

CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

An Exploration of Alpine Floristic Diversity Among Eight Peaks in the
Eastern Sierra Nevada of California

A thesis submitted in partial fulfillment of the requirements
for the Master of Science in Biology

By

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December 2022

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ABSTRACT

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To determine patterns and drivers of alpine floral diversity in the eastern Sierra Nevada of California, community composition was investigated on 8 peaks along a latitudinal gradient. The diversity of alpine flora can be attributed to both macroenvironmental factors such as latitude and elevation, and microenvironmental factors such as substrate and aspect. Using the point-intercept method vascular plant species abundances were documented, along with growth-form composition, elevation, latitude, aspect, slope, parent substrate, and substrate grain size. Diversity, dominance, and community similarity/dissimilarity were explored. Across the Sierra Nevada, alpine communities were highly dissimilar from each other (83.2%) and were divided into two distinct assemblages separated by elevation (near-treeline and near-summit) with a 91.3% dissimilarity. In addition, near-treeline sites were more dissimilar in floristic composition (66.0%) across the Sierra Nevada when compared to near-summit sites across the mountain range (34.4% dissimilarity). There was stronger dissimilarity among sites on individual peaks (range: $R=0.56-1.0$; $P=0.0043-0.0001$) than among peaks across the range ($R=0.29$, $P=0.0001$). The six environmental and topographic variables collectively explained 54.8% of the floristic

dissimilarity in community assemblages across the mountain range, with substrate grain size having the largest influence ($R^2=0.29$, $P=0.0001$), followed by aspect ($R^2=0.24$, $P=0.0001$) and elevation ($R^2=0.15$, $P=0.0001$). Aspect had the largest influence on community composition on the northern and central peaks, while substrate grain size had the largest influence on the two southernmost peaks. On individual peaks, floristic dissimilarity occurred over short elevational distances shown by large changes in beta-diversity. Species richness and diversity did not significantly differ across the range, while percent cover increased with increased latitude, coinciding with more precipitation in the northern region and drier habitats with less available optimum range in the southern region. The southern region had a higher proportion of endemic species. Further research efforts should be directed towards monitoring species existing in the climatically decoupled microhabitats created by variations in substrate grain sizes.

INTRODUCTION

Alpine regions worldwide contain high biodiversity despite demanding environmental conditions (Körner 2003) with the highest alpine plant species richness occurring in mid-latitudes in the Northern Hemisphere (Testolin et al. 2021). The alpine zone has a global distribution which accounts for approximately 3% of Earth's terrestrial land area and includes approximately 10,000 species (4% of all known higher plant species) (Körner 2003). Vegetation of this zone includes a diverse array of herbaceous plants, graminoids, mosses, lichens, and subshrubs. Although Jaccard (1912) posited that no two square meters of alpine vegetation contained the same floristic composition, a comprehensive understanding of patterns of diversity in the alpine zone at both large and small scales is currently lacking (Elliott and Jules 2005; Malanson et al. 2020; Testolin et al. 2021).

The deficit of extensive alpine floristic studies may be due to the difficulty in researching at high altitudes, including challenging access and stressful physiological effects, coupled with brief growing seasons (5-12 weeks) and short intervals of favorable weather conditions (Körner 2003; Storer et al. 2004; Chicco et al. 2018). According to Körner (2009), there were 14,226 worldwide publications with the keyword "alpine" in the title, in the 1900-2008 time period. This represents a very small fraction of the biological science research conducted which had approximately 400,000 papers published annually as of 2017 (Kelly 2018). There are many alpine regions worldwide that have never been surveyed or comprehensively studied.

Switzerland has the most alpine publications per capita (282 per one million inhabitants), followed by New Zealand and Austria. The United States ranked nineteenth (10 publications per one million inhabitants) with just 2,899 papers published between 1900-2008 (Körner 2009). This is despite having multiple alpine regions located in the Sierra Nevada, Cascade Range,

Alaska Range, Rocky Mountains, and in the Northeastern United States (including the Adirondack Mountains, Green Mountains, and White Mountains). There is a need for multidisciplinary alpine research and data collection to understand their community compositions and determine drivers of floristic diversity (Körner 2009; Capers et al. 2013; Testolin et al. 2021).

The complex topography of the alpine zone creates a multitude of microenvironmental conditions which drive the high biodiversity seen in alpine regions (Körner and Hiltbrunner 2021). Topography can include aspect, slope, parent substrate type, and parent substrate grain size (Opedal et al. 2015). Microenvironment refers to small regions (10-100 m) created by differences in topography, which creates mosaics of thermal habitats (microclimates) with steep climatic gradients ranging from 1-10 m (Körner and Hiltbrunner 2021). While large natural gradients (macroenvironment) such as latitude and elevation have been shown to influence species distributions (Jurasinski and Kreyling 2007; Smithers et al. 2019; Testolin et al. 2021), multiple studies point to topographic variability and associated microenvironments as significant influencers of floristic composition (Elliott and Jules 2005; Scherrer and Körner 2011; Kulonen et al. 2017; Oldfather and Ackerly 2018; Smithers et al. 2019; Malanson et al. 2020). Körner and Hiltbrunner in 2021 identified accounting for the actual microclimatic life conditions of alpine species and knowing their spatial distribution across habitat mosaics as critical future research questions.

Global temperatures have increased approximately 1.0-1.5°C since the Maunder Minimum over 300 years ago (Borzenkova et al. 2015) and recent studies have focused on understanding the effects of a changing climate on alpine communities (Lesica and McCune 2004; McCoullough et al. 2016; Stubbs et al. 2018; Wershow and DeChaine 2018). Alpine

regions, constrained by low temperatures, are considered among the most susceptible to a warming climate (Verrall and Pickering 2020). There is worldwide evidence of species upslope and downslope range shifts that correlate with climate warming in different alpine locations (Holzinger et al. 2008; Kopp and Cleland 2014; Auld et al. 2022). Other research shows evidence of increased species richness on peak summits worldwide due to upslope migrations in response to warming trends (Steinbauer et al. 2018).

There is also evidence that plant adaptations to extreme environmental conditions enable alpine floras to be resilient to climatic changes, and that the range of conditions created by alpine microenvironments exceeds the worst climate scenarios making alpine flora comparatively robust (Scherrer and Körner 2011; Körner and Hiltbrunner 2021). In addition, some mountains exhibit resistance to climate warming with increases in elevation, with lower elevations having increased warming while the highest elevations having no warming (Seidel et al. 2009). The amount of change the climate of individual alpine regions experiences varies considerably under the influence of many factors, and we should be cautious when applying climate trends from other mountain systems or from lower elevation climate data (Seidel et al. 2009). To adequately determine the range of natural variation in alpine community composition from evidence of a directional change over time, baseline data are needed, ideally followed by repeated surveys (Capers et al. 2013). The lack of alpine community composition and associated environmental data hinders the ability to understand if there are changes taking place, what the changes are, and why they are happening (Capers et al. 2013).

California's Sierra Nevada mountain range provides an opportunity to study alpine floristic community composition and diversity on multiple peaks along a latitudinal (and thus environmental) gradient. Initial surveys of the alpine zone in the Sierra Nevada were conducted

in the late 1800's to early 1900's were comprised of observational and occurrence data (Coville 1893; Harshberger 1911; Smiley 1921). Sharsmith (1940) authored a Ph.D. dissertation on Sierra Nevada alpine flora and recognized that it was a distinct California floristic group characterized by its geographic range, growth forms, and community composition. While more recent floristic studies have included the alpine zone of the Sierra Nevada (Went 1953; Stebbins 1982; Jackson 1985; Kimball et al. 2004; Jones 2011; Rundel and Keeley 2016; England 2019) they are often confined within subregions and do not span the alpine zone latitudinally to address diversity across the Sierra Nevada. There have been very few strictly alpine community composition studies spanning multiple locations in the Sierra Nevada (Lobnitz 1979; Pritchett and Patterson 1998; Elliot and Jules 2005). For instance, there is the Global Observation Research Initiative in Alpine Environments (GLORIA) network and methodology, developed in Austria, that is currently doing repeated sampling efforts on selected peak summits worldwide every 5 years to assess distributional shifts of alpine species related to temperature changes (Pauli et al. 2015). This project is surveying two alpine summit regions in the Sierra Nevada; Mount Langley in the Southern Sierra and Dunderberg Peak near Tioga Pass. However, it has not yet produced any publications with that data. Pairing and analyzing data on environmental conditions with floristic abundance and occurrence data can provide a framework where suitable hypotheses about alpine diversity in a changing climate can be created and tested (Körner 2009; Capers et al. 2013).

There were several objectives of this study. First, alpine floristic community data were gathered at multiple locations in the Sierra Nevada across latitudinal and elevational gradients to provide information about community composition. These macroenvironmental gradients create changes in climate and are useful variables to detect differences in diversity and community composition and can be used as a proxy to predict future outcomes (Testolin et al. 2021). It was

hypothesized that species diversity would decrease with elevation due to decreasing temperatures and less alpine area with elevation gain (Elsen and Tingley 2015; Löffler and Pape 2020; Wani et al. 2022), and that species diversity would decrease latitudinally from north-to-south due to less precipitation and higher peak elevations in the south (Dolezal et al. 2016; Cubino et al. 2022). Second, topographic features were documented at each site, and these were to be analyzed with the abundance data to see if microenvironmental differences were drivers of diversity and dissimilarity among communities. Based on published research (Elliott and Jules 2005; Scherrer and Körner 2011; Kulonen et al. 2017; Oldfather and Ackerly 2018; Smithers et al. 2019; Malanson et al. 2020), it was hypothesized that the topographically created mosaics of microenvironment would influence the distribution of alpine flora in the Sierra Nevada and there would be a sorting of species based on the topographic variables.

BACKGROUND

Location

Research was conducted during July-October of 2017 and 2018 on eight peaks in the alpine zone along the eastern crest of the Sierra Nevada mountain range in California (Figure 1; Figure 2). The Sierra Nevada is generally north-south oriented, approximately 650 km in length and varies 90-130 km in east-west width (Storer et al. 2004). It is bound by Fredonyer Pass in the north and Tehachapi Pass in the south. From west-to-east, elevations gradually rise with slopes of just 2-6% from the floor of the Central Valley to the highest peak at 4421 m (Mount Whitney, the highest point in the contiguous United States; Storer et al. 2004). Fault block geologic features make the crest, which runs north-south along the eastern side of the range, top a steep escarpment (approximately 25% slope) compared to the more gently sloping western side (Hill 2006). In the northern Sierra Nevada, the escarpment rises 600-900 m, while in the south it ascends over 2100 m from the Owens Valley (Storer et al. 2004).

Treeline is defined as the upper limit of the occurrence of tree species and demarks the beginning of the alpine zone (Körner 2003). Treeline ranges from approximately 2700 m in the northern Sierra Nevada to 3300 m in the southern Sierra Nevada, and follows the estimated 1°C decrease in temperature for every 150 m of latitude (Wenk 2015). Summit elevation gradually increases from north to south, creating an overall slope in height across its entirety, with peaks ranging from 1800-2500 m in the northern Sierra Nevada to 3000 m near Lake Tahoe, to 4000 m in the Yosemite region, and to over 4400 m in the southern Sierra Nevada (Storer et al. 2004). The alpine zone of the Sierra Nevada is located between Lake Tahoe in the north and Cottonwood Pass (10 km south of Mount Langley) in the south and encompasses approximately 320 km or 50% of the entire range, situated on the southern and central Sierra Nevada.

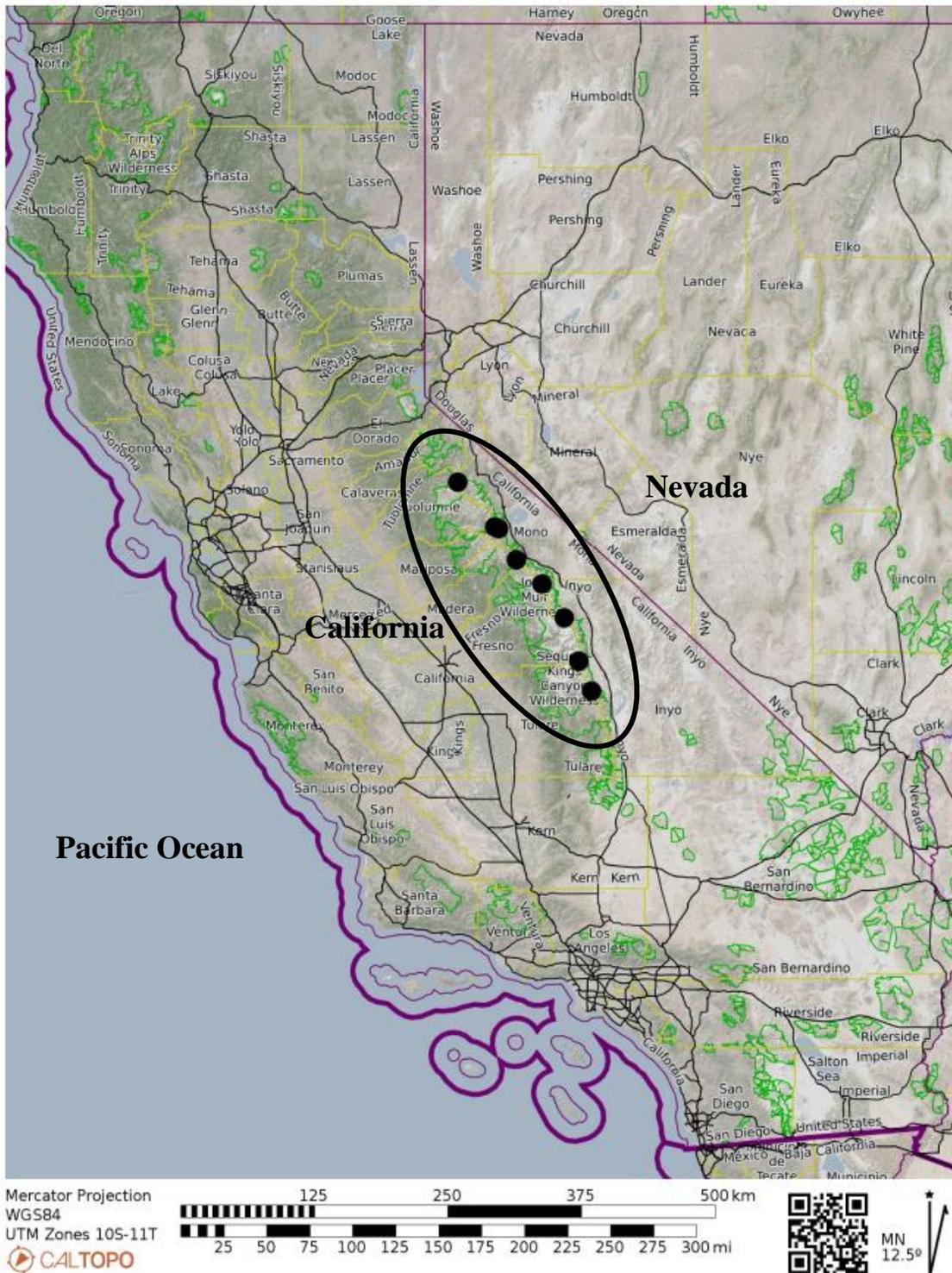


Figure 1. Regional location of the eight peaks sampled along the Sierra Nevada mountain range circled in geographic reference to California, Nevada, and the Pacific Ocean.

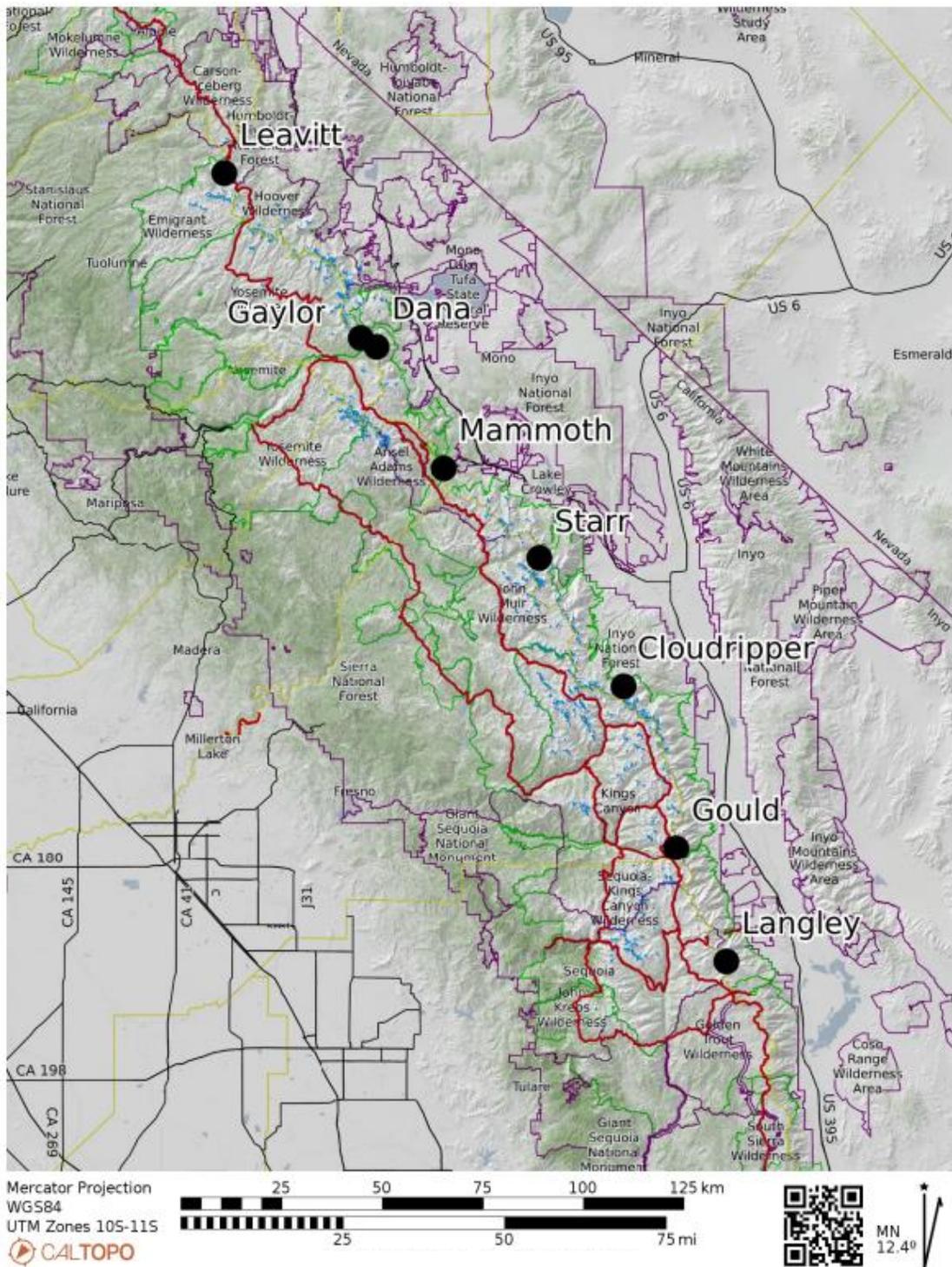


Figure 2. Individual peaks labeled across the Sierra Nevada.

