> Hook.	—	—	—	x	—	—	—	—	—	—	—	—	—	x	—	—
<i>Salix petrophila</i> Rydb.	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 crassulus</i> A. Gray	—	—	—	—	—	x	x	x	—	x	—	x	—	—	x	x
<i>Senecio fremontii</i> Torr. & A. Gray var. <i>fremontii</i>	x	x	—	—	—	x	x	x	—	x	—	—	—	x	—	—
<i>Senecio integerimus</i> Nutt.	—	—	x	x	—	—	x	x	—	—	x	x	—	—	—	x
<i>Senecio lugens</i> Richardson	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—	—
<i>Senecio serra</i> Hook.	x	—	—	—	x	—	—	—	—	—	—	—	—	x	—	—
<i>Senecio</i> sp. in Yellowstone NP	—	—	—	x	—	—	—	—	—	—	—	—	—	—	—	x
<i>Sibbaldia procumbens</i> L.	—	—	x	—	—	—	—	x	—	x	—	x	—	—	—	x
<i>Silene</i> in Yellowstone NP	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Smelowskia calycina</i> (Steph. ex Willd.) C.A. Mey.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Solidago multiradiata</i> Ait. var. <i>scopolorum</i> Gray	x	x	x	—	x	x	—	—	—	—	—	—	x	x	—	—
<i>Stellaria longipes</i> Goldie	—	x	—	—	x	—	—	—	—	x	—	—	—	—	—	x
<i>Symphyotrichum foliaceum</i> (Lindl. ex DC.) G.L. Nesom	—	—	x	x	—	—	x	x	—	—	x	x	—	—	x	x
<i>Taraxacum</i> in Yellowstone NP	—	—	—	—	—	—	—	—	x	x	—	—	—	—	—	—
<i>Taraxacum officinale</i> Weber	x	x	x	x	—	x	x	x	—	—	x	x	x	x	x	x
<i>Taraxacum officinale</i> F.H. Wigg. ssp. <i>ceratophorum</i> (Ledeb.) Schinz ex Thell.	—	—	x	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Tephroseris lindstroemii</i> (Ostenf.) A. Löve & D. Löve	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—	—

Table A-1 (continued). Yellowstone NP target region species list for each summit (BLP, SCP, SPP, and WSP) by summit area section (05 and 10) and by year. "x" indicates the species was present.

Species	BLP				SCP				SPP				WSP			
	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)	2011 (05)	2011 (10)	2016 (05)	2016 (10)
<i>Townsendia condensata</i> Parry ex Gray	–	–	–	–	–	–	–	–	x	x	x	x	–	–	–	–
<i>Townsendia parryi</i> D.C. Eat.	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
<i>Trisetum spicatum</i> (L.) K. Richt.	x	x	x	x	x	x	x	x	x	–	x	x	x	x	x	x
<i>Trisetum wolfii</i> Vasey	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–
<i>Veronica wormskjoldii</i> Roem. & Schult.	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
<i>Viola praemorsa</i> Douglas ex Lindl. ssp. <i>linguifolia</i> (Nutt.) M.S. Baker & J.C. Clausen ex M. Peck	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–

Appendix B. Yellowstone National Park 2016 Trip Report

Alpine Vegetation Monitoring in Yellowstone National Park 2016 Trip Report

February 3, 2017

Colorado Natural Heritage Program
Colorado State University
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Introduction

The Colorado Natural Heritage Program (CNHP), in partnership with National Park Service Inventory and Monitoring networks, completed a resampling of alpine vegetation and soils monitoring plots in Yellowstone National Park (NP). The monitoring sites are located near Lamar Mountain adjacent to the North Absaroka Wilderness, Shoshone National Forest, in Park County, Wyoming (Table B-1; Figure B-1). The goal of the monitoring effort is to determine status and trends of vegetation cover, soil condition, anthropogenic disturbance, and soil temperature at four high elevation peaks in Yellowstone NP. The four peaks are sampled using the GLORIA protocol (Global Observation Research Initiative in Alpine Environments): 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 sites were visited and sampled by a CNHP and National Park Service field crew over one visit from July 21 to July 27, 2016, with travel occupying two days at the beginning and one day at the tail end of the trip. The sampling was conducted over four days and involved six crew members: two CNHP field botanists (Claire Tortorelli and Dustin Gannon), along with two CNHP interns (Lydia Fahrenkrug and Alyssa Meier), the Yellowstone NP botanist (Heidi Anderson) and field botany technician (Monica Lomahukluh). 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.

