

A Comparative Analysis of Saxicolous Lichen Diversity and Cover along an
Elevation Gradient on Talus Slopes in Gunnison National Forest to Infer Possible
Climate Change Effects

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Abstract:

Climate change in Colorado has already increased temperatures by 2 °F and is predicted to continue to rise. Precipitation during winter months is predicted to increase, while projected precipitation for the spring, summer and fall is still uncertain. It is important to understand how saxicolous lichen communities (those growing on or in rock) will respond to climate change as they are primary successors and many other organisms rely on their ecological services. Saxicolous lichen communities are important primary successors of barren talus rock slopes, slowly eroding rock and creating habitats for micro and eventually macro plant communities. Some other roles of lichens include; nutrient deposition, nesting material, habitat for microscopic organisms, erode rock, and forage for reindeer (Pegau 1968, Nash et al. 1995, Crossman et al. 2001, Winchester et al. 2008). Lichen communities are expected to change in species diversity, distribution and cover along an elevational gradient and with varying aspect differences. Climate warming and changes in precipitation patterns may lead to a shift in community diversity and cover, and ultimately ecosystem function. The diversity and cover of saxicolous lichens were measured along an elevational gradient on talus slopes in Gunnison National Forest, Colorado. Six sites and a total of 180 transects were analyzed for abundance and cover of lichen thalli and bare rock using the image processing program ImageJ. Talus slopes with varying aspects and elevations had significantly different compositions of lichen species. Diversity and abundance of lichens decreased with elevation and on drier south-facing slopes. This has potential negative implications for the persistence of lichen communities that colonize harsh environments already experiencing extreme conditions. It is important to look at how these lichen communities are structured to predict how they might respond to a rapidly changing climate, as many biological models do not represent these communities. This study pursued how lichen cover and diversity will change over time as climate change progresses.

Introduction:

Lichens are widely overlooked, underappreciated and understudied symbiotic organisms that are found on all continents of earth. Lichens are a composite, symbiotic association of several organisms consisting of a fungal host, a captured photosynthetic partner, and only recently discovered, a basidiomycete yeast (Spribille et al. 2016). The fungal symbiont can be an ascomycete and is rarely a basidiomycete. The fungal partner captures a green algae and/or cyanobacteria to harvest the carbohydrates produced from photosynthesis. A lichen with a cyanobacterial photobiont will appear darker in color while a green algal partner will appear lighter green in color. The basidiomycete yeast interacts with the surface of the lichen thalli to facilitate nutrient transfer (Spribille et al. 2016). There are three growth types of lichens: fruticose, foliose (Image 12) and crustose (Image 5). Fruticose lichens grow from a single point on their attached substrate and branch in three dimensions. Foliose lichens grow flat

along their substrate and are generally large with a distinct lower and upper cortex. Included with foliose lichens are the squamulose growth form and sub-fruticose growth form. The squamulose growth form is made of small lobed thallus with stalked spore producing bodies called podetia, but can also bear more typical apothecia. A sub-fruticose lichen is one that has a distinct lower and upper cortex, lies mostly flat but is upturned or slightly branched. Crustose lichens grow tightly appressed to their substrate and lack a lower cortex. Lichens can grow on various substrates including manmade structures like metal and plastic, however, many are specialized to certain natural substrates (terricolous, saxicolous or corticolous). Terricolous lichens are those that grow on sod or bare soil. Corticolous lichens are those that grow on or within bark of a tree. Saxicolous lichens are those which grow on or within rocks and can be either foliose growing on top of rocks (epilithic) or crustose growing within the rock (endolithic).

Lichens absorb nutrients through their thallus passively from the atmosphere via liquid water and air. Due to their intimate relationship with the atmosphere, most lichen species are sensitive to pollution or rapid changes in the environment and have been used as bioindicators (Branquinho 2015, Loppi et al. 2000, Szczepaniak and Biziuk 2003, Klanderud and Totland 2005, De Guevara et al. 2014, Vingiani et al. 2015). When liquid water interacts with the lichen its metabolism is reactivated, photosynthesis occurs, and the lichens thallus grows. Lichens are poikilohydric, meaning that they cannot regulate their moisture content. Lichens have adapted to become desiccation tolerant, meaning that in response to low water conditions (drought) they are able to shut down their metabolic processes, and when reactivated with water are able to continue metabolizing until desiccating again. This ability to survive desiccation is variable between species. For instance, the crustose lichen *Rhizocarpon geographicum* can last 26 weeks without reactivation, while many fruticose species need reactivation much sooner or they perish (Ried 1953, Green and Lange 1994). In addition, lichens with a cyanobacterial photobiont are much more susceptible to drought conditions than those with green-algal photobionts. Cyanobacterial photobiont lichens need liquid water for activation, while those with green-algal photobionts can activate via water vapor (Lange et al. 1986). Even though most saxicolous lichens contain green-algae photobionts and are more tolerant to drought, a changing moisture regime in Colorado could have potentially negative effects on lichen abundance on talus slopes (Lange et al. 1986, Fraser et al. 2014). Saxicolous lichens have been chosen for this study because they are primary successors of substrate that cannot easily be colonized by vascular plants. Lichens can tolerate extreme environmental conditions but because of slow growth and colonization rates they potentially may not be able to respond well to a rapidly changing climate (Chapin et al. 2012, Fraser et al. 2014).

Due to the uncertainty of predictions on the patterns of climate change in Colorado, it is important to understand how lichens, as primary successors, will be impacted. Changes in primary succession by lichens will likely affect the secondary succession of vascular plants by not having suitable habitat for secondary succession to take place (Clements 1916). There has been significant research on how plants respond to climate change, but little research has been conducted on lichen communities (Evangelista et al. 2016, Jägerbrand et al. 2009, Ross et al. 1994, Smith 1994, Walther et al. 2002, Zorio et al. 2016). Lichens are like vascular plants in their expected response to differences in elevation and aspect. North slopes receive less sunlight, are usually cooler, wetter, and likely have reduced plant growth, but allows for greater survival at the expense of faster growth rates, in comparison to warmer south facing slopes. Competition also plays a role in structuring these communities, but this topic has not been researched enough to make predictions about the effects of climate change on competition (Armstrong 1974, Armstrong 1991, Kutiel et al. 1998). Several studies from different regions around the world have contributed to our understanding of how lichen communities will respond to climate change. The habitats that lichens inhabit are harsh, exposed and potentially the hardest environment to survive in when responding to changes in the climate (Chapin et al. 2012, Chapin et al. 2013. Climatic manipulation experiments showed drastic changes in diversity and colonization (Insarov et. al 1999, Van Herk et. al 2002, Parmesan and Yohe 2003, Chapin and Körner 2013). Thus, it is important to observe lichen communities to understand how climate change might affect the colonization of primary successors and in turn secondary succession of higher plants. The way lichens will respond to climate change is underrepresented in current biological models and are an important piece of the puzzle of how species distribution will change. Previously work has analyzed environmental factors such as rock face, slope, aspect, and microtopography which have all been found to affect lichen distribution making it difficult to model impacts to these communities (Larson 1980, Pentecost 1980).