The geologic history of the Sierra Nevada is complex, and its age is debated, but recent research suggests it was roughly in its current form 40 to 50 million years ago (Mulch et al. 2006). At present, its substrate comprises three groups: granitic, volcanic, or metamorphic rock (Hill 2006). The most notable feature is the granite substrate that dominates the southern and central portions of the mountain range, including the glacier-carved Yosemite Valley and well-known peaks such as Half Dome, El Capitan, and Mount Whitney (Storer et al. 2004). This large block of granite from the Sierra Nevada batholith forms the core of the Sierra, which has been lifted, tilted, and exposed due to tectonic and geologic processes beginning millions of years ago (Storer et al. 2004; Mulch et al. 2006). There are towering peaks, jagged crests and monolithic mountains which surround valleys, rock basins, plateaus, meadows, lakes, and rivers, creating a spectacular array of natural beauty that is difficult to describe.

Topography

Episodic glaciation during the Pleistocene shaped the structure of the alpine zone in the Sierra Nevada and has resulted in moraines, cirques, talus slopes, erratics, alpine lakes, hanging valleys, and scoured canyons (Storer et al. 2004). A consequence of glaciations in the Sierra was that the highest peaks and plateaus remained above the glaciers and thus served as scattered isolated refugia for species, creating nunataks or what have been termed “sky islands” (Dodge 1943; Howell 1947; Weldon 1967; Wenk 2015). Even with the glacial retreat, which occurred during the Holocene, these sky islands remain separated by distance and topography that still serve as physical barriers to species dispersal. Changing climatic conditions with periods of isolation and connection across the range resulted in endemism, increased species richness, and genetic diversity associated with the expansion and contraction of populations (DeChaine and Martin 2005; Baldwin et al. 2018).

Such dramatic natural terrain has created a varied physical environment in which Sierran alpine vegetation exists (Figure 3). Differences of elevation, latitude, substrate, parent material, substrate grain size, snowpack, slope, and aspect have been shown in previous studies to influence alpine species assemblages (Mark et al. 2001; Körner 2003; Irl et al. 2015; Smithers et al. 2019). Elevation is often used as a topographic feature to measure against species composition, and logically so. On average in dry air, temperature decreases with altitude at a lapse rate of 9.8°C/km (Muralikrishna and Manickam 2017). In mountain ranges with steep elevation gradients, temperature decreases quickly and is an obvious attribute to study changes in floristic composition.

Microtopography and microclimate have also been shown and predicted to be driving factors in changes of alpine species community composition (Mark et al. 2001; Moeslund et al. 2013; Smithers et al. 2019). The resultant combination of substrate types, grain sizes, aspects, and slopes in the alpine zone create diverse microhabitats for species to exist with different environmental preferences and adaptations (Dobrowski 2010; Moeslund et al. 2013). For example, the talus and rock-dominated regions near current active rock glaciers in the Sierra Nevada contain high biodiversity and offer a buffered climate for cooler, wetter adapted species (Millar et al. 2015). These microhabitats have been shown to resist warming, and they may become increasingly important as mountain refugia for biota in a warming world (Scherrer and Körner 2011).

A.



B.



Figure 3. Typical eastern Sierra Nevada topography near Mount Langley (A) and Clouddripper Peak (B). Photographs by author.

Flora

For this study and associated analyses, the term “species” was used to refer to minimum-rank taxa (Baldwin et al. 2012) and described all species, subspecies, or varieties encountered. The entire Sierra Nevada flora consists of nearly 3,500 species, subspecies, or varieties encountered (Wenk 2015) while the alpine zone above 3300 m supports nearly 600 species of vascular plant taxa (Rundel 2011; Figure 4). Ninety-seven species have elevational ranges that extend to 4000 m, while just 27 species can reach 4200 m in elevation (Rundel 2011). Growth and flowering phenologies vary with species, elevation, latitude, and snowpack but is short in duration and generally occurs between June-August (Billings and Mooney 1968; Wenk 2015). The lack of accessibility due to winter snowpack makes the alpine zone of the Sierra Nevada a relatively undisturbed environment. Invasive species are nearly non-existent, likely due to the extreme physical environment, short growing season (Rundel and Millar 2016), and limited human accessibility.

Species growth form is an important trait for survival in the alpine zone. Small plants of low stature are a hallmark of alpine vegetation (Rundel et al. 2005). Species can be divided into

growth form functional groups of herbaceous perennials, graminoid, mat/cushion, and shrub/subshrub (Rundel et al. 2005). Herbaceous perennials dominate the alpine flora of the Sierra (50%), followed by graminoids (21%), and mat/cushion species (11%; Rundel 2011). The presence of cushion plants has been shown to have a positive effect on species richness and diversity in alpine areas by acting as nurse plants and providing a buffer against deleterious microenvironmental changes (Anthelme et al. 2014; Chen et al. 2015). Alpine plants, despite their small stature, create their own microclimates and are extremely decoupled from nearby ambient air temperature (Graham et al. 2012).

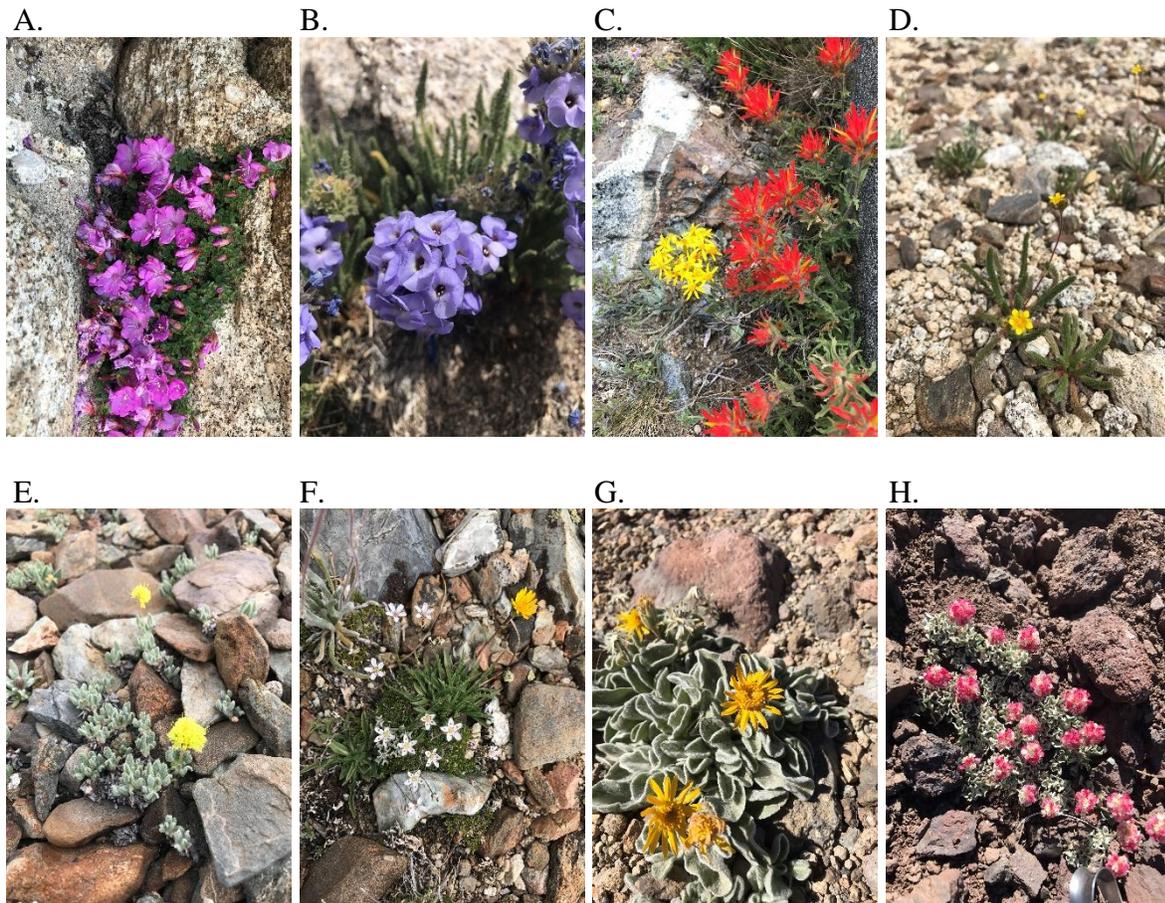


Figure 4. Alpine flora of the eastern Sierra Nevada. (A) *Epilobium obcordatum*; (B) *Polemonium eximium*; (C) *Castilleja applegatei* ssp. *pallida*, *Packera cana*; (D) *Ivesia muirii*; (E) *Eriogonum rosense*; (F) *Eremogone kingii* var. *glabrescens*, *Pyrrocoma apargioides*; (G) *Hulsea vestita* ssp. *vestita*; (H) *Eriogonum ovalifolium* var. *nivale*. Photographs by author.

Climate

Weather patterns in the Sierra result from a combination of factors, including its own topography as well as the influences of the Central Valley, Coast Ranges, and the Pacific Ocean. Characteristic of the region's Mediterranean climate, winters are generally wet and cool while summers are dry and warm (Lepley et al. 2020). Most of precipitation falls on the western side of the Sierra, as clouds release their moisture while they move up the western flank, creating a rain shadow and leaving the eastern side of the crest drier. For example, the eastern side has yearly rainfall averages from 127-381 mm, while regions on the western side can receive up to 1270 mm a year (Hill 2006). Precipitation decreases latitudinally from north to south (Storer et al. 2004) and increases with increasing elevation, mostly falling as snow (Smithers et al. 2019). Average annual precipitation ranges from 1521 mm at the summit of Leavitt to 733 mm at the summit of Langley (Table 1). Temperatures in the Sierra are significantly milder than other alpine zones in North America, due to the combination of its lower latitude range (35-40° N) and relatively close proximity to the temperature modulating Pacific Ocean (Storer et al. 2004). Nevertheless, the alpine zone of the Sierra is a distinctly harsh environment to which species have adapted over time (Körner 2003).

Above the treeline slope and aspect affect the amount of solar radiation received and are major determinants of the climatic conditions experienced by alpine vegetation (Körner 2003). Alpine species distributions are affected by multiple topographic and climatic variables, including but not limited to slope angle, aspect, substrate type, grain size, elevation, latitude, water availability, snowpack distribution, seasonal and multi-year drought, decadal weather oscillations, extreme temperatures, high wind, high UV irradiance, and species interactions (Körner 2003; Rundel and Millar 2016).

Table 1. Climate data for individual peak summit and treeline locations. Data was extracted from the PRISM Climate Group representing 30-year averages from 1981-2010, with 800 m grid size.

Peak	Coordinates (N°, W°)	Elevation (m)	Temperature °C						Annual Precip (mm)
			___Annual___		___January___		___July___		
			min	max	min	max	min	max	
Leavitt	38.2863, -119.6510	3388	-5.8	6.3	-11.6	-0.6	3.2	16.0	1521
		3047	-4.2	8.0	-9.9	0.9	4.5	18.0	1431
Gaylor	37.9188, -119.2657	3233	-5.1	7.8	-11.3	0.9	3.9	17.4	1000
		3059	-4.7	8.8	-11.3	1.7	4.6	18.6	951
Dana	37.8998, -119.2211	3775	-7.0	4.6	-12.7	-1.9	2.2	14	1302
		3051	-2.6	9.4	-8.5	2.2	6.4	19.1	1155
Mammoth	37.6308, -119.0326	3213	-3.5	8.2	-9.6	1.0	6.2	17.8	1232
		3051	-2.6	9.4	-8.5	2.2	6.4	19.1	1155
Starr	37.4291, -118.7651	3743	-7.0	5.2	-13.1	-1.1	2.1	14.4	1162
		3375	-3.9	7.0	-10.0	0.4	5.2	16.1	1105
Cloudripper	37.1494, -118.5304	3951	-8.2	3.0	-13.9	-3.0	1.2	11.7	965
		3425	-4.0	5.8	-10.1	-0.5	5.4	14.7	960
Gould	36.7797, -118.3782	3628	-6.2	5.6	-11.9	-1.1	2.6	14.8	1266
		3224	-4.4	8.2	-10.3	1.8	4.4	17.2	1040
Langley	36.5233, -118.2390	4011	-8.0	3.1	-13.8	-4.1	1.6	12.8	733
		3487	-5.9	6.7	-11.6	-0.6	2.6	16.1	627

Peak Descriptions

Across the High Sierra, eight individual peaks were surveyed with a total range of 232 km between the northern and southern peaks. From north to south they were Leavitt, Gaylor, Dana, Mammoth, Cloudripper, Starr, Gould, and Langley (Table 2). There is a difference of 1.7630° in latitude from Leavitt to Langley.

These peaks were chosen to represent the range of alpine latitudes, elevations, and profiles. Accessibility was also a criterion for inclusion in this study. Summit elevation differed at each peak with a total range of 3527-4275 m. The eight peaks surveyed had an average distance of 32 km between each peak, corresponding to an average 0.2518° change in latitude.

Table 2. Individual peak locations and survey information. Survey range on each peak differed as did the number of sites (see methods). From north to south across the eastern crest of the Sierra Nevada (232 km), treeline increased by 300 m, which corresponds to an average increase in treeline of 1.3 m/km. Total survey range including all peaks was 1037 m.

Peak	Coordinates (N°, W°)	Treeline (m)	Summit (m)	Survey Range (m)	Sites (No)	Transects (No)	Substrate
Leavitt	38.2863, -119.6510	3100	3527	3139 - 3518	7	21	Volcanic
Gaylor	37.9188, -119.2657	3170	3354	3214 - 3317	3	9	Metamorphic
Dana	37.8998, -119.2211	3180	3981	3640 - 3969	6	18	Metamorphic
Mammoth	37.6308, -119.0326	3220	3371	3240 - 3362	3	9	Volcanic
Starr	37.4291, -118.7651	3250	3916	3341 - 3617	5	15	Granitic
Cloudripper	37.1494, -118.5304	3290	4124	3523 - 3685	3	9	Granitic
Gould	36.7797, -118.3782	3340	3966	3333 - 3684	8	24	Granitic
Langley	36.5233, -118.2390	3400	4275	3641 - 4176	8	24	Granitic

Leavitt

Leavitt Peak was the northernmost peak surveyed and had the lowest summit elevation of all peaks surveyed at 3527 m. There are no mountains in the Sierra Nevada north of Leavitt that have a higher elevation. The alpine zone continues until the Lake Tahoe area, but the Sonora Pass area near Leavitt is considered the “beginning of the end” of the alpine zone of the Sierra Nevada (Storer et al. 2004). For example, just north of the Sonora Pass is Sonora Peak (3493 m), which has subshrubs present near its summit. This marks a change in alpine floristic composition as subshrubs are generally only found near the treeline in alpine communities. Leavitt is comprised of volcanic rock with a large flat summit covered in a cobble. The lowest treeline (3100 m) in the survey was located here. It was accessed via the Pacific Crest Trail from the Sonora Pass on Highway 108. Leavitt is in the Emigrant Wilderness of Stanislaus National Forest.

Gaylor

Gaylor Peak is a small nondescript peak at the eastern edge of Yosemite National Park. Its summit elevation is 3354 m. The sites surveyed were comprised of pebble made of

metamorphic rock. Gaylor was accessed via trail from the Tioga Pass on Highway 120. It straddles the boundary between Inyo National Forest and Yosemite National Park (Yosemite Wilderness).

Dana

Mount Dana is a steep mountain that rises sharply to a small summit at 3981 m. It is comprised of metamorphic rock and a large proportion of its substrate is made of boulder-size talus and massive rocks. There is broad plateau approximately halfway to its summit on its west face. It's interesting to note that a small receding glacier (Dana Glacier) occurs on its north face. Dana was accessed via trail from the Tioga Pass on Highway 108 near the entrance to Yosemite National Park. Like Gaylor Peak, it straddles the boundary between Inyo National Forest (Ansel Adams Wilderness) and Yosemite National Park (Yosemite Wilderness).

Mammoth

Mammoth Mountain is a highly trafficked peak widely known for its winter recreation at the Mammoth Mountain Ski Area. Despite such use, there are ample populations of alpine species on its summit at 3371 m, and much of the mountain is still in its natural state. It is a lava dome complex that is still active with minor recent eruptions. The substrate at its large round summit consisted of mostly pebble-size volcanic rocks. It is located within the Inyo National Forest. The peak was accessed via gondola and trail from Highway 203.

Starr

Mount Starr is a steep mountain that rises to a long, small bare crest made of granitic rock at a summit elevation of 3916 m. Its summit is mostly boulder and cobble. Starr is in the central Sierra Nevada located in the John Muir Wilderness of the Inyo National Forest, west of Little Lakes Valley. It was accessed via Mono Pass trail from Rock Creek Road.

Cloudripper

Cloudripper Peak is in the central Sierra Nevada, with a summit elevation of 4124 m. It shares a saddle with another peak, Vagabond, at 3975 m. It is in the John Muir Wilderness of the Inyo National Forest. Made of granitic rock, it sits just east of the Inconsolable Range.

Cloudripper was accessed via trail from South Lake Road.

Gould

Mount Gould rises to an elevation of 3966 m and is composed primarily of a loose granitic talus. The summit is in the center of a ridge that forms the mountain as it rises out of Onion Valley. It straddles the boundary of Kings Canyon National Park (Sequoia-Kings Canyon Wilderness) and Inyo National Forest (John Muir Wilderness). It was accessed via Kearsarge Pass trail from Onion Valley Road.

Langley

Mount Langley was the southernmost mountain surveyed with the highest summit at 4277 m. It is the seventh highest peak in the Sierra Nevada range, and the 9th highest peak in California (Hill 2006). Langley is situated 7.7 km southeast of Mount Whitney in the Cottonwood Lakes/Pass region and is considered the southern limit of the High Sierra. Langley is composed of granite and is a massive peak with a steep north face and a mostly gently sloping south face. The highest treeline in the survey (3400 m) was located here. Peak elevation decreases as you move south from Langley, until you reach the southern end of the mountain range at the Tehachapi Pass. Langley accessed from Horseshoe Meadows Road. via Cottonwood Lakes Trail to New Army Pass, ascending the west side.

METHODS

Field Surveys

To assess the alpine vegetation on each peak, transect surveys were done above the treeline at increasing elevational increments (three approximately 3 m apart) at sites where communities of at least two co-occurring species were encountered. Near peak summits at some locations, surveys were done when only one species was present, however. Treeline was defined as the upper limit of tree occurrence (Körner 2003). Surveyed sites were haphazardly chosen based on generally recognized published criteria (Mueller-Dombois and Ellenberg 1974; Godinez-Alvarez et al. 2009).

Idiosyncrasies of each peak (for example, patchy vegetation distributions, inaccessible terrain and/or snowpack, and elevational range) resulted in differing numbers of sites surveyed on each peak. Areas near lakes, ponds, streams, trails, snow, cliffs, and human disturbance (>20 m away) were avoided. Survey sites were identified with the first two letters of each peak followed by a number starting at the lowest elevation with one (for example, LE1 was site 1 on Leavitt). Three transects were used to assess the vegetation at each site. These transects were identified with a letter (for example, LE1A was the first transect sampled at site 1 on Leavitt).

The point-intercept method was used to measure species percent cover (Figure 5). Species were systematically sampled every 20 cm along 30 m transects (151 data points per transect). This method is widely used for estimating percent cover and offers a quick and efficient way to document site compositions (Godinez-Alvarez et al. 2009; Nunes et al. 2014). In addition, this amount of sampling had an appropriate amount of statistical power based on their estimated cover, small community size, and small plant size (Brady et al. 1995). All

vascular plant species located at each sampling point were recorded. Vascular plant species were identified except for grasses, sedges, and rushes, which were collectively denoted as graminoids.