Training

Since the Yellowstone NP GLORIA monitoring was the second target region to be monitored by the CNHP crew in 2016, no specific Yellowstone field training was conducted. However, prior to the

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

GLORIA summit code	Summit name	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Vegetation zone
BLP	Unnamed	44.700184	-109.826731	3195	lower alpine
SCP	Unnamed	44.695765	-109.834566	3122	lower alpine
SPP	Unnamed	44.701613	-109.835067	3169	lower alpine
WSP	Unnamed	44.694275	-109.837219	3124	lower alpine

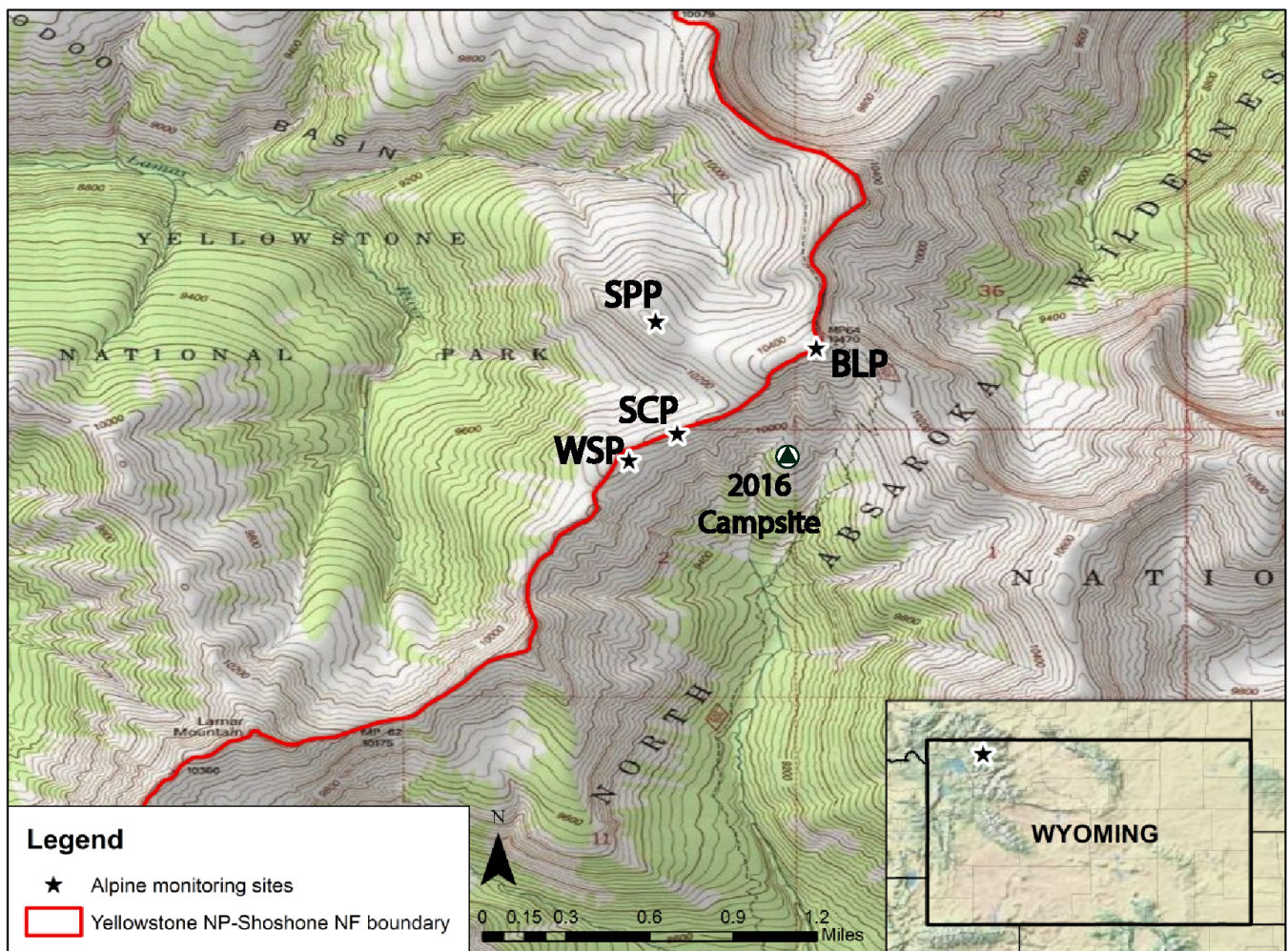


Figure B-1. Location of four alpine monitoring/sentinel sites (identified by their GLORIA site codes - BLP, SCP, SPP, and WSP) in Yellowstone NP, adjacent to the North Absaroka Wilderness in Park County, Wyoming.