This study will pursue three questions to understand how lichens in the Gunnison National Forest might be affected by global climatic changes: 1) How does the diversity and cover of lichens change along an elevation gradient on talus slopes? 2) How does the diversity and cover of these lichens change with different aspects? 3) What broad inferences can be made with the collected data and climatic data to show how lichen diversity and cover will respond to climate change?

Methods and Materials:

Field Sites: This study took place in the subalpine zone on six different granitic talus slopes of the Gunnison National Forest, near the Rocky Mountain Biological Laboratory (RMBL) (Figure 1, Figure 2, Table 1). Elevation of surveyed talus slopes ranged from 2,908 m - 3,588 m. The monthly average

precipitation in inches during summer months are; June = 1.33, July = 1.98, August = 2.15, September = 2.03 (WRCC 2016).

Field and Laboratory Methods: Six permanent study sites were established, on three paired north-facing and south-facing talus slopes, at three different elevations. First, the perimeter of each talus field site was mapped using a Trimble GeoXT. Within each of the six sites, 15 plots were randomly selected by blindly marking a paper map. At each plot center and along the two transects a discrete permanent plot marker was established using a dot of orange nail polish so it can be revisited. From each permanent plot center, two 1 m transects following north-south direction originating from the plot center were established. Along each transect the largest rock of uniform composition was chosen for sampling. Sites near trees were avoided as they can create environmental variation in comparison to the open talus slopes. The total sampling effort was: 6 sites with 30 one meter transects per site, 180 transects in total. In the field, lichens were identified to species using chemical tests (Potassium hydroxide staining), hand lens, and “A Color Guidebook to Common Rocky Mountain Lichens” (St. Claire 1999). A picture of each rock, with a meter stick laid along the transect line, was taken with an iPhone 6s (12-megapixel camera). The pictures were then loaded into ImageJ software (Schneider 2012) and the length of each lichen thallus and bare rock were measured in centimeters, noting the beginning and end of the intersection. The following data was collected at each plot: GPS coordinates, elevation, rock type, slope, aspect, transect number, identity of species intercepted, length of each species intercepted, microtopography of the rock, and total number of lichen thalli crossed by the transect.

Data Analysis: For each transect, the number and size of each lichen thallus intercepted by the transect were calculated for each species. Total length of unoccupied (bare) rock was also determined. The relative cover of each lichen species was calculated by dividing the total length of transect intercepted by thalli of a species by the total length of the entire transect (rock). These data were then used to estimate the following measures:

1. Species Composition and Total Cover at Different Sites:

The relative abundance of each species at the six sites was estimated by summing the length of each species cover per site and dividing by the total rock length at the site. Patterns of relative species abundance (cover) was examined visually for changes with elevation and aspect. The average total cover of all lichen species at each site was calculated by dividing the total intercept length of all lichen species at a site by the total length of all the rocks sampled at that site. The percent of lichen cover across the entire site was calculated by dividing the total lichen cover by total rock length and multiplying by 100.

The standard deviation of lichen cover was calculated from total lichen cover per transect among the 30 transects at each site.

2. Species Richness and Diversity Across sites:

The Shannon-Wiener Diversity Index was calculated for each site to determine differences among sites in species richness and relative abundance. Relative cover of each species was used as the metric of abundance. Differences among sites in the diversity index were tested with pairwise t-tests among all sites (Magurran 1988).

3. Lichen Thallus Size at Different Sites:

The average lichen thallus size of the five most abundant and widespread lichen species; *R. geographicum*, *L. atrobrunnea*, *L. novomexicana*, *R. geographicum*, *X. coloradoënsis* and *X. plittii*, were estimated at sites 1- 4. Size for *X. coloradoënsis* could only be calculated for sites two and four. Differences in thallus size (size distributions) were examined to estimate population colonization and growth rate among species. The differences among species mean thallus size at different sites were analyzed with an ANOVA test.

Data was analyzed and statistical analyses were completed on Excel 2016 to create figures, graphs for examining the effects of elevation and aspect on lichen diversity and cover of the lichens across sites.

Materials include: iPhone 6s, meter stick, clinometer, orange nail polish, Trimble GeoXT, Garmin eTrex Vista HCx, ArcMap v10.4, cards with site, plot and transect information, Excel 2016, ImageJ, reagents used for lichen identification (Potassium hydroxide, UV light), hand lens and “A Color Guidebook to Common Rocky Mountain Lichens” (St. Claire 1999).

Results:

Species Encountered:

Thirteen saxicolous species of lichen were observed representing nine genera, five are foliose (*Rhizoplaca chrysoleuca*, *Umbilicaria decussata*, *Umbilicaria virginis*, *Xanthoparmelia coloradoënsis*, *Xanthoparmelia plittii*) and eight crustose (*Caloplaca saxicola*, *Diploschistes scruposus*, *Lecanora novomexicana*, *Lecanora rupicola*, *Lecidea atrobrunnea*, *Lecidella stigmatea*, *Rhizocarpon disporum*, *Rhizocarpon geographicum*) (Image 1-13).

1. Species Composition and Total Cover at Different Sites:

Across the elevational gradient the species *R. chrysoleuca*, *U. decussata*, *U. virginis*, *X. coloradoënsis*, *X. plittii* and *L. novomexicana* all decreased as elevation increased. Foliose lichens were found more at north facing aspects than south facing aspects (Figure 3). The most common species were *L. atrobrunnea*, *R. geographicum*, *L. novomexicana*, *X. plittii* and *X. coloradoënsis*.

The relative cover of *L. atrobrunnea* and *R. geographicum* were the most abundant of the 13-species encountered and found at all sites except site 6. Overall *L. atrobrunnea* was the dominant lichen across all sites and was found at all sites, primarily on south facing slopes, except in sites of high elevation where cover had decreased significantly (Figure 3).

Species cover over the elevational gradient of all five foliose lichens decreased as elevation increased, and were more abundant on north facing slopes (Figure 3). It was found that there were fewer lichens at higher elevations. Uncommon crustose species included *R. disporum*, *D. scruposus*, *C. saxicola*, *L. rupicola*, *L. stigmathea* (Figure 3). Uncommon foliose species included *R. chrysoleuca*, *U. virginis*, and *U. decussata* (Figure 3).

Overall the total percent cover decreased as elevation increased. At low elevations, the north facing slope had the most cover at 60% before decreasing by 20% at the mid elevation site before further decreasing to 1% at high elevation. The low elevation site reported 58% cover before decreasing to 48% at mid elevation and then further decreasing to 42% at high elevation. There was 3% more lichen cover on the low North aspect in comparison to the low South aspect site. At mid elevations, the South aspects had 6% more cover and at high elevations the south aspect had 41% more cover (Figure 4).

2. Species Richness and Diversity Across Sites:

Diversity differed significantly among all sites except between sites 1-3 (T-statistic = -0.716, $p = 0.24$); the low elevation and mid elevation south facing slopes (Table 2, Table 3).

As elevation increased, diversity decreased, with the highest diversity value of -1.321 at low elevation North aspect. At mid North aspect, a Shannon Diversity Index value of -0.917 was calculated and at high North aspects a value of -0.073 was calculated showing there was less diversity in comparison to their matching South aspects. Mid south reporting a Shannon Diversity Index value of -1.098 and high south reporting -0.722. Species richness also decreased with elevation with a maximum of 11 species present at low and mid south aspect sites and a maximum of eight species at high south and two species at high north aspect (Table 3).