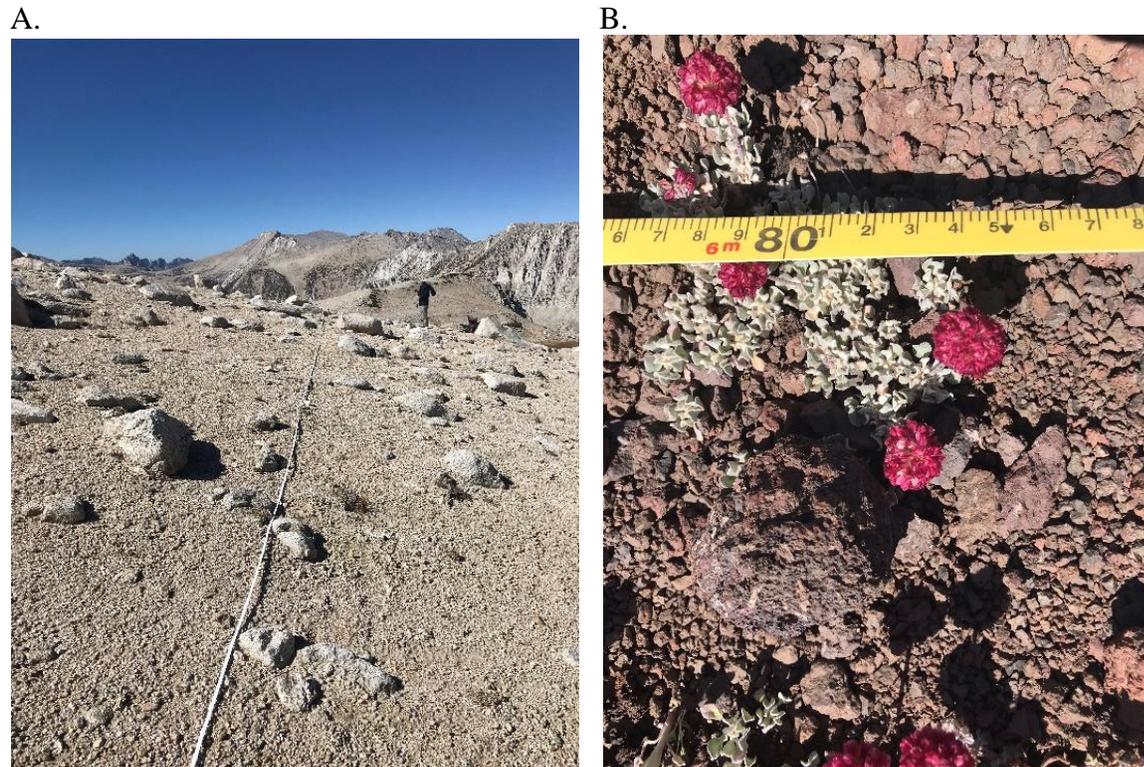


Figure 5. Point-intercept method on Starr (A). Sample data point of *Eriogonum ovalifolium* var. *nivale* on Leavitt (B).

Substrate type, substrate grain size, topographic aspect and slope, latitude, and elevation data were also collected at each site. A Garmin GPS 64st was used to determine latitude, elevation, and aspect. Slope was obtained by an Haglof C1 digital clinometer. Grain size was categorized based on the Wentworth grain size classification (Wentworth 1922) using four descriptive size classes: pebble, cobble, boulder, or mixed. Species were identified during and post-survey using a botanical species list provided by the Inyo National Forest along with the Jepson Manual (Baldwin et al. 2012), some botanical guidebooks (Munz 2003; Rose 2015;

Wenk 2015), and the calflora.org, inaturalist.org databases. Plant growth form classification was completed post-survey based on published criteria (Korner 2003; Rundel et al. 2005).

Statistical Analyses

Statistical analyses were completed using PRIMER version 7 (Clarke and Gorley 2015), Paleontological Statistics (PAST) version 4.05 software (Hammer et al. 2001), Systat version 13.1 (Systat software, San Jose, CA), and RStudio version 1.4.1106 (RStudio Team 2021). Descriptive statistical calculations and associated graphs were created using Microsoft Excel (Excel version: 18.2106.12410). Maps were created using the online service Caltopo (caltopo.com).

Percent Cover

Percent cover for each species encountered along the transects was calculated by taking the total number of positive data points on a transect and dividing that by the total possible number of data points per transect (151). A linear regression created with PAST was used to analyze percent cover with elevation (Hammer et al. 2001).

Diversity

Shannon's index values were used to quantify diversity and to compute evenness so that comparisons could be made among sites on individual peaks as well as among peaks across the mountain range (Shannon and Weaver 1949; Margurran 2004). Shannon index values can range from 0-5, while typically ranging from 1.5-3.5 (Ortiz-Burgos 2015). A high value indicates that there is a diverse and equally distributed community, while lower values represent communities of lower diversity and more dominance. A value of 0 would indicate that there was just one species in sample, or no diversity. A linear regression was used to analyze diversity with elevation using PAST (Hammer et al. 2001).

Beta-diversity is a common method of comparing compositional diversity across an environmental gradient. It is the ratio of total regional diversity (gamma diversity) and mean local diversity (alpha diversity; Whittaker 1960; Anderson et al. 2011). Alpha, beta, and gamma diversity were calculated at three different scales to show the differences in species richness in individual sites, among sites on individual peaks, and among peaks across the entire mountain range. Within site beta-diversity was calculated by taking the total species richness of that site divided by the mean species richness of all 3 transects in each site (Whittaker 1960). Within peak beta-diversity was calculated by taking the total species richness of that peak divided by the mean number of species richness at each site on the peak. Among mountain range beta-diversity was calculated by taking the total species richness of the entire mountain range divided by the mean species richness of each peak.

Evenness and Dominance

Whittaker plots were created in RStudio version 1.4.1106 (RStudio Team 2021) to compare relative species abundance (Whittaker 1965). These rank order abundance curves have the advantage of more clearly illustrating patterns and information that can be poorly displayed and understood on individual graphs (Whittaker 1956; Margurran 2004). Plots can be individually analyzed or compared, and show relative abundance proportions, species richness, and changes in evenness. Steep plots or lines signify communities with high dominance and low evenness, while shallow lines signify higher evenness (Margurran 2004). Evenness is a measure of how similar species are in their abundances. For example, a community where species have equal abundances will have a high evenness (Margurran 2004). The counter to evenness is species dominance, where one or a few species constitute the majority of abundance in a community. High diversity is equated with high evenness and low dominance.

Dissimilarity and Similarity

Although Whittaker's beta-diversity shows how species richness changes among sites, it does not address the how species composition changes (Whittaker 1960). Thus, Bray-Curtis dissimilarity values were used to show differences in site floristic composition within individual peaks and among peaks across the entire mountain range (Odum 1950; Bray and Curtis 1957; Anderson et al. 2011; Smithers et al. 2019). Bray-Curtis dissimilarity values are between 0 and 1, where 1 means the sites share all species and have the same composition. In contrast, a value of 0 indicates that the sites do not share any species and are completely dissimilar.

Ordinations with Non-Metric Multidimensional Scaling (NMDS) were performed on the Bray-Curtis dissimilarity matrix in Euclidian distance measures to visualize all sites across the entire mountain range based on their dissimilarity using PAST (Hammer et al. 2001; Legendre and Gallagher 2001; ter Braak and Smilauer 2014). A cluster analysis of the Bray-Curtis dissimilarity matrix was performed using the hierarchical clustering function in PAST with the unweighted pair-group average algorithm (cophenetic correlation=90.5%) (Clarke & Warwick 2001). Ordinations with NMDS were also used to better illustrate the dissimilarity among sites on individual peaks. Because of the distinct clustering into two groups visualized from the previous ordinations, further ordinations using NMDS on the Bray-Curtis dissimilarity matrix were performed on elevation-designated groups named near-summit (upper) and near-treeline (lower).

To determine whether there were significant differences in the dissimilarity of species assemblages on individual peaks and among peaks along the mountain range, Analysis of Similarity (ANOSIM) was performed. ANOSIM is a non-parametric permutation method which

is applied to the rank dissimilarity matrix that is regarded as analogous to Analysis of Variance (ANOVA; Clark 1993).

Communities may be identical in terms of richness and evenness but differ in taxonomic diversity of their species (Magurran 2004). To understand which species were contributing the most to the dissimilarity (and similarity) among sites on individual peaks and across the mountain range, a similarity percentage (SIMPER) analysis was used in PAST (Hammer et al. 2001). SIMPER is a method for assessing which taxa are primarily responsible for observed dissimilarities or similarities between groups of samples (Clark 1993).

To determine which predictor variables were primarily responsible for the species assemblages among sites based on the Bray-Curtis dissimilarity matrix, biota-environment (BIOENV) and distance-based linear models (DISTLM) procedures were done in PRIMER (Clark & Ainsworth 1993; Clarke & Gorley 2015). DISTLM allows for analysis of both categorical and continuous variables by expanding categorical variables into a binary set of variables before analysis. Separate matrices were built for BIOENV and DISTLM analysis for the entire mountain range, each individual peak, and by groups of near-treeline (lower) and near-summit (upper) sites.

RESULTS

Adequacy of Sampling

Site survey completeness was analyzed using the sample-based rarefaction (Mao's tau) function in PAST to determine if there were enough samples collected to appropriately draw conclusions from the data (Colwell et al. 2004). Also known as a species accumulation curve, this method depicts the expected number of observed species as a function of sampling effort and allows a researcher to evaluate the benefit of additional sampling (Deng et al. 2015). For my data, the curve approaches an asymptote (Figure 6). This indicates that most species in survey sites had been sampled, and that it was appropriate to proceed with data analysis.

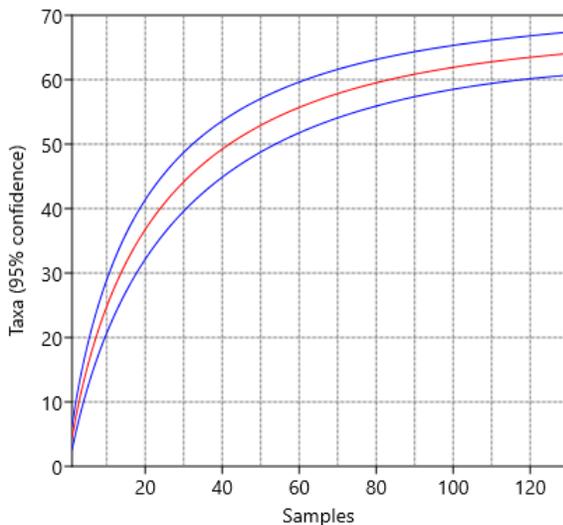


Figure 6. Species accumulation sample-based rarefaction curve (Mao's tau; red line) with 95% confidence intervals indicated by blue lines. The curve approaches an asymptote which indicates that most species in survey sites were sampled.

Richness and Abundance

Across the Sierra Nevada a total of 64 species were observed (including all graminoids recorded as one "species") representing 48 genera and 26 families (Appendix). Individual peak

species richnesses ranged from 7 to 23 species, while individual site species richnesses ranged from 2 to 13 (Table 3). Sites with the highest richness were on the central Sierran peaks of Cloudripper and Starr. The highest individual site abundances were on Leavitt (76) and Gaylor (68), and the lowest individual site abundances were on Dana (7) and Langley (5). Across the Sierra Nevada abundant species included *Eriogonum incanum*, *Eriogonum ovalifolium* var. *nivale*, *Polemonium eximium*, and graminoids. It was unlikely that grouping graminoids had a measurable effect because they did not have more than a few species per peak, at most, and occurrences were fairly constant across all sites.

Table 3. Individual peak richness, range of site species richness, and range of percent cover per peak. Endemic and rare species are notated. CA=Endemic to California. SN=Endemic to the Sierra Nevada. R=Classified as rare in California.

Peak	Peak Richness	Site Richness	Percent Cover	Endemic/Rare Species
Leavitt	23	3-10	17-53%	<i>Polemonium eximium</i> (SN)
Gaylor	8	6-8	43-51%	
Dana	14	4-5	4-21%	<i>Astragalus kentrophyta</i> var. <i>danaus</i> (CA; R) <i>Draba lemmonii</i> (SN) <i>Polemonium eximium</i> (SN)
Mammoth	7	2-5	13-20%	<i>Hulsea vestita</i> ssp. <i>vestita</i> (CA)
Starr	23	3-11	15-31%	<i>Ivesia muirii</i> (SN)
Cloudripper	18	6-13	16-18%	<i>Castilleja applegatei</i> ssp. <i>pallida</i> (CA) <i>Ivesia muirii</i> (SN) <i>Aquilegia pubescens</i> (SN) <i>Minuartia obtusiloba</i> (CA; R)
Gould	17	3-8	11-25%	<i>Phyllodoce breweri</i> (CA) <i>Polemonium eximium</i> (SN)
Langley	15	2-8	4-25%	<i>Draba breweri</i> (CA) <i>Primula suffrutescens</i> (CA) <i>Ivesia pygmaea</i> (SN) <i>Polemonium eximium</i> (SN) <i>Phlox dispersa</i> (SN; R)

Six species endemic to California were observed across the mountain range (*Astragalus kentrophyta* var. *danaus*, *Castilleja applegatei* ssp. *pallida*, *Draba breweri*, *Hulsea vestita* ssp. *vestita*, *Phyllodoce breweri*, *Primula suffrutescens*). Six species endemic to the Sierra Nevada were found (*Aquilegia pubescens*, *Draba lemmonii*, *Ivesia muirii*, *Ivesia pygmaea*, *Phlox dispersa*, *P. eximium*), along with three species classified as rare in California were documented (*Astragalus kentrophyta* var. *danaus*, *Minuartia obtusiloba*, *Phlox dispersa*; Table 3). Langley, the most southern peak, had the highest proportion (33%) of endemic species (5 species; 13% endemic to CA and 20% endemic to the Sierra Nevada), while Leavitt, the most northern peak, had the lowest proportion (4%) of endemic species (1 species; Figure 7).

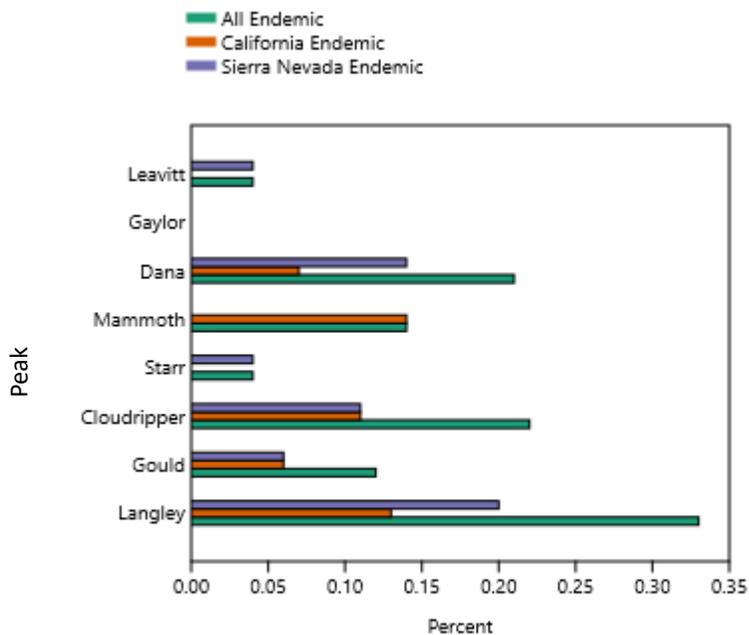


Figure 7. Proportions of endemic species across the mountain range with percent on the x-axis. Peaks are listed from top to bottom in order of latitude north-south.

Eriogonum was the largest genus observed with the most species found (*E. incanum*, *E. lobbii*, *E. ovalifolium* var. *nivale*, and *E. rosense*). The following genera each had three species:

Draba (*D. breweri*, *D. lemmonii*, and *D. oligosperma*), *Erigeron* (*E. algidus*, *E. compositus*, and *E. pygmaeus*), *Ivesia* (*I. lycopodioides*, *I. muirii*, and *I. pygmaea*), and *Phlox* (*P. condensata*, *P. diffusa*, and *P. dispersa*). Of all the species sampled 52% (33 out of 63) did not have any other members of their genus observed. The most common families present were Asteraceae (19 species), Polemoniaceae (6 species), Brassicaceae (5 species), and Polygonaceae (5 species; Appendix).

Total percent cover ranged from 4%-53% in sites across the entire mountain range (Table 3). Percent cover on Leavitt averaged 28.6% (range: 17-53%) while percent cover on Langley averaged just 11.9% (range: 4-25%) equating to a 16.7% decrease in average percent cover across the entire mountain range latitudinally from north to south ($R^2=0.16$, $P<0.0001$; Figure 8). Percent cover also decreased with elevation ($R^2=0.53$, $P<0.0001$) across the mountain range as shown with a linear regression (Figure 9).

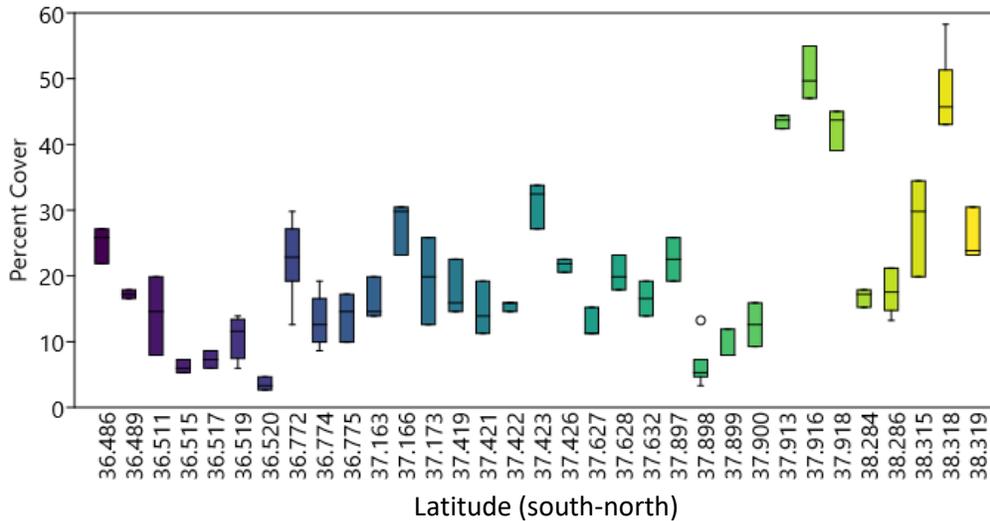


Figure 8. Box plot showing overall percent cover decreased with latitudinal decrease (right-left) along the x-axis ($R^2=0.16$, $P<0.0001$).