field season, the CNHP field crew, Claire Tortorelli, Dustin Gannon, and Lydia Fahrenkrug, met for a half day of office and field training at the CNHP office with Joe Stevens and Bernadette Kuhn in order to familiarize everyone with survey protocols and the purpose and need of using the GLORIA research methods. A site was selected in City Park, Fort Collins, on a small hill top to familiarize the crew with the methodology and practice setting up the 3 x 3-m quadrat clusters, the 1-m² quadrats, and the summit area sections.

Site Access

The CNHP crew left Fort Collins on July 21, 2016 and drove nine hours to reach 7D Ranch outside of Cody, Wyoming. It was a tight fit for four crew members, GLORIA sampling equipment, and personal gear in a mid-sized Dodge SUV. At 7D

Ranch, the CNHP crew met with the remaining crew members from Yellowstone NP and transferred gear and supplies to the 7D horse packers. That night, the entire crew camped at the Little Sunlight Campground just across the river from 7D. On July 22, all six GLORIA crew members left Sunlight Creek campsite and headed to the trailhead at Sunlight Creek. Recent downed trees over the road had been cut through and cleared to make a gap just wide enough for the mid-sized SUV to pass through. The crew was able to drive across each of the creek crossings, except the very last one beyond where the road turns into a two track. The creek crossings were very deep, just barely low enough to drive through with an all-wheel drive vehicle. Water from the creek crossings was splashed over the hoods of the vehicles. Higher clearance and four-wheel drive is recommended and could be necessary if the crossings are deeper in subsequent sampling years.



Figure B-2. 2016 campsite with easy access to the ridge and Yellowstone NP GLORIA summits. July 2016.

The crew reached the Sunlight Creek trailhead (i.e. two track) and began hiking around 9:30 a.m. The trail was moderately well maintained and easy to follow. They reached their basecamp below the boundary line of the Shoshone National Forest and Yellowstone NP around 12:00 p.m. The horse packers from 7D Ranch met the crew at a high camp below Boundary Line Peak and unloaded gear (Figure B-2). The campsite was located within 0.25 miles of the trail. The access to water was on a steep slope of loose scree, but it was not too far from the camp, approximately 150 meters away. The 7D Ranch packed in bear-proof metal paniers for the crew's food, trash and other aromatic products. No notable wildlife was encountered during the 2016 sampling event, although grizzly bear tracks were spotted in the persistent snow banks between some of the summits.

The summits were reached by hiking 20 to 30 min from the campsite straight up the ridge in between BLP and SCP. The slope steepens and becomes loose when cutting under the snowfield just before making the ridge, caution is advised. From here, the summits were clearly visible and navigating was easy along the alpine tundra. The locations of the Yellowstone NP summits and 2016 campsite are shown in Figure B-1.

Field Sampling

The high summit points (HSP) were located on each peak after about 10 minutes of searching with the aid of GPS devices. Once the HSP on each summit was determined, the crew located the capped rebar markers at the 5-m and 10-m points on each summit's cardinal directions using GPS coordinates and measurements recorded during the initial monitoring effort in 2011. Using the 5-m and 10-m points for reference, the summit area sections were delimited and marked using pin flags (Figure B-3). The 3 x 3-m quadrats were located and the "spider," the 3 x 3-m tape measure grid, was laid out to begin sampling the 1-m² plots nestled within the corners of the grid. The crew did not have any significant difficulties relocating the hardware installed during the initial monitoring event. Often the nails and washers were overgrown by the tundra, and on BLP, the crew could not locate the E3-3 and the E3-1 corner markers of the E 3 x 3-m quadrat. The crew was able to install nails at the 10-m line on SPP and WSP. In 2011, the sampling crew was unable to install these marker nails due to the presence of deep snow fields.



Figure B-3. Dustin Gannon, CNHP field botanist, marks the edge of a summit area section using a measuring tape on BLP in Yellowstone NP.