3. Lichen Thallus Size at Different Sites:

On South facing aspects the mean thallus size increased from low to mid elevations before decreasing at high elevations. On North facing aspects *L. atrobrunnea* and *L. novomexicana* mean thallus size increased

with elevation while *R. geographicum* and *X. plittii* decreased with elevation. The mean thallus size of *L. atrobrunnea*, *R. geographicum*, *L. novomexicana* and *X. plittii* was unable to be calculated for the high elevation North aspect so the high elevation sites were omitted. The mean thallus size of *L. atrobrunnea* and *L. novomexicana* increased with elevation by ~50%, until complete absence in high elevation north aspect sites. *Rhizocarpon geographicum* decreased average size by 3 mm and the foliose lichen *X. plittii* decreased in size by 8 mm from low to mid elevation at north aspect sites.

The mean thallus size of all crustose lichens increased from low to mid elevation before decreasing at high elevation south aspect sites. *Lecanora atrobrunnea* and *R. geographicum* increased ~5 cm while *L. novomexicana* increased <3 mm. At the high elevation sites, all three-crustose species decreased in mean thallus size by ~50%. However, the foliose *X. plittii* had the highest cover at 3.966 cm at low elevation, decreasing to 3.284 cm in the mid elevation and not present at high elevations (Figure 5).

Lecanora novomexicana at low elevation south aspects was greater in size and more numerous than at North aspect sites. At South aspects from low to high elevation the mean thallus size increased from 1.756 to 1.787 cm while also increasing in the number of thalli from 15 to 66. The North aspect low site only had three thalli while the North mid aspect site had 18 thalli. From low to mid elevation on North aspects mean thallus size increased from 0.499 to 0.895 cm. The largest thalli were at the mid elevation north site at 6 to 7 cm across (Figure 6).

The thallus size of *L. atrobrunnea* decreased with elevation for south aspects from 2.173 to 2.605 cm and decreased in number of thalli from 141 to 134. North aspect means thallus size increased from 1.114 to 1.540 cm and increase from 87 thalli to 97 thalli. The largest thallus was 19-20 cm at the low elevation South aspect site (Figure 7).

The number of thalli of *R. geographicum* increased from 71 to 96 on South facing aspects but the size of the thalli increased from 0.513 to 1.057. The North aspects thalli number dropped from 119 to 69 as well as the mean size from 1.826 to 0.874 cm. Across all sites the largest thallus size was reported at 11-12 cm at the low elevation North aspect site (Figure 8).

Xanthoparmelia coloradoënsis was only observed at North aspects, decreasing in mean thallus size from 4.252 to 2.719 cm and number of thalli from 19 to 9 as elevation increased. The largest thallus was 15-16 cm at the low North aspect site (Figure 9).

Xanthoparmelia plittii decreased in the number of thalli in elevation by 15% at North and South aspects. On South aspects, the mean thallus size dropped by 0.389 cm, while North aspects dropped 0.812 cm. The largest thallus across all sites was found at the low South aspect site at 16-17 cm (Figure 10).

Discussion:

Aspect and Elevation:

Overall the diversity and cover of lichen decreased with elevation. The pattern between North and South aspects was harder to decipher and possibly depends on unmeasured environmental factors such as snow melt, precipitation, growing season and temperature.

On south slopes *R. geographicum* cover increased as elevation increased and appears to be more adapted to the southern slopes in Gunnison National Forest, based on consistent thallus number and size increase (Figure 3, Figure 8). Previous research has shown that *R. geographicum* is more common on southern aspect and can last 26 weeks without reactivation, and may be well suited to a warming climate (Armstrong 1974, Green and Lange 1994).

The differences between south facing sites 1- 3 were not significant, showing that these low and mid elevation communities are similar in diversity and cover. This was not observed with the other south facing site comparisons 1- 5 or 3 - 5, where at site 5 lichen community diversity decreased. This is likely due to a shorter growing season and less precipitation.

The small thallus size of *L. novomexicana* at site 2 may indicate that it receives less sunlight and more precipitation, as the mean thallus size and number of thalli are much lower in comparison to the three other sites. The thallus number and size on South aspects was much larger than North aspects supporting that South aspects receive less precipitation and more sunlight. While sampling the low North site several squamulose and terricolous foliose species were encountered (*Cladonia* sp., *Peltigera* sp.), as well as several bryophyte species which require more water and less sunlight (Ried 1953). This indicates that this site is less harsh having the ability to support foliose and fruticose species. This is further supported by the presence of *X. coloradoënsis* and *X. plittii* at higher number of thalli and size at low elevations (Figure 9, Figure 10). At mid elevations, the thallus number and size decrease indicating that the mid elevation site receives less precipitation or has a shorter growing season. The presence of *X. coloradoënsis* only at North aspects and decreasing in size and number with elevation is further support that it is drier at mid and high elevation sites (Figure 9). The large number and size of *X. plittii* on South aspects hints that it is more tolerant of dry conditions than the other foliose species (Figure 10). The largest thalli of *X. plittii* was found at the low South aspect site eluding that it is more tolerant of dry conditions.

The presence of *L. novomexicana* at site 6 is somewhat an anomaly and may be attributed to quick and successful colonization even though it is adapted to more arid climates (Nash 2002).

At site 6 almost all rocks that were intersected were completely bare, with only *L. novomexicana* and *L. stigmatea* present in low abundance. The significant differences in site 6 can likely be attributed to a combination of several different environmental factors, including different rock substrate (consisting of sedimentary rocks and less granitic rock), which allowed for a rock face with more frequent rock falls.

When surveying site 6 there were several active rock falls observed. The few lichen thalli that were seen, were on buried rocks, or large boulders but still had less lichen cover and species present than any other site (Figure 3). Previous studies have shown that on an elevational gradient crustose lichen cover does increase until a certain threshold, this can likely be attributed to the active rock wall disrupting colonization as well as environmental factors (Baniya et al. 2010, John and Dale 1990). When sampling, *X. plittii* was observed to be at the edge of the talus field site, however, it did not cross any transects. It is likely that the edge of a talus field has more water availability and less harsh conditions. A similar pattern was observed at site 5 and may account for why there was less foliose species present in transects.

The mean thallus size and number of thalli of *L. atrobrunnea* differing so greatly between sites can likely be attributed to fast colonization rates rather than elevation, aspect or other unmeasured environmental factors. There is a slight relationship with North facing aspects as *L. atrobrunnea* increases in thalli size and number with elevation. This shows that *L. atrobrunnea* may be more adapted to colder, wetter alpine sites.

The use of *L. atrobrunnea* as a species to estimate talus slope age or colonization may be applicable as it is the most abundant and contains some of the largest thalli. There are however, problems with lichenometric dating, and the analyses must be used sparingly to report age of a rock fall or colonization. Lichenometric dating may not reliably report a talus slope age due to various environmental factors such as growth rates varying from year to year due to differences in precipitation (Osborn et al. 2015). Another reason for the ineffective estimation of lichenometric dating is that boulders on the talus slope may shift from year to year exposing lichens on varying microtopography's of the rock to sunlight and precipitation over the years. The tendency for lichen thalli to eventually deteriorate from their initial colonization point as they grow outwards adds to the complexity of measuring thalli to deduce colonization and rock fall age. The growing season for these lichens may also be different among sites due to differing rates of snow melt, but this was not able to be evaluated. Low elevation sites having a longer grow season with more precipitation and high elevation sites having a shorter grow season with less precipitation. With no consistent growth rates, it is difficult to accurately assess the age of talus slope.