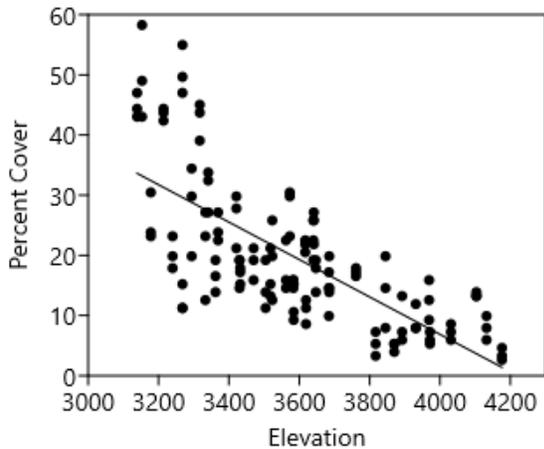
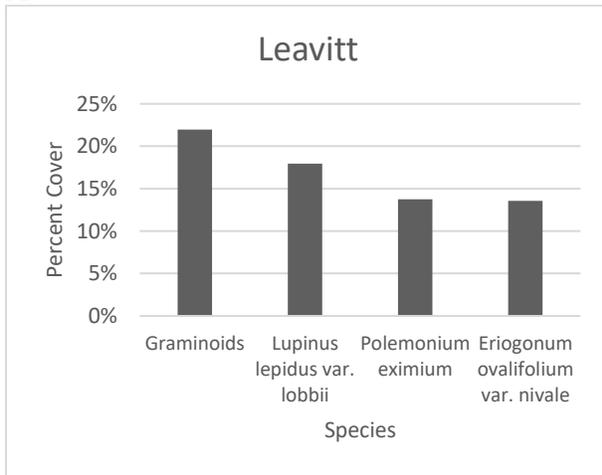


Figure 9. Linear regression ($R^2=0.53$, $P<0.0001$) showing percent cover decrease with elevational increase across the Sierra Nevada.

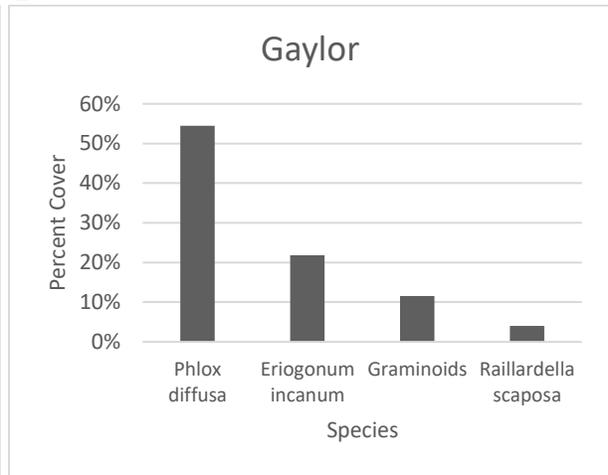
Dominance and Evenness

Individual peaks had distinct species assemblages and species dominance when compared across the mountain range (Figure 10). Graminoids were widespread across the mountain range and occurred in 107 out of 129 of the transects (83%). They constituted the most dominant taxon on Leavitt, Starr, and Gould, and were the second most dominant proportion on Dana and Cloudripper. The next most dominant species per peak were as follows: Leavitt (*Lupinus lepidus* var. *lobbii*), Gaylor (*P. diffusa*), Dana (*P. eximium*), Mammoth (*Phacelia hastata* var. *compacta*), Starr (*E. incanum*), Cloudripper (*E. rosense*), Gould (*P. eximium*), and Langley (*E. ovalifolium* var. *nivale*) (Figure 10). Graminoids as a group and Eriogonum (*E. ovalifolium* var. *nivale*, *E. lobbii*, and *E. incanum*) were consistently dominant on all peaks. *P. eximium* was among the dominant species on four peaks.

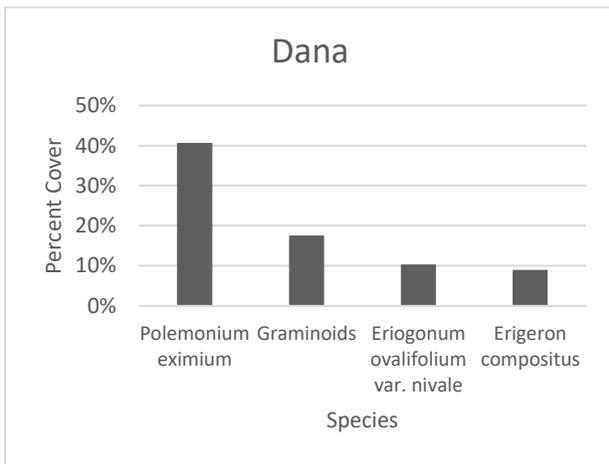
A.



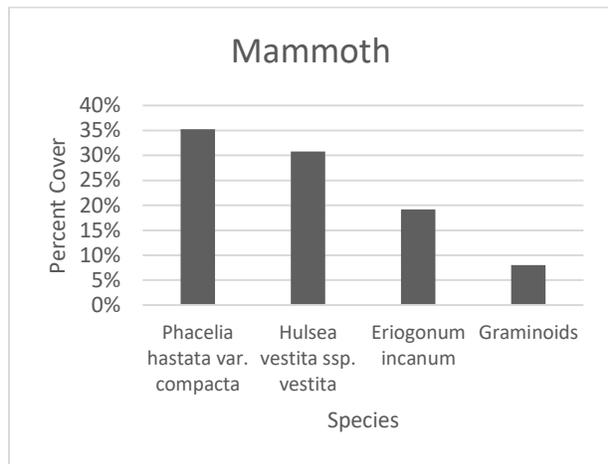
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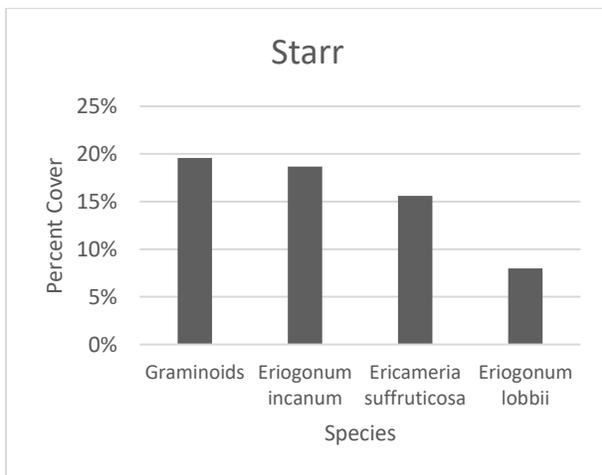
C.



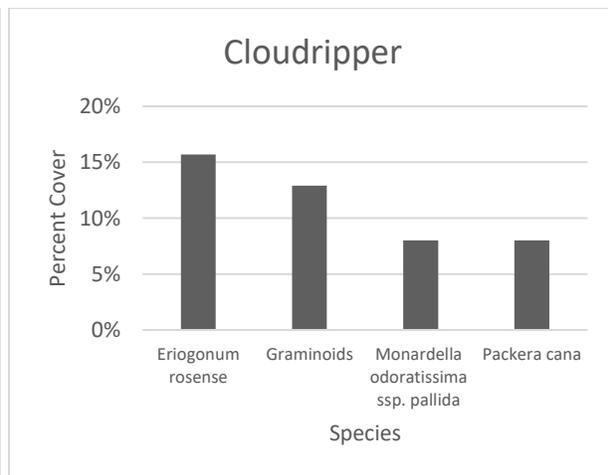
D.



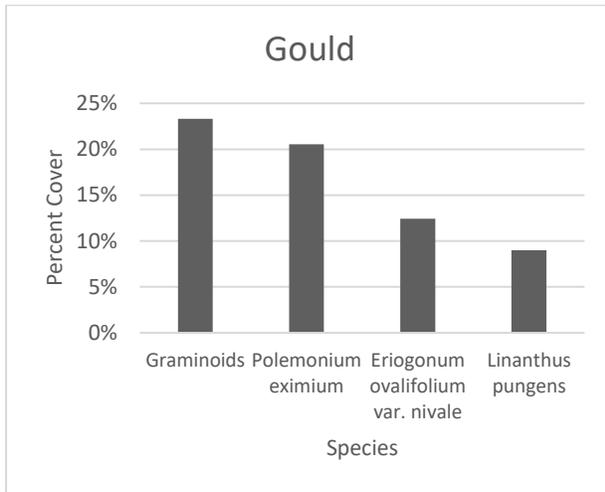
E.



F.



G.



H.

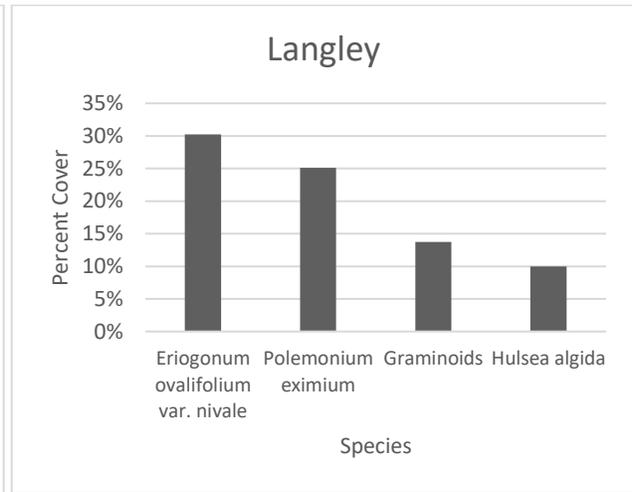
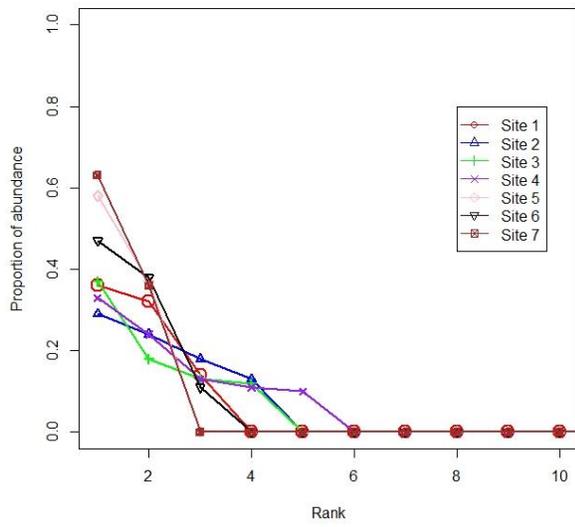


Figure 10. The proportions of the most dominant species, as indicated by percent cover, on each individual peak.

Whittaker plots for each mountain peak (Figure 11) indicated that sites at the higher elevations (near-summit) were less even and had decreased species richness than sites at lower elevations (near-treeline), except for Cloudripper. However, this may reflect a sampling anomaly at Cloudripper because the summit of Cloudripper was inaccessible during data collection, hence, the upper portion of that peak was not surveyed. When comparing the Whittaker plots, communities that had more than 4 species in each site have high evenness (near-treeline sites), while having fewer than 3 species per site indicated low evenness and high dominance (which correspond to the near-summit sites). These graphs illustrate that, across the mountain range, as elevation increased on individual peaks, both richness and evenness declined while a few species increased in dominance.

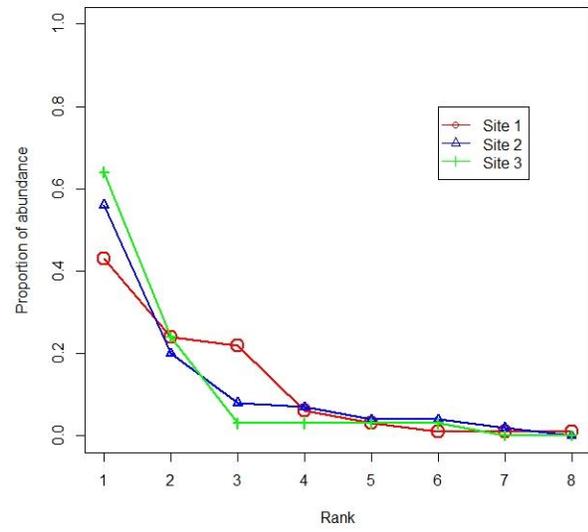
A.

Leavitt



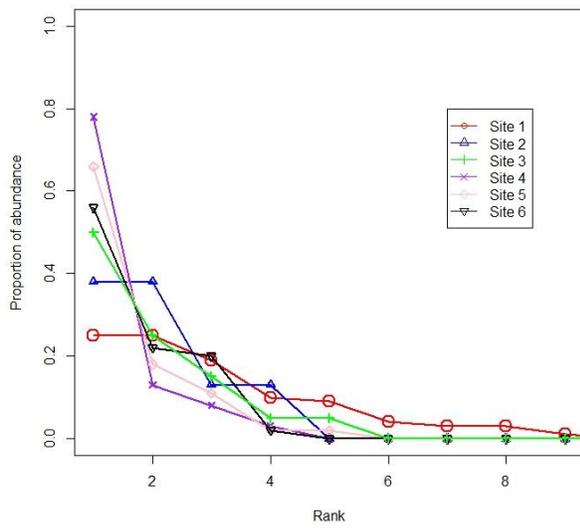
B.

Gaylor



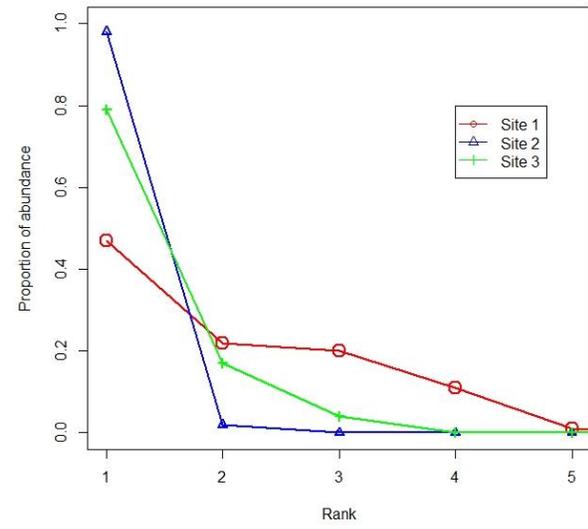
C.

Dana

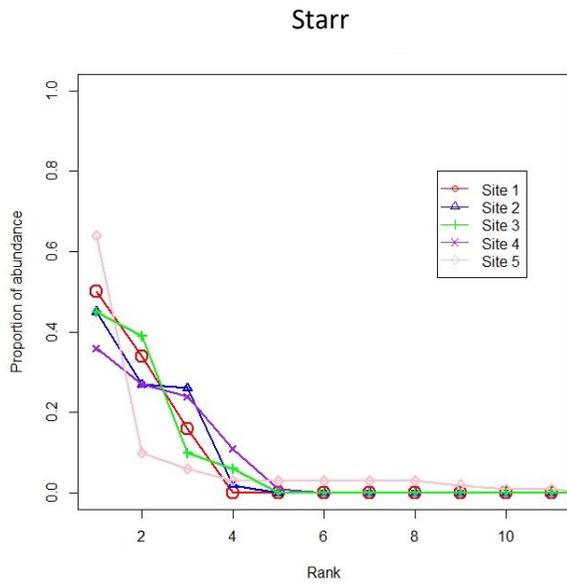


D.

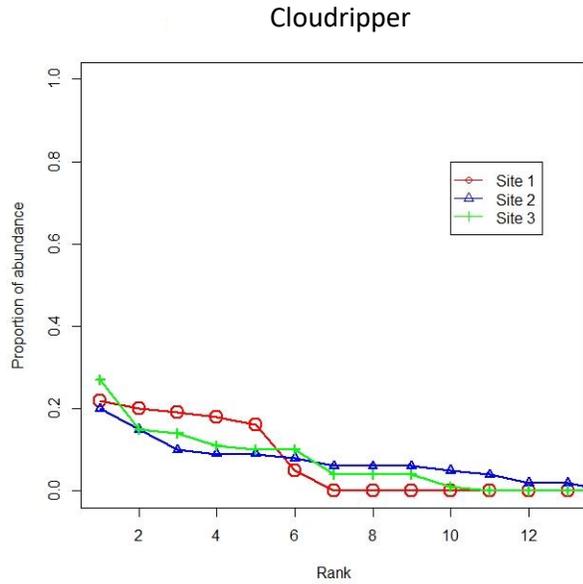
Mammoth



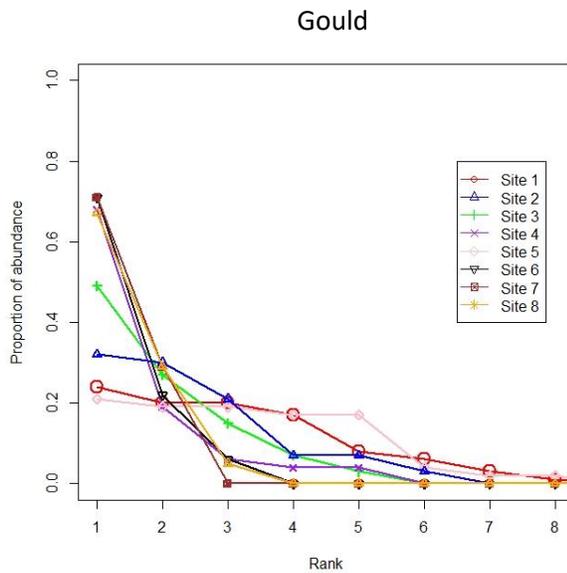
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G.



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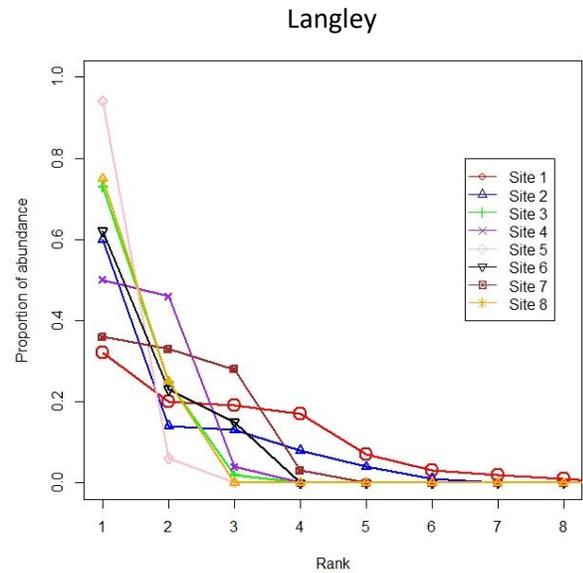


Figure 11. Whittaker plots for each peak showing the relative abundance of each species in rank order from most to least abundant. Each line represents a different site on each mountain. Site numbers increase with elevation on each peak (e.g., 1 is near tree line; 8 is near the summit).

Diversity

Diversity, as indicated by the Shannon Index, declined overall with increased elevation ($R^2=0.14$, $P<0.0001$; Figure 12) and varied widely among sites (0-2.2) but with no continuous pattern across latitude (Figure 13). Cloudripper had the highest diversity and Gaylor had the least diversity (Figure 13). Diversity did not vary with substrate and sites with mixed-size substrates contained high diversity, while sites with boulder substrates had the least diversity (Figure 13). Sites facing north and northwest had the highest diversity, while sites facing south, southwest, and west had the least diversity (Figure 13).