Soils and Photos

After the summit plots were laid out, two crew members took all of the photos required by the GLORIA protocol and took soil samples as explained in the Rocky Mountain Network sampling protocol. The temperature loggers had been located, retrieved, and replaced prior to late July by a Greater Yellowstone Network and Yellowstone NP field crew two days before vegetation sampling.

Vegetation Sampling

As some members of the crew were locating and marking the summit area section boundaries and the 3 x 3-m quadrats, other crew members began sampling the summit area sections and the 1-m² quadrat clusters nestled within the corners of the 3 x 3-m quadrats. Using a grid made of PVC pipe and string strung to have 100 cross sections, the crew members used the end of a pin flag to record each “hit” at each cross section, whether plant, rock, bare ground, or litter. The 1-m² quadrats required two crew members, one recorder and one botanist, to identify the species “hit” (Figure B-4). These took between 20 min and 70 min, depending on the percentage of quadrat covered in vegetation and the

particular botanist’s familiarity with the specific flora and the protocol. The summit area sections took one botanist between 40 min and 90 min, depending on the area of the summit area section, the plant diversity, and the difficulty of the terrain (i.e. steep and loose rock). All resulting plant specimens collected by the crew were sent to the Yellowstone NP Herbarium for curation in winter 2016/2017.

Conclusion

The 2016 sampling crew completed a full resample of the four Yellowstone NP GLORIA summits including the following: soil samples were collected for bulk density and chemistry using the Rocky Mountain Network protocol, all GLORIA field forms were completed, 1 x 1-m² quadrat and summit area section vegetation sampling were completed, and photo documentation of all plots occurred. Overall, the four summits took a crew of six people four days to complete (The sampling timeline is provided in Appendix C: 2016 Yellowstone NP Summit Site Field Log). The sampling likely went much quicker than the initial monitoring effort due to the plot markers already being in place, the swap of temperature loggers by the Greater Yellowstone Network/

Yellowstone NP crew prior to the late July monitoring effort, the six-person sampling crew with four experienced botanists, and the four days of beautiful, sunny weather. Inclement weather would have slowed the sampling process considerably, and should be taken into account for future sampling events. Additionally, no lichen data were collected in 2016, which also shortened the time required for sampling.

Literature Cited

Pauli, H., M. Gottfried, D. Hohenwallner, K. Reiter, R. Casale, and G. Grabherr, editors. 2004. The GLORIA field manual: multi-summit approach. European Communities, Belgium.