The age of the rock falls and lichen communities can be estimated when sites are eventually revisited and if growth rates are able to be calculated. Currently, it is unknown whether lichens will increase in abundance at high elevation sites as the climate changes. Drought conditions will likely shift lichens to higher elevations, while a climate scenario with increased precipitation might allow continual colonization at currently inhabited elevations.

Climate Change:

According to the Intergovernmental Panel on Climate Change (IPCC) the effects of climate change in Colorado is still uncertain (Pachauri et al. 2014). Over the past 30 years Colorado's average

temperature has increased 2°F and all climate models suggest that warming will continue to substantially increase. However, the climate models are inconclusive of how precipitation is expected to change (Pachauri et al. 2014). The Representative Concentration Pathways (RCP) 4.5 medium-low emission scenario predicts annual precipitation to change from -5% to +6%. Under the RCP 8.5 high emissions scenario, a -3% to +8% change in precipitation is expected (Pachauri et al. 2014). Winter precipitation is expected to increase, however, predictions on the effects of precipitation in other seasons is uncertain (Pachauri et al. 2014).

If summer precipitation were to increase in this area, erosion of these rocks would increase, further facilitating a community that cannot easily be colonized, where on a more stable slope the cover of lichen would likely increase (Fischer et al. 2010). Using site 6 as an example we can expect that if the substrate that lichens require is shifting and eroding away too quickly for colonization, species richness would be reduced even more than it is already on these slopes and others. Lichen colonization takes several years and with sites with active rock walls and talus slope that there will be little colonization, the almost complete lack of lichen species supports that this is an active rock fall site. Snow patches still covered parts of the slope even late into the summer months (7/27/2017 - 7/28/2017), which could also contribute to decreased colonization of lichens. Whereas south facing site five on the other side of the basin had a much larger community in comparison (Figure 3). The colonization of foliose species is a restricting factor, if the substrate and precipitation is not appropriate, there is restricted colonization if they are asexually producing through isidia and soredia (Armstrong 1981).

Low sites likely receive the most precipitation resulting in greater diversity and evenness. Due to the reliance on summer rains, increased drought could be devastating to the survival of foliose species in mid and high elevation south facing sites. It is known that crustose lichens will have higher survivability in drier conditions as they are able to desiccate more efficiently than foliose species.

However, drought during the summer months could facilitate a shift in lichen communities with more arid species colonizing or loss of less drought-tolerant species that are currently present. Lichen response to climate change has been documented mostly in northern latitude European countries showing that lichens are sensitive to a changing climate. It is assumed that without regular precipitation during the growing season lichen communities will suffer and deteriorate because their biological tolerances will not be able to handle the changes or these alpine communities and will shift to more arid adapted species.

Over the past 22 years it was observed in the Netherlands that lichen diversity in the arctic and alpine regions show a decline of about 50% of the 329-species surveyed while the ranges of subtropical species was increasing, this was determined by latitudinal distribution and ecological determinants (van

Herk et al. 2002, Klanderud and Totland 2005). There are some exceptions to these reports, for example two lichens *Flavocetraria cucullata* and *Flavocetraria nivalis* are genetically equipped to survive in a new climate deduced by their genetic composition across the Arctic (Jozsef et al. 2010). This is most likely to be a small proportion of species while the rest are in severe decline (Van Herk et al. 2002).

It is expected with the climate models that more arid species will increase their range if summertime drought conditions increase, reducing lichen diversity and the cover of less drought tolerant species. On the other hand, if summer and winter precipitation is to increase so will the colonization and survival of these lichens, however erosion will also increase and it is speculated that if erosion is too quick there will be little to no colonization. However, liquid water is still required even for arid species to colonize, so if drought is severe enough it may restrict even these species from colonizing talus slopes.

Lecidea atrobrunnea may be more suited to North aspect high elevation sites, if precipitation were to increase it is likely that *L. atrobrunnea* abundance and cover will increase. If precipitation were to decrease it is likely that *R. geographicum* and *L. novomexicana* would become more abundant and have higher cover on North and South aspects.

Further research is needed to reveal the relationship of lichen cover, growth and diversity changes in response to climate change every five to ten years. Different data collection techniques may also help reveal a pattern, for example by running a single transect starting from the edge of the talus field to the highest point reachable. Measuring more environmental factors (grow season length, temperature, precipitation, exposure, etc.) would also help reveal other possibilities for the patterns shown.

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Tables and Figures:

Species Encountered:



Image 1: *Caloplaca saxicola*: Crustose with shallow lobed margins; yellow-orange to dark orange; Lecanorine apothecia; Thallus and apothecia K+ purple (St. Clair 1999, Rada 2017).



Image 2: *Diploschistes scruposus*: Crustose with continuous to coarsely cracked thallus; White-gray blue; Apothecia black lecanorine common and immersed in thallus; Cortex K- or K+ yellow (St. Clair 1999, Rada 2017).

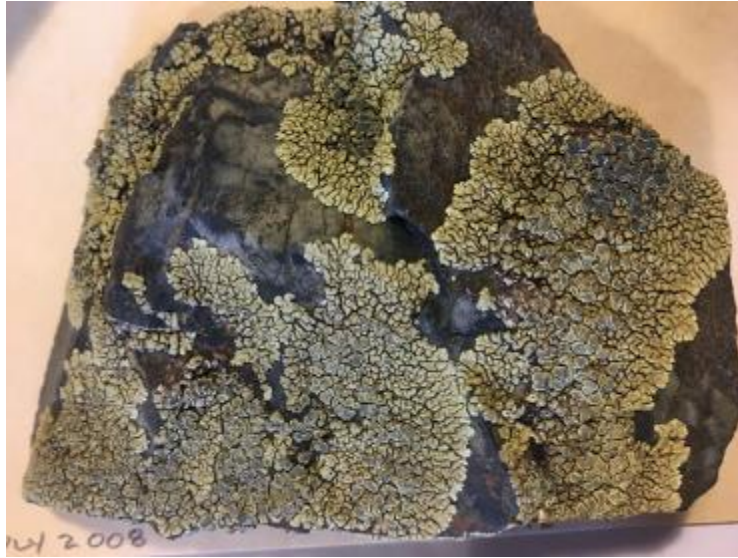


Image 3: *Lecanora novomexicana*: Crustose with lobate margins; Yellow-green in color; Common in circular patches; Lecanorine apothecia common; Apothecia tan to bluish black in color; +/- densely pruinose; Cortex K+ pale yellow, medulla K-; Warm desert sites to alpine (St. Clair 1999, Rada 2017).



Image 4: *Lecanora rupicola*: Crustose chinky-areolate; White to dark gray in color; Lecanorine apothecia white; Cortex K+ yellow; Granitic rocks boreal to alpine sites (St. Clair 1999, Rada 2017).