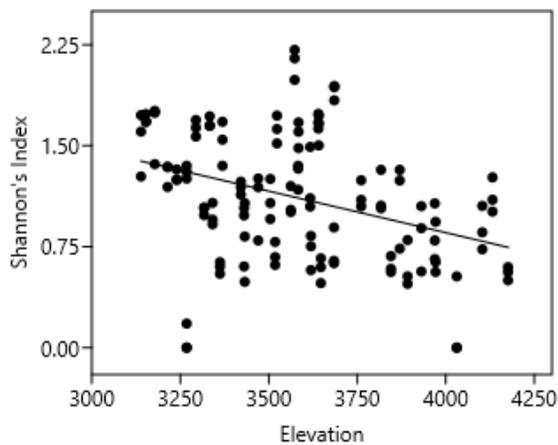
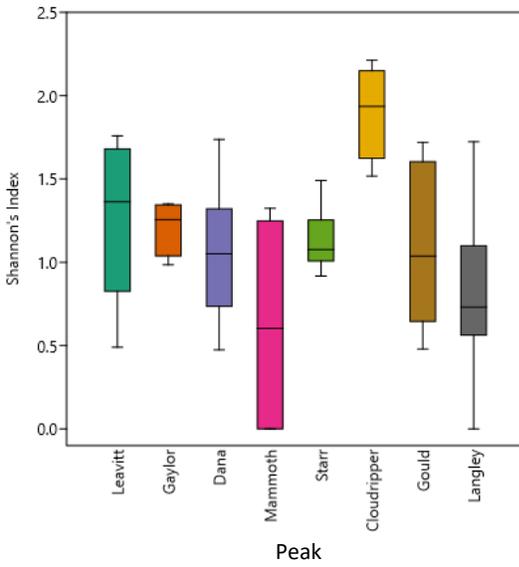
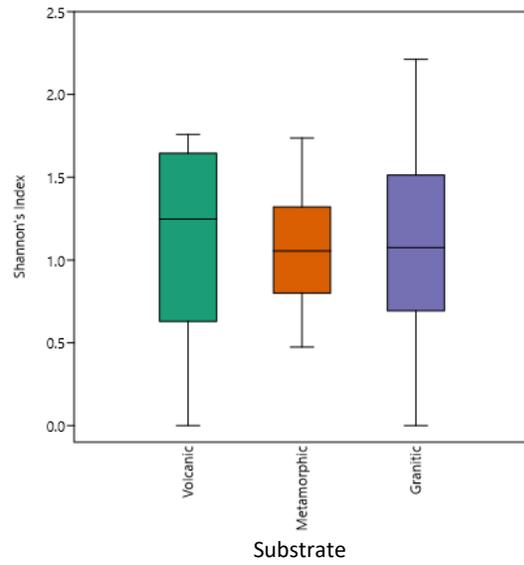


Figure 12. Linear regression ($R^2=0.14$, $P<0.0001$) showing overall decrease in diversity with elevational increase including all sites across the mountain range.

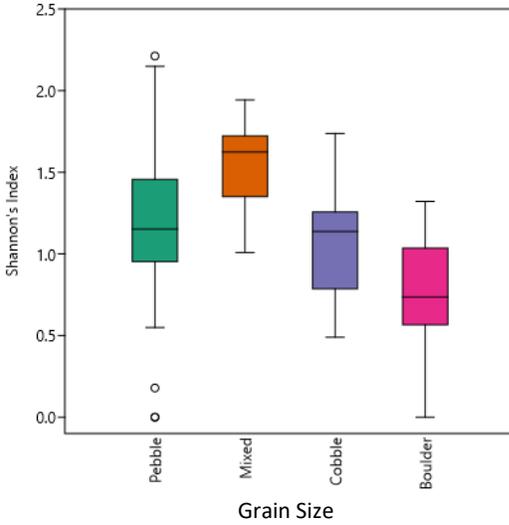
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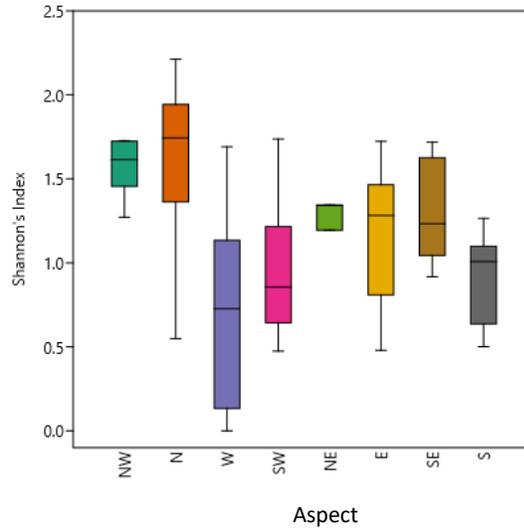


Figure 13. Box plots of Shannon's diversity index related to: (A) peak (latitude decrease left-right); (B) substrate; (C) grain size; and (D) aspect.

Individual peaks across the Sierra Nevada had significantly lower within site beta-diversity (mean=1.24, SD=0.16) compared to between site beta-diversity (mean=3.73, SD=2.02)

using a two-sample t-test (Welch, two-tailed; $t=8.06$, $df=42.52$, $P<0.0001$; Figure 14). When looking at the beta-diversity between sites on individual peaks with elevational increase, there was a greater change of beta-diversity in near-summit sites, except for Starr and Cloudripper, which had a larger change of beta-diversity in the near-treeline sites (Figure 14).

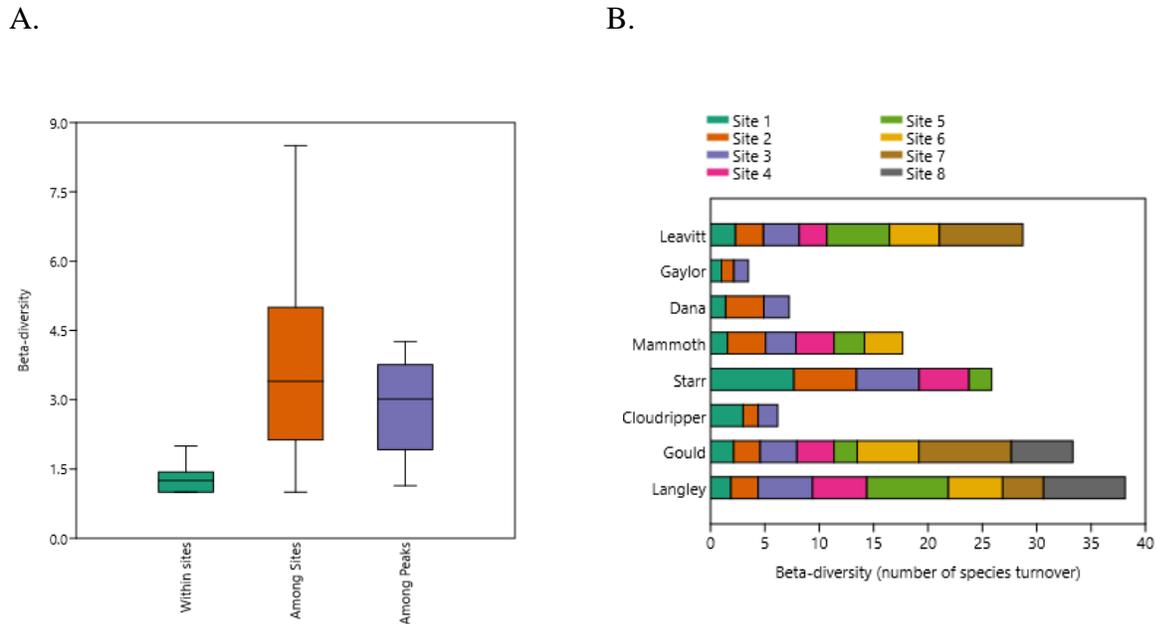


Figure 14. (A) Box plots comparing beta-diversity within sites, among sites on individual peaks, and among peaks across the mountain range. (B) Beta-diversity change (species turnover) on individual peaks is shown (sites 1-8 from left-right along the x-axis). The y-axis shows peaks in order of latitude (north-south top to bottom).

Dissimilarity and Similarity

NMDS based on a Bray-Curtis dissimilarity matrix showed that vegetation at sites across the mountain range were clearly divided into two groups separated by elevation (one-way ANOSIM: $R=0.95$, $P=0.0001$; $stress=0.11$; Figure 15). A cluster analysis of the Bray-Curtis dissimilarity matrix using the hierarchical clustering function in PAST with the unweighted pair-group average algorithm (cophenetic correlation=90.5%) provided further evidence of a strong

dissimilarity between upper and lower elevation groups of sites across the entire mountain range (Clarke & Warwick 2001; Figure 16). Sites were grouped into upper (near-summit) and lower (near-treeline) categories corresponding to elevation ranges between 3512-4176 m (near-summit), and between 3139-3845 m (near-treeline). There was an overlap of 333 m between groups in the elevational range of 3512-3845 m which corresponds to the approximate increase in treeline (300 m) between Leavitt and Langley.

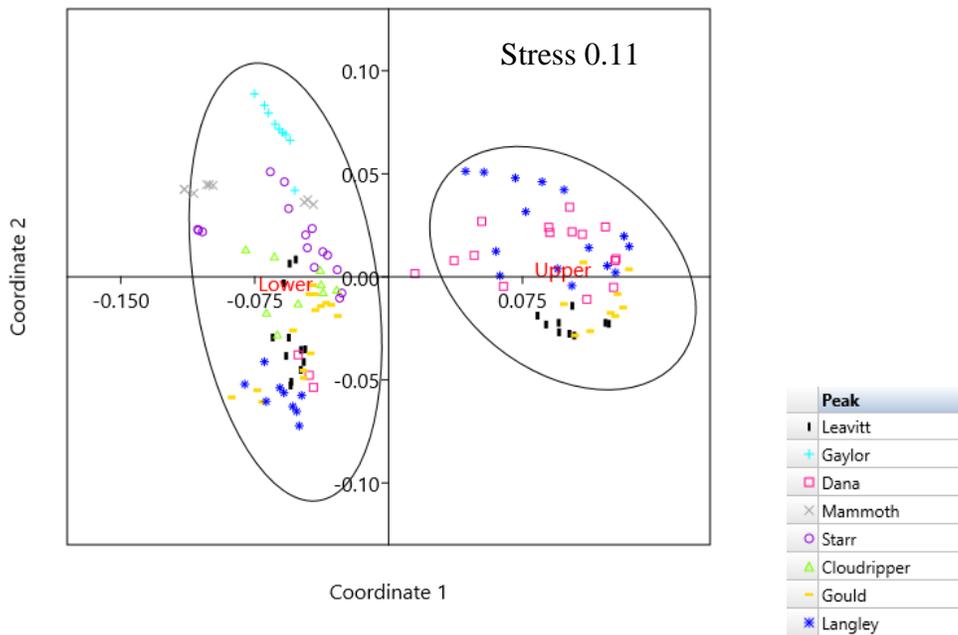


Figure 15. NMDS with 95% CI of all sites across the mountain range using the Bray-Curtis dissimilarity matrix. Two distinct clusters emerge based on near-summit (upper) and near-treeline (lower) elevational differences (one-way ANOSIM: $R=0.95$, $P=0.0001$).

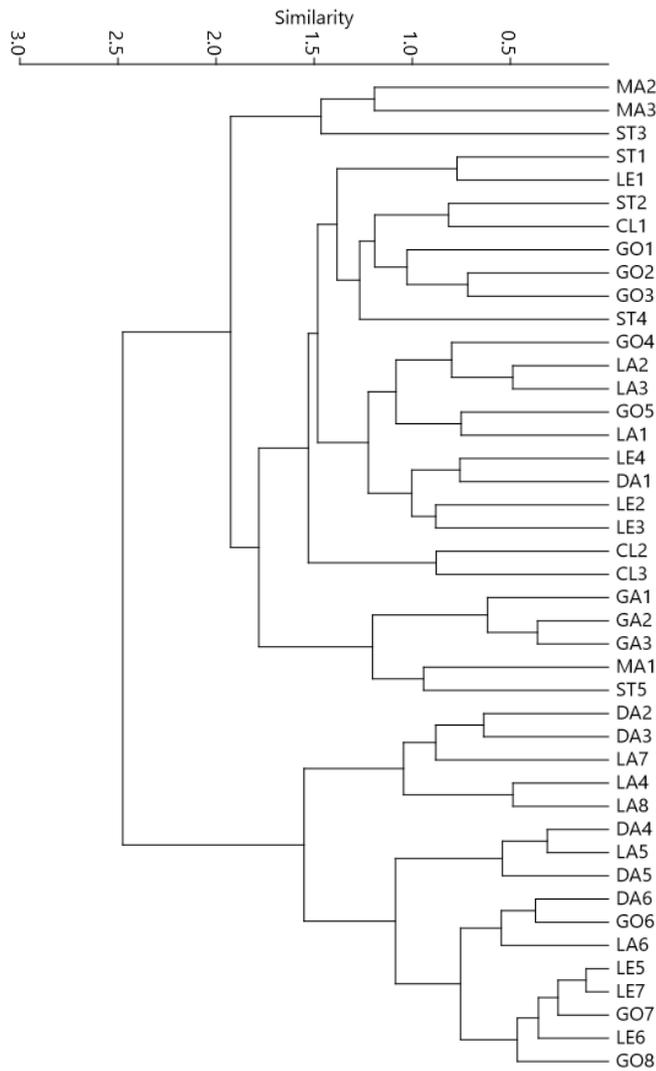


Figure 16. Hierarchical clustering dendrogram using pair-group algorithm in PAST with the Bray-Curtis dissimilarity matrix. Two groups emerge corresponding to differences in elevation (designated near-treeline and near-summit) across the mountain range.

A NMDS plot of the lower elevation near-treeline group of sites showed that the plant communities on individual peaks were significantly dissimilar from each other (one-way ANOSIM: $R=0.62$, $P=0.0001$) with the exception of Leavitt and Dana ($R=0.04$, $P=0.3481$) and Gould and Dana ($R=0.16$, $P=0.0841$). Gaylor was completely dissimilar from Dana, Cloudripper, and Langley ($R=1$, $P<0.004$). Across axis 1 individual peaks aligned with latitude from Gaylor in the north to Langley in the south, with the exception of Leavitt and Dana (stress=0.12; Figure 17). This suggested greater similarity in near-treeline vegetational composition between neighboring peaks than distant peaks along the latitudinal gradient.

A NMDS plot of the near-summit upper elevation group of sites also showed that individual peaks were significantly dissimilar from each other (one-way ANOSIM: $R=0.30$, $P=0.0001$). Leavitt and Langley had the highest dissimilarity ($R=0.54$, $P=0.0004$), while Dana and Langley had the least dissimilarity ($R=0.13$, $P=0.0296$; Figure 18). When individual sites were compared across the mountain range they were distinct in composition and strongly dissimilar from each other (one-way ANOSIM: $R=0.94$, $P=0.0001$; Table 4; Figure 19).

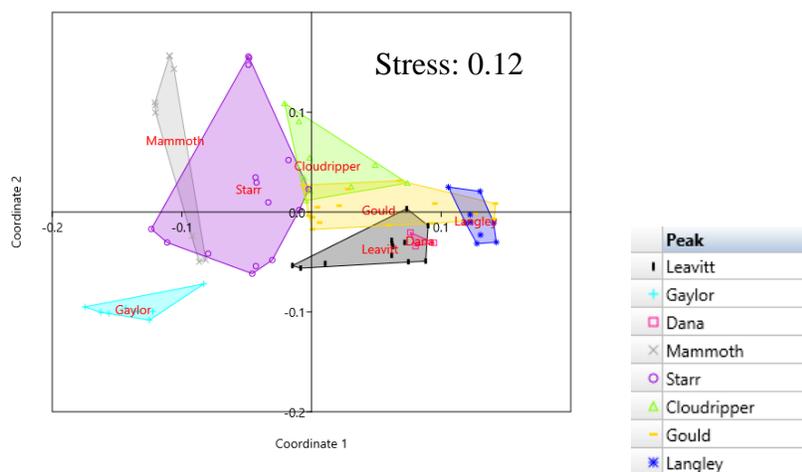


Figure 17. NMDS of the near-treeline group of sites (3139-3845 m) across the mountain range using the Bray-Curtis dissimilarity matrix. Colored convex hulls group sites on eight individual peaks.

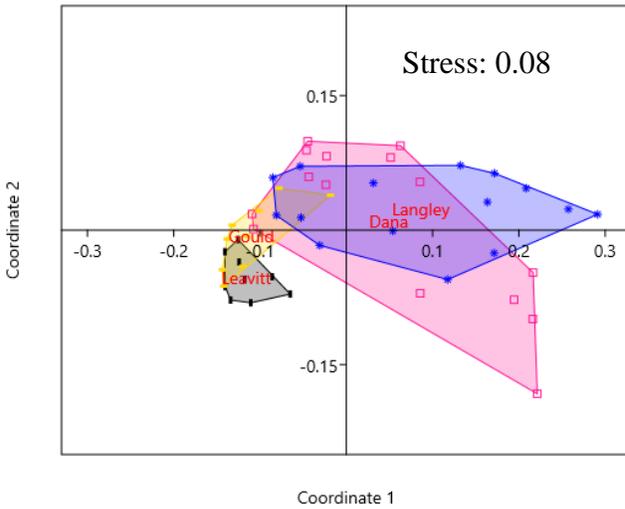


Figure 18. NMDS of the near-summit group of sites (3512-4176 m) across the mountain range using the Bray-Curtis dissimilarity matrix. Colored convex hulls group sites on four individual peaks.

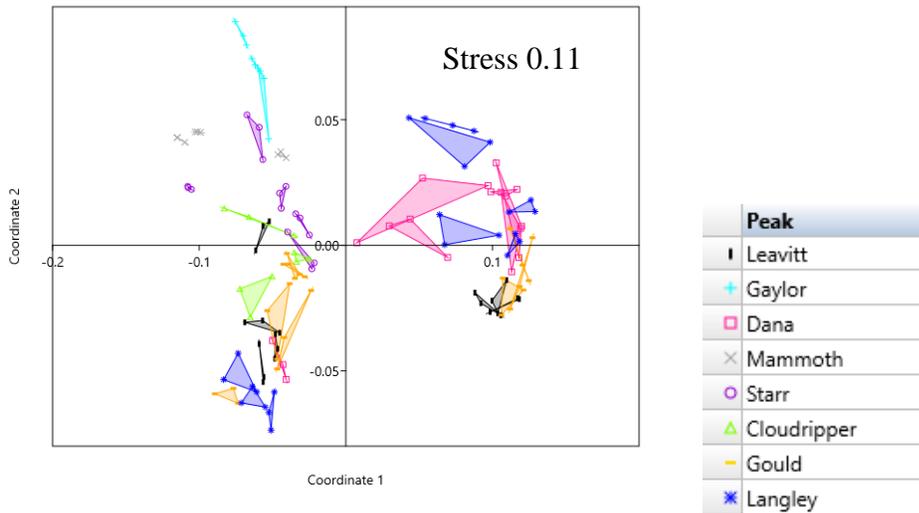


Figure 19. NMDS of individual sites across the mountain range using the Bray-Curtis dissimilarity matrix. Color represents individual peaks. Each single convex hull represents individual sites with three transects in each.

Separate ANOSIM's and SIMPER's were created for each individual peak, and for comparing peaks across the mountain range. The species composition of sites at each peak

differed significantly. Vegetation dissimilarity averaged 68.9% and varied from 24.8 to 90.9%, with Gaylor ($R=0.56$, $P=0.0039$) and Starr ($R=1$, $P=0.0001$) exhibiting the greatest difference. When compared together there were also significant differences among the peaks across the mountain range (83.2% dissimilarity), although they had a lower R-value ($R=0.29$, $P=0.0001$) than within peak R-values, indicating a stronger dissimilarity among sites on individual peaks than among all sites across all peaks.

Near-summit sites across the entire mountain range had an average dissimilarity of 34.4% ($R=0.30$, $P=0.0001$) while the near-treeline sites across the mountain range had and averaged dissimilarity of 66.0% ($R=0.62$, $P=0.0001$). Across the Sierra Nevada, near-treeline sites were nearly twice as dissimilar from each other as the near-summit sites and when comparing these upper-lower groups they had a 91.3% dissimilarity ($R=0.95$, $P=0.0001$; Table 4).