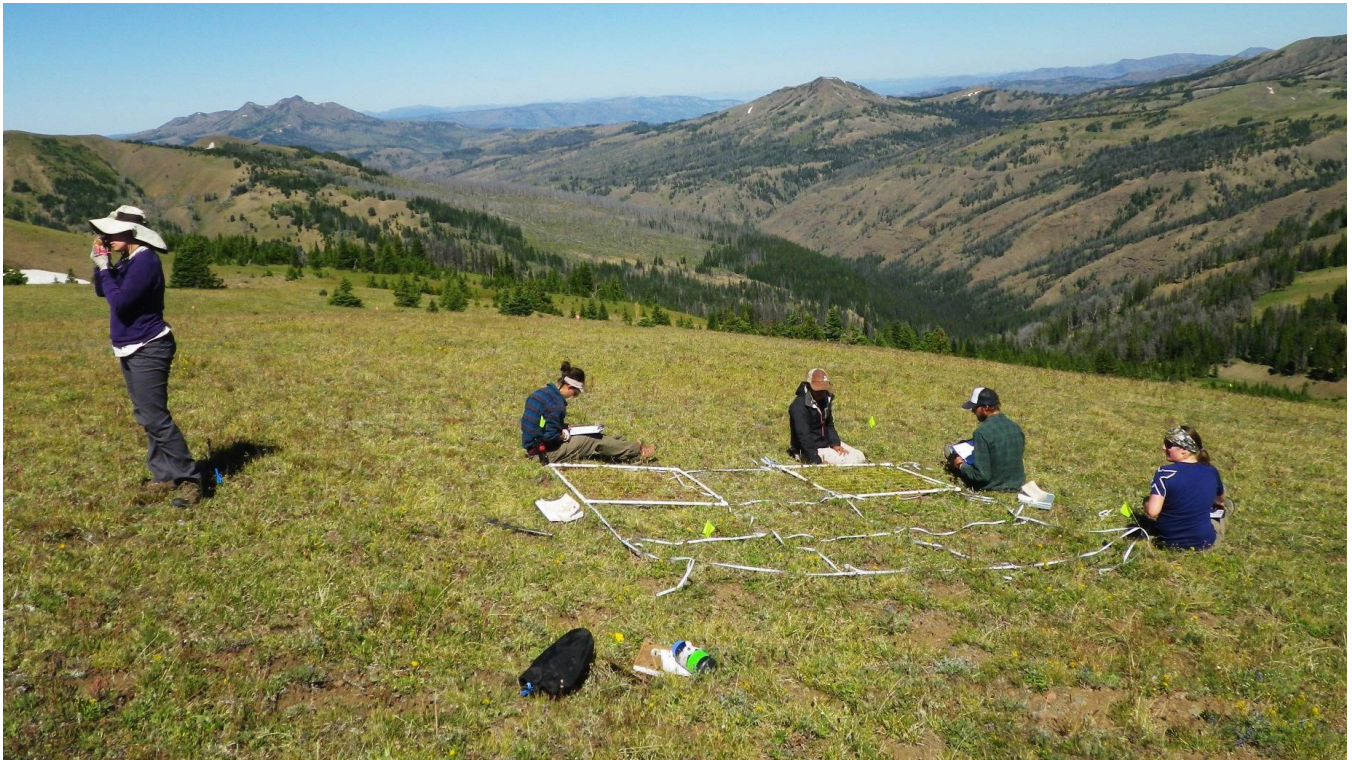


Figure B-4. GLORIA monitoring crew samples 1-m² quadrats at Yellowstone NP using PVC pipe and string grids nestled in the corners of the 3 x 3-m "spider" quadrat. July 2016.

Appendix C. 2016 Yellowstone National Park Summit Site Field Log

Table C-1. 2016 Yellowstone NP summit site field log.

Date	Peak	Persons	Activity	Notes
7/21/2016	n/a	Claire Tortorelli, Dustin Gannon, Heide Anderson, Lydia Fahrenkrug, Alyssa Meier, Monica Lomahukluh	Drove from Fort Collins, through Cody WY to 7D Ranch. Gave supplies to packers, and camped at Little Sunlight Campground	9 hours from Ft. Collins to 7D ranch with some quick supplies stops. Little sunlight campground is a bit tricky to find (bring water)
7/22/2016	n/a	Claire Tortorelli, Dustin Gannon, Heide Anderson, Lydia Fahrenkrug, Alyssa Meier, Monica Lomahukluh	Drove to TH from Little sunlight campground. Hiked ~3 hours to campsite under ridge. Met packers and moved campsite up in elevation.	Creek crossings were just barely passable in the all-wheel drive SUV. Parked at the last creek crossing along the road. Followed 2 track to trail. Lots of trees down over trail. Campsite is flattish, but close to the ridgeline and has access to water, although very steep.
7/23/2016	BLP	Claire Tortorelli, Dustin Gannon, Heide Anderson, Lydia Fahrenkrug, Alyssa Meier, Monica Lomahukluh	40 min to BLP summit from camp site. Completed peak and returned to camp by 6 pm	10 hours of sampling to complete BLP. E 3 x 3 m was missing 3-3 and 3-1 corner nails. For list of unknown collections see field notebook
7/24/2016	SCP	Claire Tortorelli, Dustin Gannon, Heide Anderson, Lydia Fahrenkrug, Alyssa Meier, Monica Lomahukluh	Hiked to and completed SCP summit.	For a complete list of collected unknown species see field notebook
7/25/2016	SPP	Claire Tortorelli, Dustin Gannon, Heide Anderson, Lydia Fahrenkrug, Alyssa Meier, Monica Lomahukluh	Hiked to and completed SPP summit	Installed missing 10 m nails. For a complete list of collected unknown species see field notebook
7/26/2016	WSP	Claire Tortorelli, Dustin Gannon, Heide Anderson, Lydia Fahrenkrug, Alyssa Meier, Monica Lomahukluh	Hiked to and completed WSP summit around 1 pm. Packed up and returned to the vehicle. Returned to Sunlight Creek Campground and camped	Got back to sunlight campground at 8pm. QC'd data forms once back at camp.
7/27/2016	n/a	Claire Tortorelli, Dustin Gannon, Lydia Fahrenkrug, Alyssa Meier	Drove back to Fort Collins	–

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