Image 5: *Lecidea atrobrunnea*: Crustose light gray-brown to dark brown; Well-developed black hypothallus; Lecideine apothecia black and common; Cortex and medulla K- (St. Clair 1999, Rada 2017).



Image 6: *Lecidella stigmata*: Crustose granular to areolate; White gray to grayish brown; Lecideine black apothecia sessile or adnate; Cortex K+ yellow; montane to alpine tundra (St. Clair 1999, Rada 2017).



Image 7: *Rhizocarpon disporum*: Crustose; Dark gray; black hypothallus; Lecideine black apothecia common; Medulla K- or K+ red (St. Clair 1999, Rada 2017).



Image 8: *Rhizocarpon geographicum*: Crustose; Bright yellow to greenish yellow, dull or shiny; Well-developed hypothallus; Lecideine black apothecia, flat to convex; Medulla K-; Boreal and alpine sites (St. Clair 1999, Rada 2017).



Image 9: *Rhizoplaca chrysoleuca*: Foliose, umbilicate, solitary to crowded and fused, lacking rhizines; Green thallus; Lecanorine orange apothecia; Medulla K- (St. Clair 1999, Rada 2017).



Image 10: *Umbilicaria decussata*: Foliose, umbilicate, lobate, distinctly pruinose ridged; Lacking rhizines; Lecideine black apothecia rare; Medulla K-; Subalpine sites to desert (St. Clair 1999, Rada 2017).



Image 11: *Umbilicaria virginis*: Foliose, black-gray, umbilicate, rounded to irregularly lobate, wrinkled or well developed uneven ridges; Lecideine black apothecia common; Rhizines present; Subalpine and alpine (St. Clair 1999, Rada 2017).



Image 12: *Xanthoparmelia coloradoënsis*: Foliose, narrow lobes; Pale green to yellow green; Lecanorine apothecia brown and common; Lacking isidia or soredia; Medulla K+ yellow to orange; Various rock from mid to high elevations in intermountain west (St. Clair 1999, Rada 2017).



Image 13: *Xanthoparmelia plittii*: Foliose, adnate to loosely attached; densely isidiate at center of thallus; Pale green to yellow green; Lecanorine apothecia rare; pale brown rhizines; Medulla K+ yellow to orange; various rocks throughout intermountain west (St. Clair 1999, Uebel 2007).

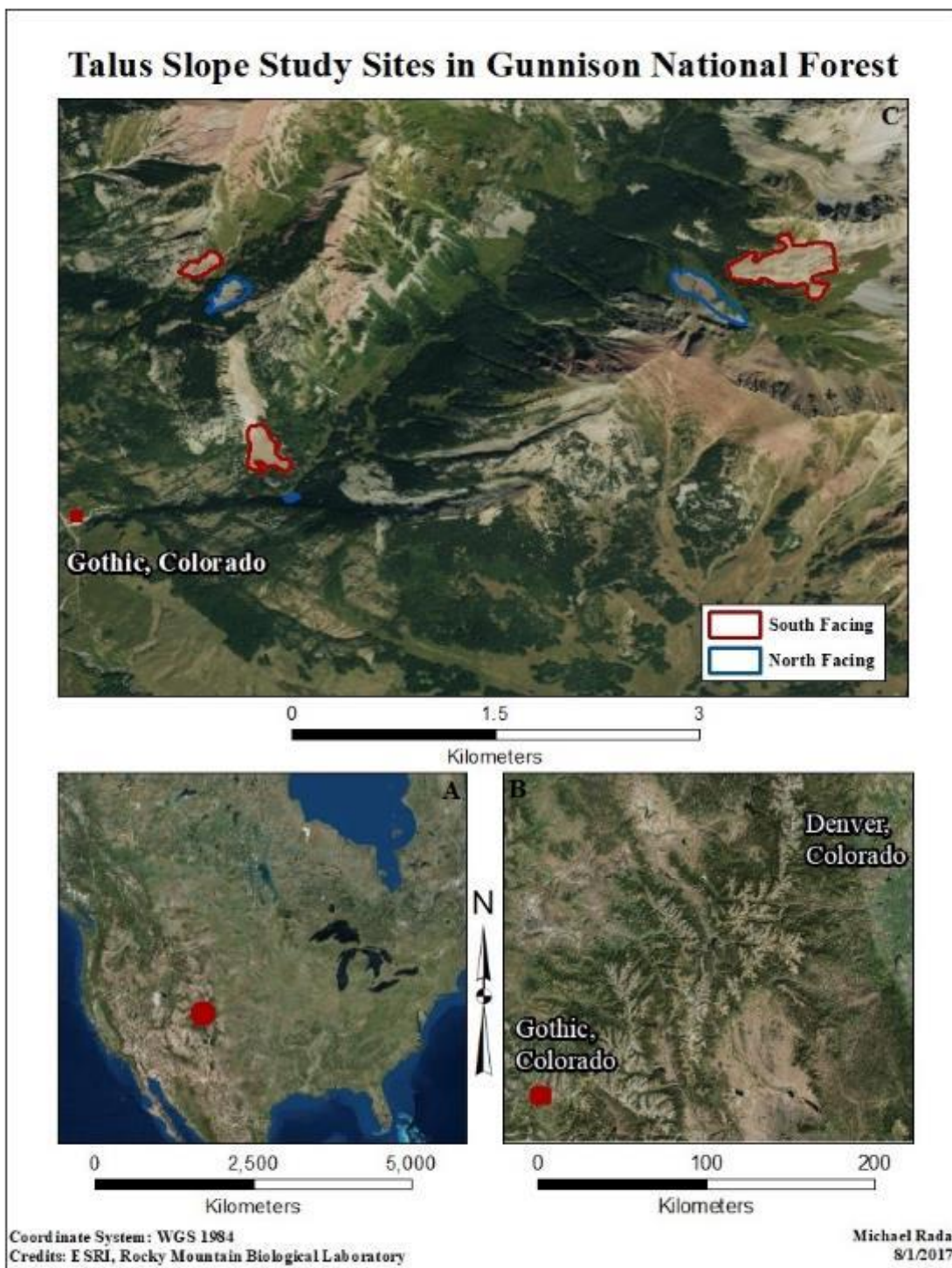


Figure 1. General location of the study area near the Rocky Mountain Biological Laboratory, Gothic, Colorado, USA (maps A, B), and the six study sites on north-facing (blue outline) and south-facing (red outline) talus slopes, relative to RMBL (map C).