Table 4. One-way ANOSIM and SIMPER results based on the Bray-Curtis dissimilarity matrix.

Peak	R-value	P-value	SIMPER (% dissim)
Leavitt	0.8634	0.0001	68.5
Gaylor	0.5638	0.0039	24.8
Dana	0.6708	0.0004	62.1
Mammoth	1.0	0.0043	85.0
Starr	1.0	0.0001	90.9
Cloudripper	0.9835	0.0038	75.0
Gould	0.8862	0.0001	73.9
Langley	0.9054	0.0001	71.0
Mountain Range			
All peaks	0.2942	0.0001	83.2
Near-summit sites	0.3020	0.0001	34.4
Near-treeline sites	0.6191	0.0001	66.0
Between treeline-summit	0.9536	0.0001	91.3
Among all sites	0.9436	0.0001	82.8

On average, 2.5 species were responsible for $\leq 50\%$ of the dissimilarity among sites on individual peaks (range 1-5 species) and an average of 9 species were, on average, responsible

for $\leq 90\%$ of the dissimilarity on individual peaks (range 5-13 species). *P. eximium* was a large contributor to the dissimilarity on four peaks (Leavitt, Dana, Gould, and Langley). *E. ovalifolium* was largely responsible for the dissimilarity on three peaks (Leavitt, Gould, and Langley), while *E. incanum* contributed to dissimilarity on both Gaylor and Starr. Graminoids as a group were shown to be a large contributors to the community dissimilarity shown on Dana, Starr, Gould, and Langley (Table 5).

Five peaks had unique species only found on that particular peak, contributing to $\leq 50\%$ of the dissimilarity among sites surveyed: Leavitt (*L. lepidus* var. *lobbii*, 14.7%); Gaylor (*P. diffusa*, 29.0%); Mammoth (*P. hastata* var. *compacta*, 31.9%); Starr (*E. suffruticosa*, 14.2%); and Cloudripper (*E. rosense*, 13.2%). Notably Cloudripper did not share species that contributed to 50% or less of the dissimilarity with any other peak, and it had the highest number of species (5) contributing to $\leq 50\%$ of its dissimilarity (*E. rosense*, *M. odoratissima*, *P. cana*, *C. applegatei* ssp. *pallida*, and *E. algidus*; Table 5)

Four individual peaks had distinctly dissimilar groups of near-treeline and near-summit sites (Leavitt, Dana, Gould, and Langley). There were fewer total species per peak found in the near-summit sites (average 5.5, range 4-8) compared to the near-treeline sites (average 14, range 9-20). Leavitt's near-summit sites had three unique species and shared three species with its near-treeline sites; Dana's near-summit sites had five unique species and shared three species with its near-treeline sites; Gould's near-summit sites had two unique species and shared two species with its near-treeline sites; Langley's near-summit sites had three unique species and shared just one species with its near-treeline sites. All four near-summit regions of individual peaks were heavily dominated by *P. eximium* (N-S: 55.5%, 59.6%, 69.8%, and 62.1% cover) and graminoids (N-S: 36.9%, 17.6%, 27.0%, and 13.8% cover). The two northern peaks had more

species in the near-summit regions (Leavitt, 6; Dana, 8) than the two southern peaks, Gould, and Langley (4 each).

Table 5. (A-H) Species contributing to dissimilarity in community vegetation of each peak from the SIMPER function in PAST based on a Bray-Curtis dissimilarity matrix. Columns show species relative percent cover and percent contribution to dissimilarity among all sites on individual peaks, and between elevation-based groups of near-treeline and near-summit sites for each individual peak. Peaks where all sites were within the near-treeline elevation group are shown under the ‘all sites’ column only.

%Cover=Percentage cover, %Contr=Percentage contribution to dissimilarity. CA=Endemic to California. SN=Endemic to the Sierra Nevada. R=Classified as rare in California.

A.

Leavitt	All Sites		Near-treeline 3139-3294 m		Near-summit 3512-3518 m	
	%Cover	%Contr	%Cover	%Contr	%Cover	%Contr
Graminoids	22.0	8.8	17.8	9.3	36.9	26.6
<i>Lupinus lepidus</i> var. <i>lobbii</i>	18.0	14.7	20.4	19.0		
<i>Polemonium eximium</i> (SN)	13.8	17.2			55.5	41.2
<i>Eriogonum ovalifolium</i> var. <i>nivale</i>	13.6	14.5	18.8	13.4		
<i>Ivesia lycopodioides</i>	7.1	9.9	9.9	11.5		
<i>Ericameria suffruticosa</i>	6.8	8.7	9.5	13.9		
<i>Penstemon heterodoxus</i> var. <i>heterodoxus</i>	6.3	7.3	8.8	9.7		
<i>Solidago multirada</i>	1.7	2.6	2.3	3.8		
<i>Erigeron algidus</i>	1.6	2.7	2.2	3.9		
<i>Astragalus whitneyi</i> var. <i>whitneyi</i>	1.4	2.2	1.9	3.2		
<i>Ericameria discoidea</i>	1.2	2.0	1.6	2.8		
<i>Packera werneriiifolia</i>	1.0	1.8			3.8	17.4
<i>Achillea millefolium</i>	1.5	1.7	2.0	2.6		
<i>Arnica mollis</i>	0.8	1.0	1.2	1.7		
<i>Phlox diffusa</i>	0.8	1.1	1.2	1.7		
<i>Eriogonum incanum</i>	0.6	1.0	0.4	0.6	1.3	6.2
<i>Cymopterus cinerarius</i>	0.5	0.9			2.1	6.5
<i>Chaenactis alpigena</i>	0.4	0.6	0.6	0.9		
<i>Calyptridium umbellatum</i>	0.4	0.6	0.4	0.6	0.4	2.1
<i>Phacelia hastata</i> var. <i>compacta</i>	0.3	0.4	0.4	0.6		
<i>Linum lewisii</i> var. <i>lewisii</i>	0.1	0.2	0.1	0.2		
<i>Erysimum perenne</i>	0.1	0.2	0.1	0.2		
<i>Eriogonum lobbii</i>	0.1	0.1	0.1	0.2		

B.

Gaylor	All Sites 3214-3317 m	
	%Cover	%Contr
<i>Phlox diffusa</i>	54.5	29.0
<i>Eriogonum incanum</i>	21.8	15.6
Graminoids	11.5	27.0
<i>Raillardella scaposa</i>	4.4	11.9
<i>Calyptidium umbellatum</i>	2.3	5.2
<i>Penstemon heterodoxus</i> var. <i>heterodoxus</i>	2.6	5.2
<i>Lupinus lepidus</i> var. <i>lobbii</i>	2.6	4.7
<i>Raillardella argentea</i>	0.3	1.3

C.

Dana	All Sites		Near-treeline 3640 m		Near-summit 3817-3969 m	
	%Cover	%Contr	%Cover	%Contr	%Cover	%Contr
<i>Polemonium eximium</i> (SN)	40.7	33.5			59.6	48.5
Graminoids	17.6	15.7	25.0	18.3	17.6	15.7
<i>Erigeron compositus</i>	9.3	11.8			14.0	18.6
<i>Eriogonum ovalifolium</i> var. <i>nivale</i>	10.3	10.9	25.0	6.2		
<i>Ivesia lycopodioides</i>	4.5	6.1	9.4	16.0	1.6	4.9
<i>Packera wernerifolia</i>	4.5	6.6	18.8	19.0		
<i>Phlox diffusa</i>	3.5	3.7	10.4	19.1		
<i>Astragalus kentrophyta</i> var. <i>danaus</i> (CA; R)	2.1	4.2			3.1	6.6
<i>Pyrrocoma apargioides</i>	1.0	1.1	3.1	9.0		
<i>Boechea lemmonii</i>	1.0	1.7			3.1	2.8
<i>Draba lemmonii</i> (SN)	0.7	1.4			0.5	2.1
<i>Castilleja nana</i>	1.0	1.2	3.1	6.1		
<i>Androsace septentrionalis</i>	1.7	1.8	4.2	3.0	0.5	0.8
<i>Linum lewisii</i> var. <i>lewisii</i>	0.3	0.4	1.0	3.2		

D.

Mammoth	All Sites 3240-3362 m	
	%Cover	%Contr
<i>Phacelia hastata</i> var. <i>compacta</i>	35.3	31.9
<i>Hulsea vestita</i> ssp. <i>vestita</i> (CA)	30.8	30.6
<i>Eriogonum incanum</i>	19.2	21.4
Graminoids	8.0	8.9
<i>Chaenactis alpigena</i>	4.5	4.9
<i>Calyptidium umbellatum</i>	1.8	2.2
<i>Phlox diffusa</i>	0.5	0.6

E.

Starr	All Sites 3341-3617 m	
	%Cover	%Contr
Graminoids	19.6	12.7
<i>Eriogonum incanum</i>	18.7	17.6
<i>Ericameria suffruticosa</i>	15.6	14.2
<i>Hieracium horridum</i>	6.8	7.9
<i>Leptosiphon nuttallii</i> ssp. <i>pubescens</i>	6.6	8.2
<i>Phacelia hastata</i> var. <i>compacta</i>	5.5	6.8
<i>Hypericum anagalloides</i>	4.2	5.2
<i>Monardella odoratissima</i> ssp. <i>pallida</i>	3.7	4.9
<i>Calyptidium umbellatum</i>	2.2	2.4
<i>Eriogonum lobbii</i>	1.9	9.4
<i>Oxyria digyna</i>	1.8	2.2
<i>Achillea millefolium</i>	1.8	2.1
<i>Heuchera rubescens</i>	1.1	1.5
<i>Gentiana newberryi</i> var. <i>tiogana</i>	0.7	0.8
<i>Erigeron pygmaeus</i>	0.7	0.8
<i>Linanthus pungens</i>	0.7	0.8
<i>Chaenactis alpigena</i>	0.7	0.8
<i>Silene sargentii</i>	0.7	0.8
<i>Penstemon davidsonii</i> var. <i>davidsonii</i>	0.4	0.5
<i>Castilleja nana</i>	0.2	0.4
<i>Cystopteris fragilis</i>	0.2	0.3
<i>Ivesia muirii</i> (SN)	0.2	0.3
<i>Eriogonum ovalifolium</i> var. <i>nivale</i>	0.2	0.3

F.

Cloudripper	All Sites 3523-3685 m	
	%Cover	%Contr
<i>Eriogonum rosense</i>	15.7	13.2
Graminoids	12.9	6.3
<i>Monardella odoratissima</i> ssp. <i>pallida</i>	7.7	8.2
<i>Packera cana</i>	7.7	7.1
<i>Draba oligosperma</i>	7.3	6.6
<i>Pyrrcoma apargioides</i>	7.3	6.1
<i>Erigeron algidus</i>	7.0	8.3
<i>Eriogonum ovalifolium</i> var. <i>nivale</i>	6.6	8.4
<i>Castilleja applegatei</i> ssp. <i>pallida</i> (CA)	6.3	9
<i>Raillardella argentea</i>	3.8	5.7
<i>Phlox condensata</i>	3.5	4.2
<i>Ivesia muirii</i> (SN)	3.5	3.5
<i>Minuartia obtusiloba</i> (R)	2.4	3.5
<i>Erigeron pygmaeus</i>	2.4	2.8
<i>Castilleja nana</i>	2.4	2.7
<i>Eremogone kingii</i> var. <i>glabrescens</i>	1.7	2.2
<i>Linanthus pungens</i>	1.4	1.9
<i>Aquilegia pubescens</i> (SN)	0.4	0.6

G.

Gould	All Sites		Near-treeline 3333-3584 m		Near-summit 3619-3684 m	
	%Cover	%Contr	%Cover	%Contr	%Cover	%Contr
Graminoids	23.3	11.4	20.7	12.5	27	36.2
<i>Polemonium eximium</i> (SN)	20.5	22.8			69.8	48.9
<i>Eriogonum ovalifolium</i> var. <i>nivale</i>	12.4	15.2	17.8	20.2		
<i>Linanthus pungens</i>	9.2	8.6	13.1	9.8		
<i>Ericameria discoidea</i>	8.7	11.5	12.5	17.6		
<i>Penstemon davidsonii</i> var. <i>davidsonii</i>	6.2	6.5	8.9	7.2		
<i>Monardella odoratissima</i> ssp. <i>pallida</i>	5.1	5.8	7.3	8.5		
<i>Primula suffrutescens</i>	4.4	5.4	6.2	7.2		
<i>Achillea millefolium</i>	4.2	5.0	6.0	7.8		
<i>Senecio fremontii</i> var. <i>occidentalis</i>	3.0	4.1	3.6	4.7	1.6	7.7
<i>Phacelia hastata</i> var. <i>compacta</i>	1.2	1.6	1.6	2.0		
<i>Hulsea algida</i>	0.5	0.8			1.6	7.2
<i>Castilleja applegatei</i> ssp. <i>pallida</i>	0.5	0.6	0.7	0.9		
<i>Ranunculus eschscholtzii</i> var. <i>oxynotus</i>	0.3	0.4	1.3	0.5		
<i>Oxyria digyna</i>	0.2	0.3	1.5	0.4		
<i>Raillardella argentea</i>	0.2	0.3	0.2	0.4		
<i>Phyllodoce breweri</i> (CA)	0.2	0.2	0.2	0.3		

H.

Langley	All Sites		Near-treeline 3641-3845 m		Near-summit 3971-4176 m	
	%Cover	%Contr	%Cover	%Contr	%Cover	%Contr
<i>Eriogonum ovalifolium</i> var. <i>nivale</i>	30.2	30.6	24.3	18.6		
<i>Polemonium eximium</i> (SN)	25.1	24.6			62.1	48.4
Graminoids	13.7	11.5	20.6	9.0	13.8	22.3
<i>Hulsea algida</i>	9.5	11.5			23.6	28.1
<i>Penstemon davidsonii</i> var. <i>davidsonii</i>	5.4	5.3	13.9	18.0		
<i>Primula suffrutescens</i> (CA)	4.9	4.7	12.7	16.1		
<i>Senecio fremontii</i> var. <i>occidentalis</i>	4.4	4.3	11.5	14.6		
<i>Phlox dispersa</i> (SN; R)	2.6	3.2	6.7	9.7		
<i>Antennaria media</i>	1.4	1.6	3.6	5.2		
<i>Erysimum perenne</i>	0.7	0.9	1.8	2.7		
<i>Raillardella argentea</i>	0.7	0.7	1.8	2.2		
<i>Ivesia pygmaea</i> (SN)	0.5	0.6	1.2	1.4		
<i>Phyllodoce breweri</i>	0.5	0.5	1.2	1.7		
<i>Draba breweri</i> (CA)	0.2	0.4			0.6	1.2
<i>Epilobium obcordatum</i>	0.2	0.3	0.6	0.8		

Growth-form Composition

Herbaceous perennials were the most common growth-form present accounting for 51% of species found, followed by cushion/mat species (23%) and graminoids (20%). Subshrubs were found the least accounting for just 6% of species (4 species total; Figure 20). When comparing near-summit and near-treeline elevation groups, more herbaceous perennials and graminoids were in the near-summit group compared with the near-treeline group, and less cushion and mat species were in the near-summit than the near-treeline group. There were no subshrubs in the near-summit group of sites (Figure 21).

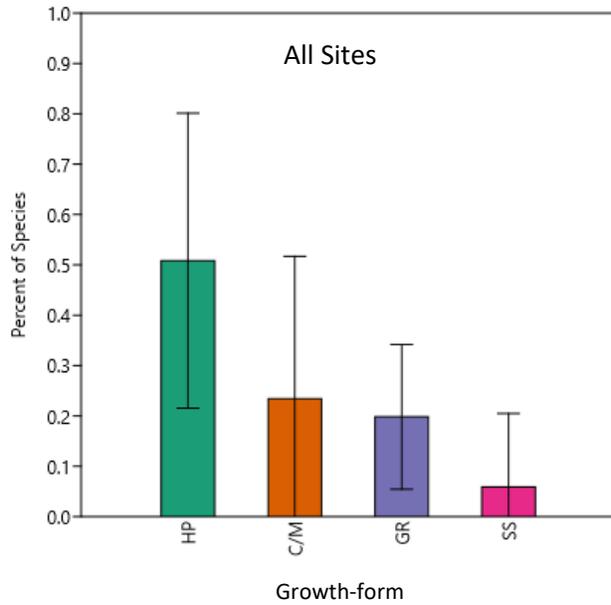
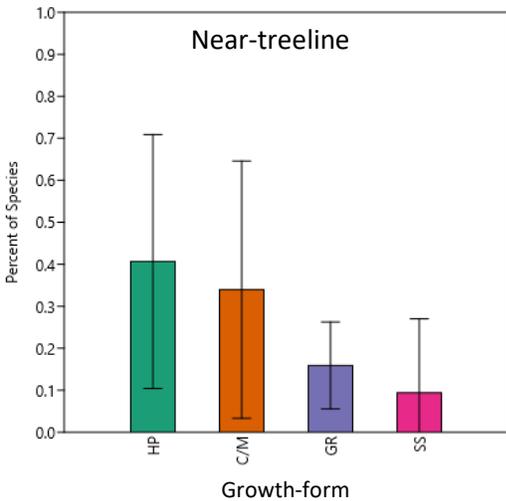


Figure 20. Mean proportions of growth-form composition across the Sierra Nevada. Growth forms were herbaceous perennials (HP), cushion and mat (C/M), graminoids (GR) subshrubs (SS).

A.



B.

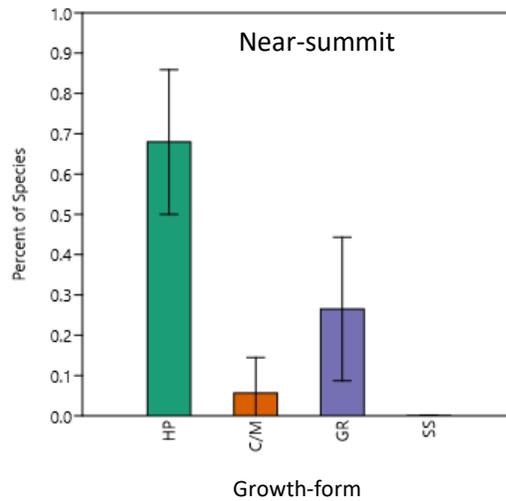


Figure 21. Mean proportions of growth-form composition for (A) near-treeline and (B) near-summit elevation groups across the mountain range.

Environmental Variables

Across the Sierra Nevada, substrate grain size had the largest influence on vegetation dissimilarity ($R^2=0.285$, $P=0.0001$), followed by aspect ($R^2=0.236$, $P=0.0001$) and elevation ($R^2=0.149$, $P=0.0001$). Substrate type, slope, and latitude had smaller significant influences on species composition ($R^2=0.072$, $P=0.0001$; $R^2=0.068$, $P=0.0001$; $R^2=0.038$, $P=0.0001$; Table 6). All six environmental variables together explained 54.8% of the floristic dissimilarity across the entire mountain range.