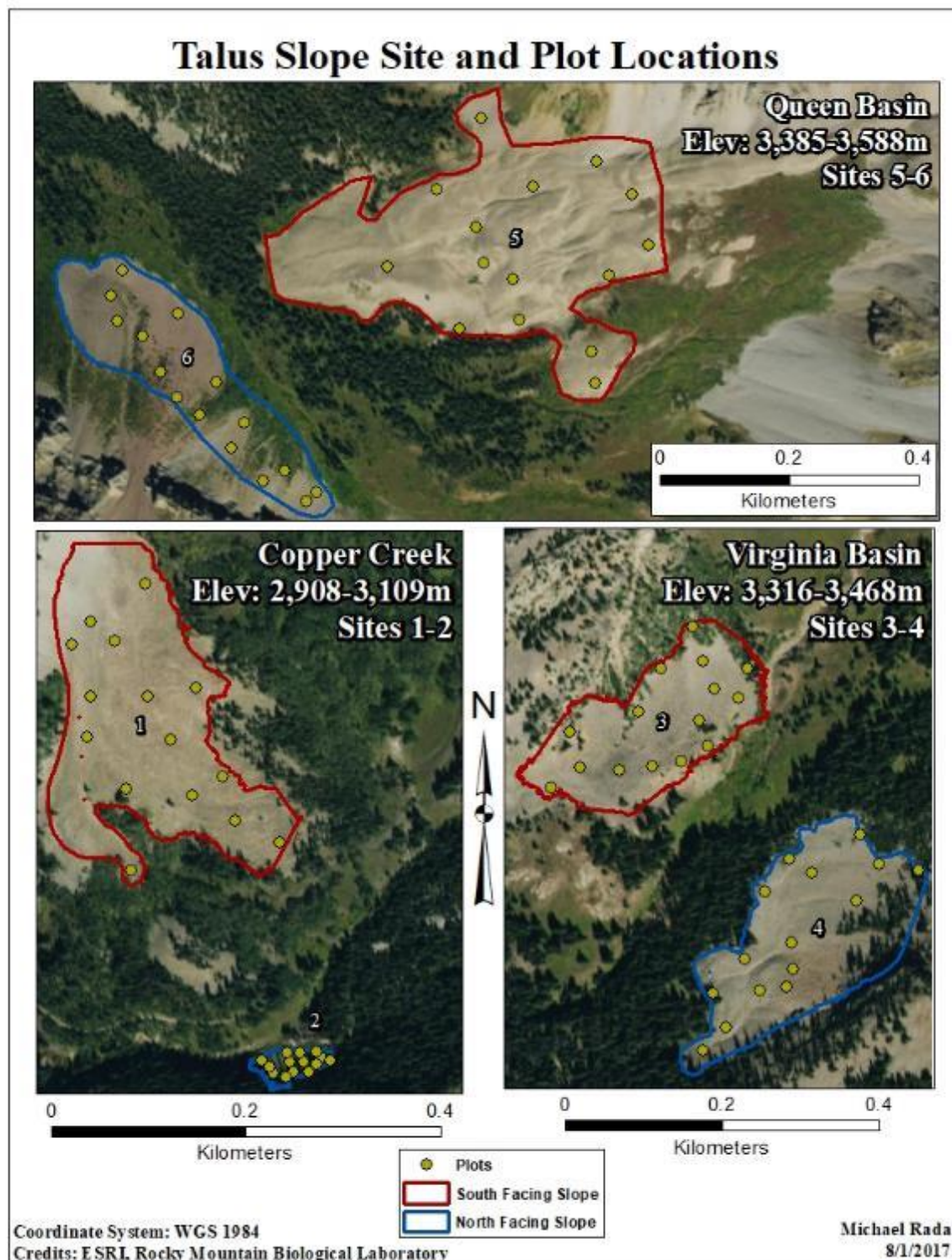


Figure 2. A series of maps showing each of the six sites sampled and 15 randomly chosen plots with each site.

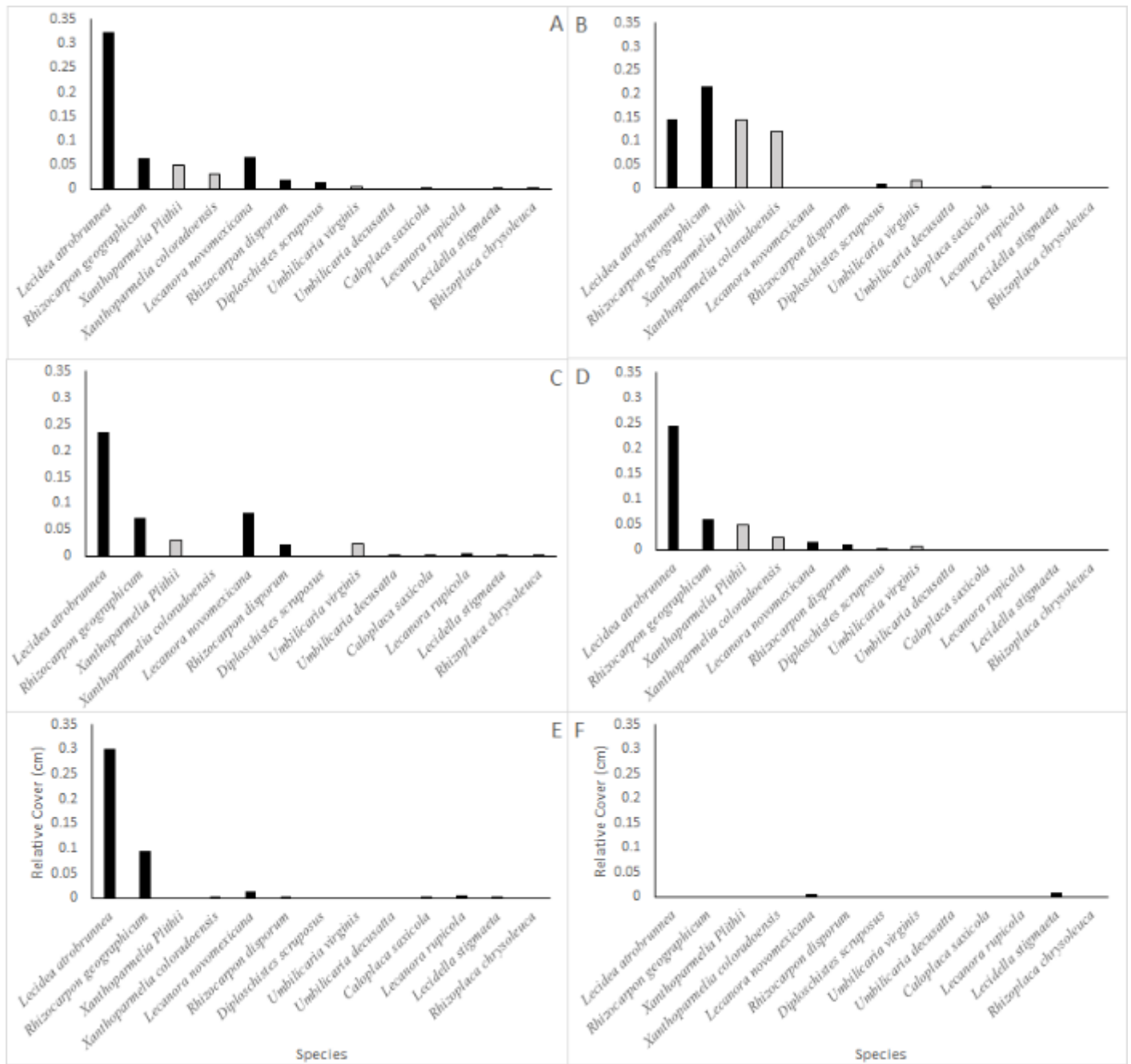


Figure 3. Relative cover of 13 species of lichens at the six study sites. Site 1 Low South **A**. Site 2 Low North **B**. Site 3 Mid South **C**. Site 4 Mid North **D**. Site 5 High South **E**. Site 6 High North **F**. Black bars indicate crustose species and gray bars indicate foliose species.