The vegetation composition of individual peaks had unique relationships with elevation, substrate, grain size, aspect, and slope. The floristic dissimilarity was more strongly explained by the variables on individual peaks than across the Sierra Nevada (Tables 6-14). Across the mountain range the substrate grain size had the R^2 value, 0.285, while on individual peaks the highest R^2 values from predictor variables ranged from 0.491 to 0.974. All predictor variables combined explained more of the variation on individual peaks (Leavitt: $R^2=0.895$; Gaylor: $R^2=0.539$; Dana: $R^2=0.726$; Mammoth: $R^2=0.974$; Starr: $R^2=0.936$; Cloudripper: $R^2=0.788$; Gould: $R^2=0.805$; and Langley: $R^2=0.862$) than across the mountain range ($R^2= 0.548$).

Aspect had the largest influence on species composition on five central and northern peaks (Leavitt, Gaylor, Mammoth, Starr, and Cloudripper). Grain size had the largest influence on two most southern peaks (Langley and Gould), followed by elevation having the largest influence on Dana.

Table 6. Results from DISTLM and BIOENV analyses on the Bray-Curtis dissimilarity matrix across the entire mountain range. Significant effects at $\alpha=0.05$ level are in bold. Pseudo-F: F-value generated from DISTLM analysis. *P*-values were generated from 9999 permutations of the data. All variables significantly explained variation across sites. All six variables together explained 54.8% of the variation ($R^2=0.548$).

Variable	Pseudo-F	R^2	<i>P</i> -Value	Spearman
Grain Size	16.586	0.285	0.0001	0.331
Aspect	5.349	0.236	0.0001	0.176
Elevation	22.229	0.149	0.0001	0.280
Substrate	4.910	0.072	0.0001	0.068
Slope	9.268	0.068	0.0001	0.080
Latitude	5.009	0.038	0.0001	0.053

Table 7. Leavitt results from DISTLM and BIOENV analyses. All four variables combined explained 89.5% of the variation ($R^2=0.895$).

Variable	Pseudo-F	R^2	<i>P</i> -Value	Spearman
Aspect	23.244	0.804	0.001	0.756
Grain Size	15.191	0.628	0.001	0.696
Elevation	17.303	0.477	0.001	0.738
Slope	11.037	0.367	0.001	0.721

Table 8. Gaylor results from DISTLM and BIOENV analyses. Grain size is not included in the analysis as all sites were comprised of pebble. All three variables combined explained 53.9% of the variation ($R^2=0.539$).

Variable	Pseudo-F	R^2	<i>P</i> -Value	Spearman
Aspect	3.505	0.539	0.012	0.380
Slope	5.169	0.425	0.004	0.598
Elevation	4.199	0.375	0.003	0.598

Table 9. Dana results from DISTLM and BIOENV analyses. All four variables combined explained 72.6% of the variation ($R^2=0.726$).

Variable	Pseudo-F	R^2	<i>P</i> -Value	Spearman
Elevation	15.641	0.494	0.0001	0.821
Grain Size	14.499	0.475	0.001	0.782
Slope	11.433	0.416	0.0012	0.587
Aspect	0.514	0.031	0.6976	-0.080

Table 10. Mammoth results from DISTLM and BIOENV analyses. Grain size was excluded from the analysis as all sites were comprised of pebble. All three variables combined explained 97.4% of the variation ($R^2=0.974$).

Variable	Pseudo-F	R^2	<i>P</i> -Value	Spearman
Aspect	113.62	0.974	0.004	0.756
Slope	5.77	0.452	0.0174	0.636
Elevation	4.08	0.368	0.0448	0.268

Table 11. Starr results from DISTLM and BIOENV analyses. All four variables combined explained 93.6% of the variation ($R^2=0.936$).

Variable	Pseudo-F	R^2	<i>P</i> -Value	Spearman
Aspect	5.794	0.491	0.0002	0.411
Slope	5.700	0.305	0.0001	0.809
Grain Size	4.503	0.258	0.0005	0.435
Elevation	2.672	0.171	0.0204	0.026

Table 12. Cloudripper results from DISTLM and BIOENV analyses. All four variables combined explained 78.8% of the variation ($R^2=0.788$).

Variable	Pseudo-F	R^2	<i>P</i> -Value	Spearman
Aspect	11.184	0.615	0.0103	0.861
Slope	9.769	0.583	0.0083	0.795
Elevation	6.398	0.478	0.0143	0.718
Grain Size	2.069	0.228	0.1089	0.056

Table 13. Gould results from DISTLM and BIOENV analyses. All four variables combined explained 80.5% of the variation ($R^2=0.805$).

Variable	Pseudo-F	R^2	<i>P</i> -Value	Spearman
Grain Size	14.441	0.684	0.0001	0.656
Aspect	14.109	0.573	0.0001	0.678
Elevation	10.803	0.329	0.0001	0.477
Slope	2.011	0.084	0.0908	0.043

Table 14. Langley results from DISTLM and BIOENV analyses. All four variables combined explained 86.2% of the variation ($R^2 =0.862$).

Variable	Pseudo-F	R^2	<i>P</i> -Value	Spearman
Grain Size	28.885 ₃	0.733	0.001	0.831
Elevation	24.169	0.523	0.001	0.755
Aspect	4.208	0.387	0.003	0.229
Slope	1.844	0.077	0.147	0.049

Sites with pebble-size substrates were found to support graminoids, *E. ovalifolium* var. *nivale*, *E. incanum*, *P. diffusa*, *L. lepidus* var. *lobbii*, *P. hastata* var. *compacta*, *E. suffruticosa*, and *H. vestita* ssp. *vestita*. These species accounted for 94.1% of the similarity among all pebble sites. Sites with pebble-size substrates also had the lowest average similarity of 19.3% (Table 15). Sites with cobble-size substrates were found to support graminoids, *P. eximium*, *P. werneriiifolia*, *E. discoidea*, *E. ovalifolium* var. *nivale*, and *L. pungens*. These species accounted for 98.5% of the similarity among all cobble sites. Sites with cobble substrates had an average similarity of 46.5% (Table 15). Sites with boulder-size substrates were found to contain *P. eximium*, graminoids, *H. algida*, and *E. compositus* which accounted for 99.6% of the similarity among all boulder sites (Table 15). Sites with boulder-size substrates had the highest average similarity of 53.2%. Sites with substrate of mixed-size grains were found to support graminoids, *E. ovalifolium* var. *nivale*, *P. suffrutescens*, *M. odoratissima* ssp. *pallida*, *L. pungens*, *P.*

davidsonii var. *davidsonii*, *S. fremontii* var. *occidentalis*, and *R. argentea* which accounted for 90.3% of the similarity among all mixed grain size sites. Mixed-size substrate sites had an average similarity of 25.8% (Table 15).

Table 15. SIMPER analysis showing percent similarity within sites based on substrate grain size across the mountain range.

Pebble Avg similarity 19.3%	Contr %	Cobble Avg similarity 46.5%	Contr %	Boulder Avg similarity 53.2%	Contr %	Mixed Avg similarity 25.8%	Contr %
<i>Graminoids</i>	35.6	<i>Graminoids</i>	56.9	<i>P. eximium</i>	79.9	<i>Graminoids</i>	42.3
<i>E. ovalifolium</i> var. <i>nivale</i>	23.9	<i>P. eximium</i>	34.0	<i>Graminoids</i>	14.5	<i>E. ovalifolium</i> var. <i>nivale</i>	15.8
<i>E. incanum</i>	16.6	<i>P. werneriiifolia</i>	2.7	<i>H. algida</i>	3.9	<i>P. suffrutescens</i>	8.9
<i>P. diffusa</i>	8.7	<i>E. discoidea</i>	2.6	<i>E. compositus</i>	1.4	<i>M. odoratissima</i> ssp. <i>pallida</i>	6.5
<i>L. lepidus</i> var. <i>lobbii</i>	2.4	<i>E. ovalifolium</i> var. <i>nivale</i>	1.7	<i>A. kentrophyta</i> var. <i>danaus</i>	0.2	<i>L. pungens</i>	5.2
<i>P. hastata</i> var. <i>compacta</i>	2.4	<i>L. pungens</i>	0.6	<i>I. lycopodioides</i>	0.1	<i>P. davidsonii</i> var. <i>davidsonii</i>	5.1
<i>E. suffruticosa</i>	2.3	<i>C. cinerarius</i>	0.5	<i>B. lemmonii</i>	0.1	<i>S. fremontii</i> var. <i>occidentalis</i>	4.9
<i>H. vestita</i> ssp. <i>vestita</i>	2.3	<i>I. lycopodioides</i>	0.2	<i>D. lemmonii</i>	0.02	<i>R. argentea</i>	1.6

Average similarity ranged from 22.5% in north-facing sites to 73.1% in northeast-facing sites. Common species in north-facing sites included *E. ovalifolium* var. *nivale*, graminoids, and *E. rosense*. The northwest-facing sites included graminoids, *L. lepidus* var. *lobbii*, and *E. suffruticosa*. Similarly, the westerly-facing sites (west, southwest, and south-facing) shared *P. eximium* and graminoids whereas the easterly-facing sites (southeast, east, and northeast-facing) shared graminoids and *E. incanum*.

Table 16. SIMPER analysis showing percent similarity among sites based on aspect across the mountain range.

N		NW		W		SW	
Avg similarity	Contr %						
22.5%		37.1%		25.5%		33.2%	
<i>E. ovalifolium</i> var. <i>nivale</i>	21.7	<i>Graminoids</i>	35.7	<i>P. eximium</i>	68.9	<i>P. eximium</i>	52.0
<i>Graminoids</i>	19.4	<i>L. lepidus</i> var. <i>lobbii</i>	18.6	<i>Graminoids</i>	16.1	<i>Graminoids</i>	35.0
<i>E. rosense</i>	10.5	<i>E. suffruticosa</i>	13.5	<i>H. vestita</i> ssp. <i>vestita</i>	6.9	<i>E. ovalifolium</i> var. <i>nivale</i>	8.8
<i>P. hastata</i> var. <i>compacta</i>	9.5	<i>C. applegatei</i> ssp. <i>pallida</i>	10.1	<i>H. algida</i>	2.4	<i>E. compositus</i>	1.4
<i>I. lycopodioides</i>	8.8	<i>E. algidus</i>	8.5	<i>E. ovalifolium</i> var. <i>nivale</i>	1.7	<i>P. werneriiifolia</i>	0.8

S		SE		E		NE	
Avg similarity	Contr %	Avg similarity	Contr %	Avg similarity	Contr %	Avg similarity	Contr %
26%		24.2%		26.2%		73.1%	
<i>P. eximium</i>	49.2	<i>Graminoids</i>	46.2	<i>Graminoids</i>	39.4	<i>P. diffusa</i>	54.9
<i>Graminoids</i>	32.7	<i>E. incanum</i>	16.8	<i>E. incanum</i>	20.4	<i>E. incanum</i>	25.0
<i>H. algida</i>	6.9	<i>L. pungens</i>	10.8	<i>P. eximium</i>	10.8	<i>Graminoids</i>	15.9
<i>E. ovalifolium</i> var. <i>nivale</i>	3.1	<i>P. davidsonii</i> var. <i>davidsonii</i>	4.1	<i>P. diffusa</i>	9.6	<i>R. scaposa</i>	3.5
<i>E. lobbii</i>	2.1	<i>P. suffrutescens</i>	3.9	<i>E. ovalifolium</i> var. <i>nivale</i>	4.4	<i>C. umbellatum</i>	0.7

DISCUSSION

The alpine flora of California's Sierra Nevada range is usually described as if it were a single cohesive unit (Chabot and Billings 1972; Storer et al 2004; Rundel 2012). This study indicated that is not the case. Individual peaks differ and there is spectrum of variation in community composition spanning the alpine zone that, until now, had not been thoroughly explored. Differences in diversity, percent cover, endemic and rare species proportions, growth-form proportions, dominance, evenness, and community composition across latitude, elevation, aspects, and grain sizes were documented.

Sierran alpine community compositions were highly dissimilar across the macroenvironmental scales of latitude and elevation at the sites surveyed (Table 4). This was indicated by beta-diversities that often changed abruptly and over short elevational distances (Figure 13) and the dissimilarities in community composition among peaks based on similarity analyses across the mountain range (Table 4). Macroenvironment has been shown to sort alpine communities at broad scales in the nearby White Mountains of California (Smithers et al. 2019) and is now documented in the Sierra Nevada. Similar to the findings by Smithers et al. (2019), across the Sierra, climate appears to be an important driver of community composition. However, the microtopography is also important with unique features of habitat and substrate type also influential at structuring community composition at both broad scales and on individual peaks.

While species richness varied site to site on individual peaks, it did not differ significantly across latitude (Table 3). This agrees with the findings by Testolin, et al. (2021), in which models showed regional richness of alpine ecosystems to be mostly independent of macroclimatic gradients. Species diversity, as measured by Shannon's index, varied peak to

peak, but also did not show a relationship with latitude at broad scales. Percent cover, however, declined across latitude (Figure 8). This means that while species richness and diversity were not associated with latitude, percent cover was. There simply was not as much vegetation on the southern peaks in comparison with the central or northern peaks despite the southern peaks having similar species richnesses and diversities.

The southern peaks had the highest summit elevations and their alpine zones were in a higher elevational band than the northern peaks. For example, the treeline at Langley in the south was 300 m higher than the treeline at Leavitt in the north. This elevated treeline compresses the optimum near-treeline species habitat in the southern region. The inverse pattern was found for the northern peaks. The near-summit species habitat was a more compressed zone as the summit elevation was considerably lower than the southern peaks (Table 2). This seems to be why there were fewer near-treeline compositional sites on Langley, which had five sites included with near-summit species compositions. On the other hand, Leavitt had just two sites included in the near-summit species composition group.

While treeline is constrained by low temperature globally (Körner 2003), and temperature generally decreases with latitudinal increase in the northern hemisphere, the temperatures in the alpine zone of the southern peaks of the Sierra Nevada were colder than the temperatures in the alpine zone of the northern peaks (1.7-2.2°C colder annual minimum temperatures; 1.3-3.2°C colder annual maximum temperatures; Table 1). In addition, less than half the annual precipitation falls on the southern peak of Langley compared to the northern peak of Leavitt (Table 1). This regionally drier environment that adds to the stressors encountered by the southern alpine flora. Colder, drier environments have been shown to have negative effects on species growth (Körner 2003). The highest elevation sites on the southernmost peak, Langley,

experiences some of the harshest alpine climates in the Sierra Nevada. Some of the sites there had just 4% cover and supported only one or two species and a large proportion of flora are restricted to relatively protected microhabitats. *P. eximium* and *H. algida* at these sites were found growing only in rock crevices or nestled under boulders. Even the near-treeline sites were sparsely populated on the southernmost peaks. Small populations of *E. obcordatum*, *P. davidsonii* var. *davidsonii*, and *P. suffrutescens* were discovered in small crevices of mixed-size substrates very close to the treeline.

In the alpine zone of the Sierra, less precipitation equals less snowfall, and snowfall is an important environmental factor that shapes alpine plant communities. The accumulation of snowbeds act as a thermal buffer from the climate (Björk and Molau 2007). Soil temperatures under snowbeds will commonly stay above freezing temperature despite ambient below freezing air temperatures (Körner 2003). This feature is critical to the survival of some alpine plants as they begin to emerge in the spring (Björk and Molau 2007). With less precipitation and lower temperatures in the southern region, it follows that early freezing is another harsh feature of the environment that alpine flora experiences. This is probably a major reason for the lack of vegetation seen on the southern peaks.

While floristic community composition was dissimilar among peaks of the Sierra Nevada (83.2%), the sites on individual peaks were also highly dissimilar from one another (Table 4). The elevational change from site to site on individual peaks was a strong predictor of species composition ($R=0.67-1.0$) but became less influential when comparing peaks across the mountain range ($R=0.29$), which meant elevation had a stronger influence on individual peaks than across the mountain range. Smithers et al. (2019) also found a stronger relationship between elevation and community composition at the scale of the individual peak relative to the entire

mountain range. At broader scales there are more influences on community composition (treeline, geology, regional climate, biotic interactions) than at the scale of an individual peak. On single peaks, community compositions changed abruptly in congruence with unique topographic features while elevational bands further shaped species distributions.

As expected, floristic diversity in the Sierra Nevada declined overall with elevational increase on individual peaks (Figure 12). Although diversity varied among peaks (Figure 13), there was, unexpectedly, no clear association with latitude. Diversity was the highest on the central peak of Cloudripper. However, because of its previously unglaciated plateau, Cloudripper is more than just a peak. Its notably high diversity may be a modern artifact of the plateau's ancient role as a glacial refugium for plants (Wenk 2015). In addition to having the highest diversity, Cloudripper also had more species sharing dominant proportions than the other peaks (Table 5).

Beta-diversity (species turnover) was higher from site-to-site on individual peaks than from peak-to-peak across the Sierra Nevada (Figure 14). Beta-diversity was also low within individual sites, meaning that locations surveyed by transects at each of the sites supported compositionally similar sets of species (Figure 14). The alpine zone in the Sierra really consists of multiple floras, and it may be more appropriate to consider peaks, near-treeline groups, near-summit groups, or subregions of the Sierra as unique assemblages.

An interesting finding was that beta-diversity was high in the near-treeline sites on the central peaks of Cloudripper and Starr. This contrasted with the overall trend of beta-diversity being low in the near-treeline sites across the range. This large change in community composition among sites just above treeline at those two peaks may be a regional feature, or it may be indicative of species that are shifting ranges.

A distinct compositional separation of near-treeline communities and near-summit communities was consistent across peaks (Figure 15; Table 4). Only 23% of the species found in this study occurred near the summit of one or more peaks. In addition, at near-summit elevations, sites were significantly more compositionally similar to each other across the range than were the sites that were located near-treeline (Table 4). The existence of these convergent high alpine floras, despite the isolation from one another that is imposed by elevation and latitude was remarkable. Physiological limitations associated with exposure to extreme cold, desiccating winds, and variations in snowbed cover prevent the majority of alpine species from occurring at the highest parts of peaks (Körner 2003; Björk and Molau 2007). As a result, only the few species capable of tolerating the most extreme environments occur near the summits throughout the entire Sierra Nevada range.

Species dominance increased with elevation while evenness decreased across the Sierra Nevada (Figure 11). Near-summit sites were heavily dominated with *P. eximium* and graminoid spp. *P. eximium* is found only above 3200 m. In addition to being a spectacular beauty, it is also a food source for the North American pika (*Ochotona princeps*; Wenk 2015), an alpine specialist mammal. Despite being a Sierra endemic, it is widespread (not rare) and appears on many peak summits. *P. eximium* features dense leaves divided into 20-35 deeply lobed leaflets that help retain warm air and moisture, with extremely aromatic sticky glands which attract pollinators, and large round flowering heads composed of many tubular vibrant violet flowers that reflect the most energetic wavelengths of visible light (Wenk 2015). *H. algida* is another high elevation specialist found in the Sierra (and western North America). It is an aster with hairy leaves and bright yellow flowers topping tall stems (40 cm). The large size and showy nature of these high elevation species may be a relic of a cooler glaciated Sierra, as research shows during the last

glacial period (between 25-15,000 bp) there were significantly more forbs and grasses in the alpine zone than at present (Clark et al. 2019).

An interesting discovery was that the elevational distance between the lowest occurrences and upper occurrences of *P. eximium* on the southern peaks was considerably greater (approximately 250 m) compared with where it occurred in the northern peaks (approximately 30 m elevation range; personal observation). This means that available habitat space for this species on the northern peaks may disappear if climate change driven warming temperatures cause the elevational range of *P. eximium* to shift upward.