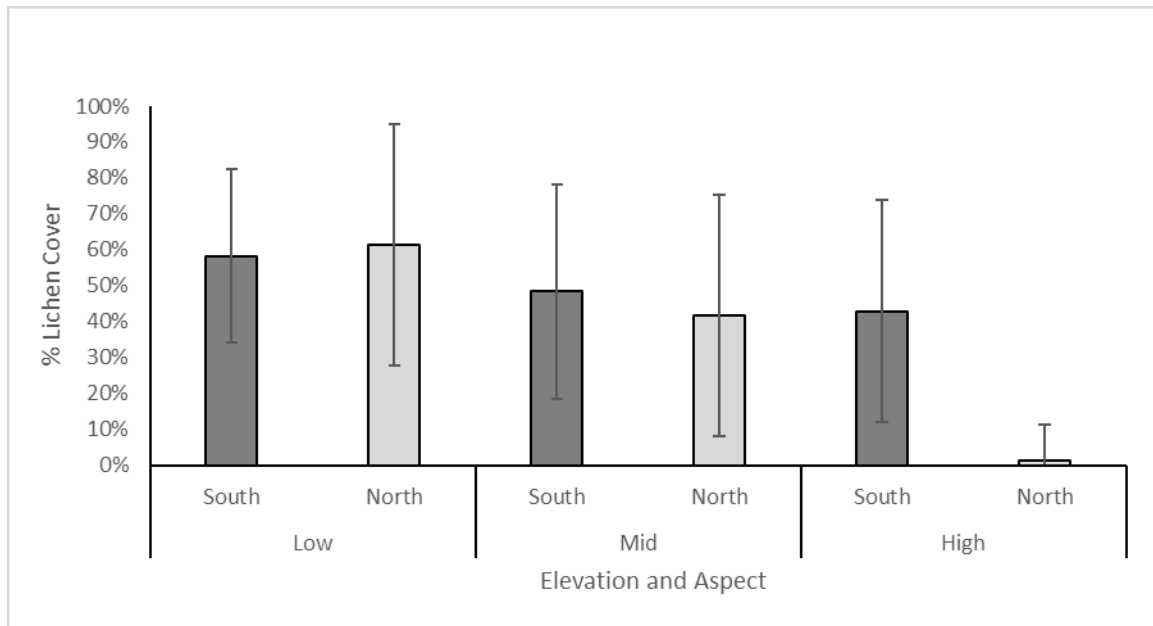


Figure 4. Percent total lichen cover over elevation gradient and aspect.

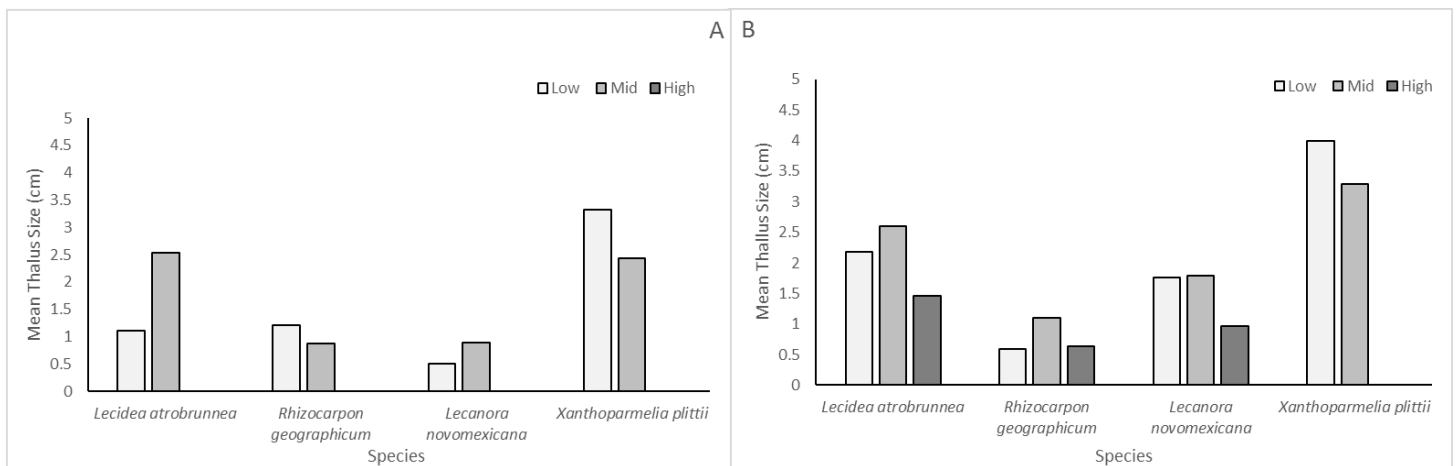


Figure 5. The mean thallus size of *R. geographicum*, *L. atrobrunnea*, *L. novomexicana*, *X. plittii* across all sites. Mean thallus size along North aspect **A**. Mean thallus size along South aspect **B**.

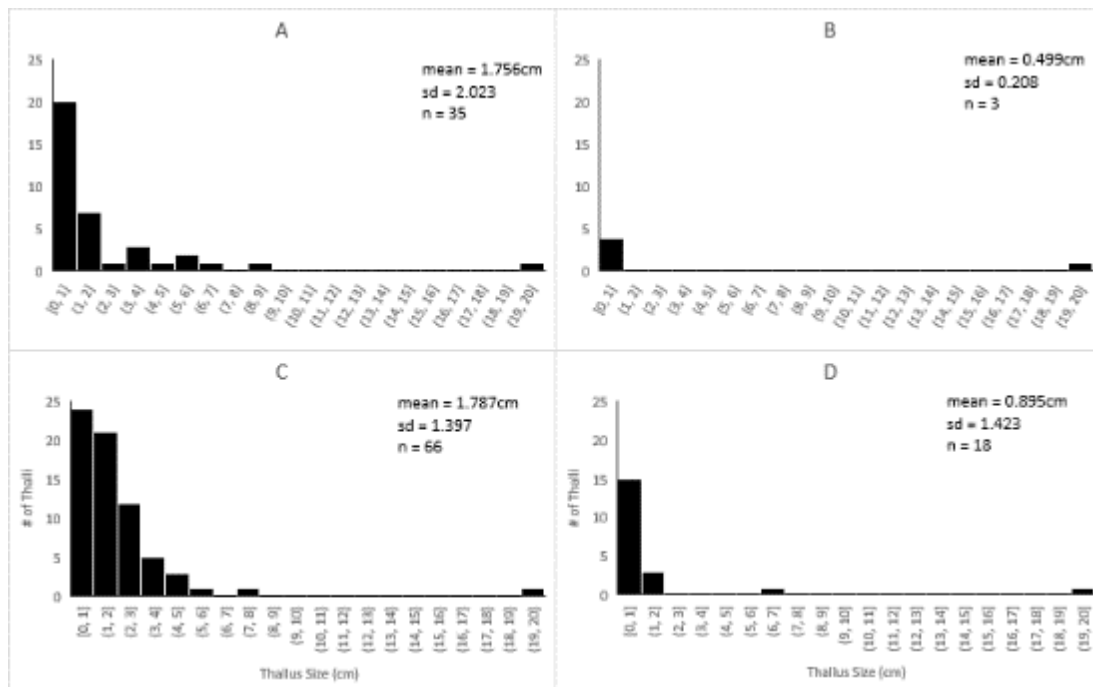


Figure 6. The size, number of thalli, mean thallus size and standard deviation of *L. novomexicana* across sites 1- 4. Low South **A.** Low North **B.** Mid South **C.** Mid North **D.**