Although near-treeline communities were more even (Figure 11) and more dissimilar from one another than near-summit communities across the Sierra, there were a few species that were widespread across the near-treeline sites. These included *E. incanum*, *E. ovalifolium* var. *nivale*, *P. diffusa*, and graminoids. These species should be considered generalists of the near-treeline alpine zone in the Sierra Nevada. The proportions of the four alpine plant growth-forms (herbaceous perennials, cushion and mat plants, graminoids, and subshrubs) followed previously documented patterns (Rundel 2011), in near-treeline sites as well as across the Sierra Nevada (Figures 20 and 21). However, the proportions of these growth forms at near-summit sites were unique. There was a higher proportion of herbaceous perennials and a lower proportion of cushion/mat species in the near-summit communities than the near-treeline communities (along with zero subshrubs).

Although a Sierran alpine flora existed in various forms during the past 2.6 million years of the Pleistocene, the currently existing flora has been shaped within the approximate 11,600 years of the ongoing interglacial Holocene (Storer et al. 2004). During the Pleistocene glaciations large portions of the Sierra Nevada were covered with ice fields and alpine glaciers

but some peaks escaped as unglaciated refuges (sky islands; Storer et al. 2004; Wenk 2015). Interglacial cycles have been much shorter (approximately 10,000 yrs.) than the glacial cycles (approximately 90,000 yrs.), therefore, the presence of ice has been a historically predominant feature (Gillespie and Clark 2011). Most recently, the Sierra lacked glaciers prior to the Little Ice Age, 800 years ago, during which there were significant alpine glacial advances making the wettest Sierran climate in the Holocene (Gillespie and Clark 2011) followed by a retreat that is still ongoing. With glacial retreat species were able to migrate and recolonize peaks once again while exposed peaks that had served as refugia maintained, expanded, or lost their flora (Wenk 2015). The differences in species composition among peaks in near-treeline and near-summit alpine vegetation that occurs today reflects this history. While all the peaks surveyed in this study were most likely unglaciated at their summits, Leavitt, Dana, Cloudripper, Gould, and Langley are likely to have provided refugia for species. Each of these peaks were at a high enough elevation to provide ample area for species to exist through glaciations. *P. eximium* was found on each of these (and observed on Cloudripper) and likely persisted during the last glaciation. There are topographic features and grain sizes on these summits' characteristic of microrefugia; large boulders, mixed grain-sizes, and large relatively flat areas (a feature of unglaciated summits).

As the climate changes, predictions of alpine plant range shifts are currently limited by a lack of topoclimatic as well as habitat information (Smithers et al. 2019). Temperature, precipitation, and snowpack are important contributors to floristic community composition (Björk and Molau 2007; Gentili et al. 2014), but they are also variables presently available with raster sizes of insufficient resolution to capture the variation on individual peaks and their distinct near-treeline and near-summit zones. For instance, the climate data that was gathered

from PRISM (Table 1) had an 800 m grid size, which is quite large in comparison to the size of individual peaks. It is useful for general descriptions but cannot be used to explain the finer details of community composition. There are disjunct data sets such as the climate, snow, and soil moisture data set for the Tuolumne and Merced River watersheds with a 100 m raster size (Roche et al. 2018), but at the time of data analysis for this study a comprehensive data set for the entire Sierra Nevada at the appropriate grid size was not available. In addition, local weather station data are generally very poor indicators of the true climate alpine plants experience, both because alpine plants are decoupled from ambient air temperature (Scherrer and Körner 2011; Graham et al. 2012), and because there are too few alpine weather stations in the Sierra Nevada to adequately represent the variation in weather patterns.

Environmental and topographic variables (substrate grain size, aspect, elevation, substrate, latitude, and slope) were shown to partly explain the variation in community composition across the Sierra Nevada (Table 6), with grain size and aspect having the largest influence overall. However, on individual peaks, the environmental and topographic variables explained more of the variation in community composition while having stronger yet unique relationships to them (Tables 7-14). For example, aspect had the largest influence on community composition on the northern and central peaks of Leavitt, Gaylor, Mammoth, Starr, and Cloudripper, while grain size had the largest influence on the southern peaks of Gould and Langley. Elevation was the largest explanatory topographic variable for only one steep individual peak, Dana. However, it was just barely more influential than grain size (Tables 7-14). At the scale of mountain range, non-climatic differences among peaks (such as treeline, geology, regional climate, biotic interactions) likely reduce variation that is explainable by elevation

(Smithers et al. 2019). This is why substrate grain size and aspect were more influential than elevation across the Sierra.

The influence of grain size was very evident on the southern peaks of Langley and Gould. Seventy-five percent of the vegetation occurring in habitats with mixed-size or boulder-size substrates (Table 15). These peaks were also characterized by remarkably large unvegetated bare (personal observation). Mixed-size and boulder-size substrates can provide three-dimensional sheltered spaces (microhabitats) for species to exist within that decouple their immediate habitat from the ambient temperature. These microhabitats may act as buffers against wind, desiccation, and temperature changes (Kulonen et al. 2017). Some microhabitats are also known as microrefugia, and they can support locally favorable climates within larger areas of unfavorable warmer climates, creating cold-air pools and temperature inversions (Gentili et al. 2014). Across the Sierra Nevada, floristic diversity was higher in mixed grain size sites, probably because of the existence of these favorable conditions (Figure 13). Sometimes there were as many as four species coexisting in the same area in a mixed-size site. For example, on Starr, there was a site at which *C. alpigena*, *E. incanum*, *I. muirii*, and a graminoid species all grew in one rocky crevice.

Sites with pebble-size substrates were the least similar in floristic composition across the Sierra Nevada (Table 15). Interestingly, these pebble sites were habitats for dominant species that were unique to just one or two peaks, contributing to the large floristic dissimilarity among pebble sites. For instance, *E. suffruticosa* (found on Leavitt and Starr), *H. vestita* ssp. *vestita* (unique to Mammoth), and *L. lepidus* var. *lobbii* (found on Gaylor and Leavitt) all grew in pebble sites. Because sites with pebble-sized substrates do not appear to have significant topographical buffers from the climate, and, therefore, it is possible that the species on these peaks exist in favorable climate conditions that are not found on other peaks.

On the northern and central peaks floristic dissimilarity was best explained by aspect (Tables 7-8; 10-11) with north and northwest facing aspects containing the highest diversity (Figure 13). Differences in aspect affect the angle and amount of sunlight received by alpine plants, with warmer aspects supporting more colonization and creating a positive effect on species migration (Winkler et al. 2016). In addition, in the northern hemisphere, north-facing aspects in the alpine often receive more sunlight in the morning, compared to afternoon, because sun-blocking cloud cover often develops in the latter part of the day. This allows enables morning-exposed sites to retain moisture, something that can be important for species persistence and migration (Körner 2003). Aspect can also determine the amount of snowpack that develops (creating snowbeds), enabling areas to retain moisture and thermally buffered (Körner 2003). In turn, these factors can influence the establishment of species. In this study, high elevation communities were often found in the warmer south, southwest, and west aspects.

The largest proportion of endemic species was found on the southernmost peak, Langley, with the smallest proportion of endemic species on the northernmost peak, Leavitt (Figure 7). This may be attributable to the ongoing glacial-interglacial climate (Björk and Molau 2007). Endemic and rare species have been shown to have small climatic niches and be more susceptible to changes in climate (Vincent et al. 2020). *P. dispersa* is a rare Sierra Nevada endemic that was documented on Langley and occurs mainly around New Army Pass. Its congener, *P. condensata*, is a more widespread species. *Draba*, is thought to have been restricted to sky islands during the last glaciation and then subsequently differentiated into a great diversity of species that occur across the Sierra (Wenk 2015). *D. breweri*, a California endemic, was found on Langley, and *D. lemmonii*, a Sierra Nevada endemic was found on Dana.

It is still a reasonable conclusion that no two square meters of alpine vegetation contain the same floristic composition, as Paul Jaccard noted in 1912. Today, even though we know much more about alpine communities, our understanding is nowhere near comprehensive. This puts alpine science at an extreme disadvantage as we consider the potential consequences of a warming climate from cyclical and anthropogenic influences (Ganopolski et al. 2016; Hausfather and Peters 2020). Although the probability of another glacial cycle has been debated, predications are that the current interglacial could last another 50-100,000 years (Ganopolski et al. 2016). The lasting impacts of the unusually long interglacial Holocene along with the ongoing effects of anthropogenically-induced climate warming will meaningfully influence the alpine plants of California's Sierra Nevada. In the Sierra Nevada, climate warming is predicted to have multiple effects over the next century, including increased minimum and maximum temperatures, less precipitation and loss of snowpack, with increasing drought conditions (Siirila-Woodburn et al. 2021).

Future study and conservation efforts of Sierran alpine vegetation should be multifaceted. A focus on the alpine flora of the southern peaks, with the least percent cover and the highest proportion of endemic species should be a priority. Likewise, species that occur in climatically decoupled microhabitats also merit more attention as does the monitoring of near-treeline and near-summit regions for compositional changes. Elevational bands and unique topographic features should be considered when documenting species occurrences.

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APPENDIX

Table of all alpine flora surveyed. Growth form abbreviations are as follows: HP = herbaceous perennial; M/C = mat or cushion; SS = subshrub; GR = graminoid. Abbreviation (Abbr) column represents the shorthand names used in graphs. Lower and upper elevation range limits are for all of California (Baldwin et al. 2012). Peaks notated as LE (Leavitt), GA (Gaylor), DA (Dana), MA (Mammoth), ST (Starr), CL (Clouddripper), GO (Gould), and LA (Langley). Biogeography abbreviations are as follows: CA endemic to California; CA* endemic to the Sierra Nevada; (R) classified as rare in California; CA+ found in California and slightly beyond its borders; WNA found in western North America; NA+ found in North America and beyond. Biogeography and common names were derived from Baldwin et al. (2012) and Cal Flora (calflora.org).

Family	Species	Common Name	Abbr	Growth Form	Bio-geography	Elevation Range (m)	Peaks
Apiaceae	<i>Cymopterus cinerarius</i>	Gray's cymopterus	CYCI	HP	WNA	2100-3500	LE
Asteraceae	<i>Achillea millefolium</i>	Common yarrow	ACMI	HP	NA+	0-3650	LE, ST, GO
Asteraceae	<i>Antennaria media</i>	Alpine pussytoes	ANME	M/C	WNA	1800-3900	LA
Asteraceae	<i>Arnica mollis</i>	Hairy arnica	ARMO	HP	NA+	2500-2500	LE
Asteraceae	<i>Chaenactis alpigena</i>	Sharsmith Pincushion	CHAL	HP	CA+	2200-3900	LE, MA, ST
Asteraceae	<i>Ericameria discoidea</i>	Whitestem goldenbush	ERDI	SS	WNA	2300-3800	LE, GO
Asteraceae	<i>Ericameria suffruticosa</i>	Singlehead goldenbush	ERSU	SS	WNA	2100-3800	LE, ST
Asteraceae	<i>Erigeron algidus</i>	Sierra fleabane	ERAL	HP	CA+	2600-3700	LE, DA, CL
Asteraceae	<i>Erigeron compositus</i>	Cut leaf fleabane	ERCO	M/C	NA+	2000-4300	DA
Asteraceae	<i>Erigeron pygmaeus</i>	Pygmy fleabane	ERPY	M/C	CA+	2900-4100	ST, CL
Asteraceae	<i>Hieracium horridum</i>	Prickly hawkweed	HIHO	HP	WNA	1350-3300	ST
Asteraceae	<i>Hulsea algida</i>	Alpine gold	HUAL	HP	WNA	3000-4000	GO, LA
Asteraceae	<i>Hulsea vestita</i> ssp. <i>vestita</i>	Pumic hulsea	HUVE	HP	CA	2400-3350	MA
Asteraceae	<i>Packera cana</i>	Woolly groundsel	PACA	HP	WNA	1200-3500	CL
Asteraceae	<i>Packera werneriiifolia</i>	Hoary groundsel	PAWE	HP	WNA	3000-3650	LE, DA
Asteraceae	<i>Pyrrocoma apargioides</i>	Alpine flames	PYAP	HP	CA+	2200-3800	DA, CL
Asteraceae	<i>Raillardella argentea</i>	Silky raillardella	RAAR	HP	WNA	1800-3900	GA, CL, GO, LA
Asteraceae	<i>Raillardella scaposa</i>	Green leaved raillardella	RASC	HP	WNA	2000-3500	GA
Asteraceae	<i>Senecio fremontii</i> var. <i>occidentalis</i>	Western dwarf mountain ragwort	SEFR	HP	CA+	2800-4000	GO, LA

Asteraceae	<i>Solidago multiradiata</i>	Northern goldenrod	SOMU	HP	NA+	1250-3950	LE
Boraginaceae	<i>Phacelia hastata</i> var. <i>compacta</i>	Timberline phacelia	PHHA	HP	WNA	1500-4000	LE, ST, GO
Brassicaceae	<i>Boecheira lemmonii</i>	Lemmon's rockcress	BOLE	HP	WNA	2000-4350	DA
Brassicaceae	<i>Draba breweri</i>	Brewer's draba	DRBR	HP	CA	3100-4100	LA
Brassicaceae	<i>Draba lemmonii</i>	Granite draba	DRLE	M/C	CA*	3050-4000	DA
Brassicaceae	<i>Draba oligosperma</i>	Few seeded draba	DROL	M/C	WNA	2000-3950	CL
Brassicaceae	<i>Erysimum perenne</i>	Sand dune wallflower	ERPE	HP	WNA	2000-4000	LE, LA
Caryophyllaceae	<i>Eremogone kingii</i> var. <i>glabrescens</i>	King's sandwort	ERKI	M/C	WNA	2100-4050	CL
Caryophyllaceae	<i>Minuartia obtusiloba</i>	Alpine sandwort	MIOB	M/C	NA+ (R)	3150-3700	CL
Caryophyllaceae	<i>Silene sargentii</i>	Sargent's catchfly	SISA	HP	WNA	2400-3800	ST
Cyperaceae	Gramminoids	Sedges	GRAM	GR			ALL PEAKS
Ericaceae	<i>Phyllodoce breweri</i>	Brewer's heather	PHBR	HP	CA	1200-3500	GO, LA
Fabaceae	<i>Astragalus kentrophyta</i> var. <i>danaus</i>	Sweetwater mountains milkvetch	ASKE	M/C	CA (R)	2900-4000	DA
Fabaceae	<i>Astragalus whitneyi</i> var. <i>whitneyi</i>	Balloon milkvetch	ASWH	HP	CA+	1550-3500	LE
Fabaceae	<i>Lupinus lepidus</i> var. <i>lobbii</i>	Lobb's lupine	LULE	HP	WNA	2000-3500	LE, GA
Gentianaceae	<i>Gentiana newberryi</i> var. <i>tiogana</i>	Sierra alpine gentian	GENE	HP	CA+	1500-4000	ST
Hypericaceae	<i>Hypericum anagalloides</i>	Tinker's penny	HYAN	HP	WNA	0-3220	ST
Juncaceae	Gramminoids	Rushes	GRAM	GR			ALL PEAKS
Lamiaceae	<i>Monardella odoratissima</i> ssp. <i>pallida</i>	Pale mountain monardella	MOOD	HP	WNA	1000-3100	ST, CL, GO
Linaceae	<i>Linum lewisii</i> var. <i>lewisii</i>	Lewis' flax	LILE	HP	NA+	0-3660	LE, DA
Montiaceae	<i>Calyptridium umbellatum</i>	Pussypaws	CAUM	HP	WNA	240-4300	LE, GA, DA, MA, ST
Onagraceae	<i>Epilobium obcordatum</i>	Rockfringe	EPOB	HP	WNA	1700-4000	LA
Orobanchaceae	<i>Castilleja applegatei</i> ssp. <i>pallida</i>	Wavyleaf indian paintbrush	CAAP	HP	CA	1900-3600	CL, GO
Orobanchaceae	<i>Castilleja nana</i>	Dwarf alpine indian paintbrush	CANA	HP	WNA	2400-4200	DA, ST, CL

Plantaginaceae	<i>Penstemon davidsonii</i> var. <i>davidsonii</i>	David's penstemon	PEDA	HP	WNA	2000-3750	ST, GO, LA
Plantaginaceae	<i>Penstemon heterodoxus</i> var. <i>heterodoxus</i>	Sierra beardtongue	PEHE	M/C	WNA	2700-3900	LE, GA
Poaceae	Gramminoids	Grasses	GRAM	GR			ALL PEAKS
Polemoniaceae	<i>Leptosiphon nuttallii</i> ssp. <i>pubescens</i>	Nuttall's linanthus	LENU	SS	WNA	2800-3500	ST
Polemoniaceae	<i>Linanthus pungens</i>	Granite prickly phlox	LIPU	SS	WNA	1700-4000	ST, CL, GO
Polemoniaceae	<i>Phlox condensata</i>	Condensed phlox	PHCO	M/C	WNA	2000-4000	CL
Polemoniaceae	<i>Phlox diffusa</i>	Spreading phlox	PHDIF	M/C	WNA	1100-3600	LE, GA, DA, MA
Polemoniaceae	<i>Phlox dispersa</i>	High Sierra phlox	PHDIS	M/C	CA* (R)	3600-4200	LA
Polemoniaceae	<i>Polemonium eximium</i>	Sky pilot	POEX	HP	CA*	3000-4200	LE, DA, GO, LA
Polygonaceae	<i>Eriogonum incanum</i>	Frosted wild buckwheat	ERIN	M/C	CA+	1900-4000	LE, GA, MA, ST
Polygonaceae	<i>Eriogonum lobbii</i>	Lobb's wild buckwheat	ERLO	M/C	WNA	1000-3800	LE, ST
Polygonaceae	<i>Eriogonum ovalifolium</i> var. <i>nivale</i>	Sierran cushion wild buckwheat	EROV	M/C	WNA	1700-4200	LE, DA, ST, CL, GO, LA
Polygonaceae	<i>Eriogonum rosense</i>	Mount rose wild buckwheat	ERRO	M/C	WNA	2300-4000	CL
Polygonaceae	<i>Oxyria digyna</i>	Alpine mountain sorrel	OXDI	HP	NA+	1800-4000	ST, GO
Primulaceae	<i>Androsace septentrionalis</i>	Pygmy-flower rock-jasmine	ANSE	HP	NA+	2700-3600	DA
Primulaceae	<i>Primula suffrutescens</i>	Sierra primrose	PRSU	HP	CA	2000-4200	GO, LA
Ranunculaceae	<i>Aquilegia pubescens</i>	Sierra columbine	AQPU	HP	CA*	2600-3650	CL
Ranunculaceae	<i>Ranunculus eschscholtzii</i> var. <i>oxynotus</i>	Eschscholtz's buttercup	RAES	HP	CA+	2700-4300	GO
Rosaceae	<i>Ivesia lycopodioides</i>	Clubmoss ivesia	IVLY	HP	CA	3000-4000	LE, DA
Rosaceae	<i>Ivesia muirii</i>	Granite mousetail	IVMU	HP	CA*	2900-4000	ST, CL
Rosaceae	<i>Ivesia pygmaea</i>	Dwarf ivesia	IVPY	HP	CA*	2700-4000	LA
Saxifragaceae	<i>Heuchera rubescens</i>	Pink alumroot	HERU	HP	WNA	1000-4000	ST
Woodsiaceae	<i>Cystopteris fragilis</i>	Fragile fern	CYFR	HP	NA+	50-4100	ST