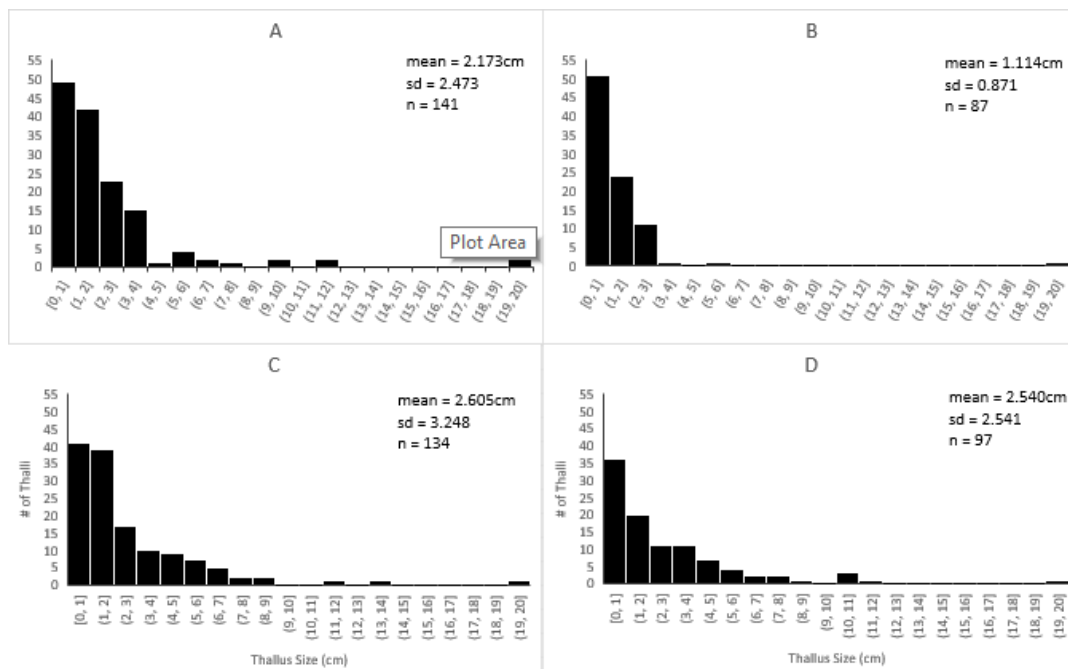


Figure 7. The size, number of thalli, mean thallus size and standard deviation of *L. atrobrunnea* across sites 1- 4. Low South **A.** Low North **B.** Mid South **C.** Mid North **D.**

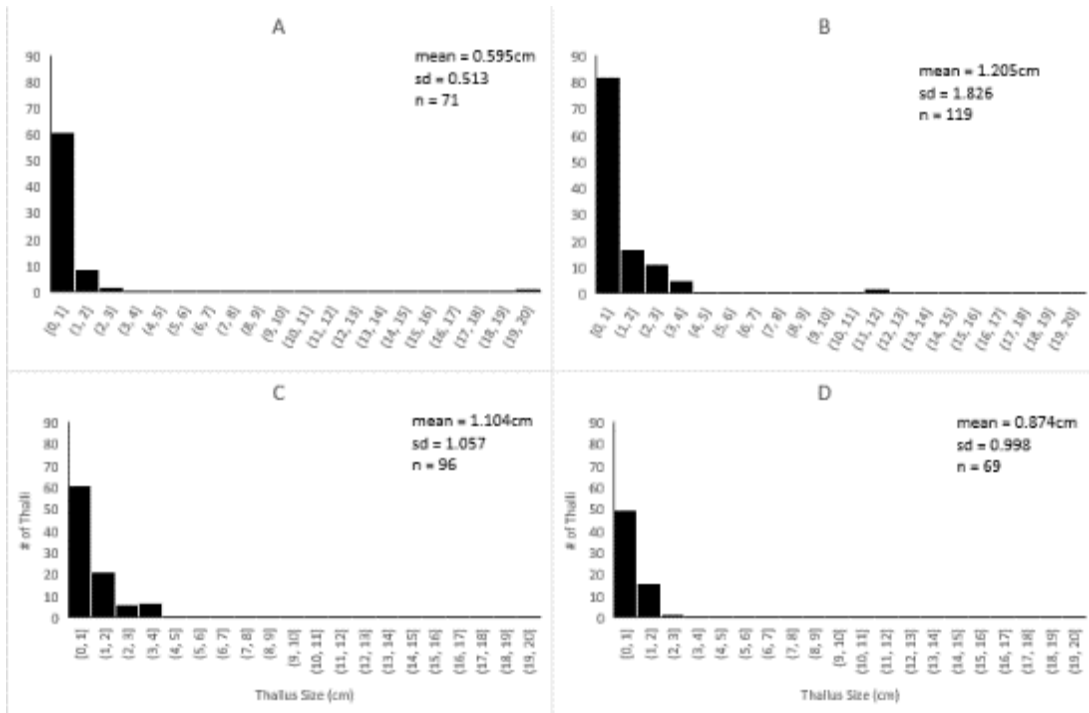


Figure 8. The size, number of thalli, mean thallus size and standard deviation of *R. geographicum* across sites 1- 4. Low South **A**. Low North **B**. Mid South **C**. Mid North **D**.

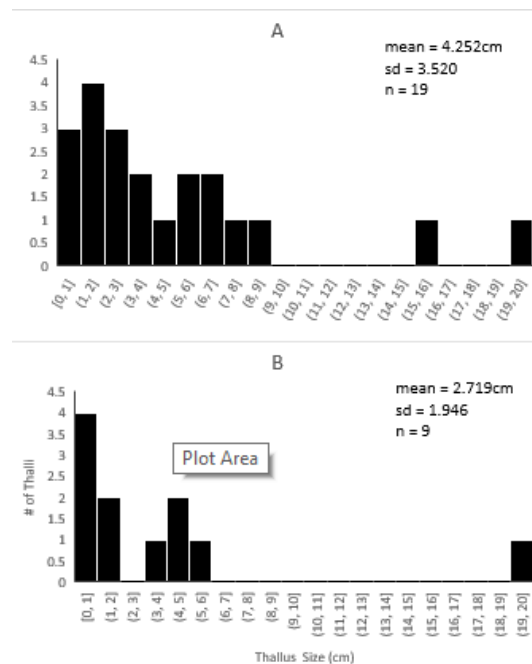


Figure 9. The size, number of thalli, mean thallus size and standard deviation of *X. coloradoënsis* between sites 2 and 4. Low North **A**. Mid North **B**.

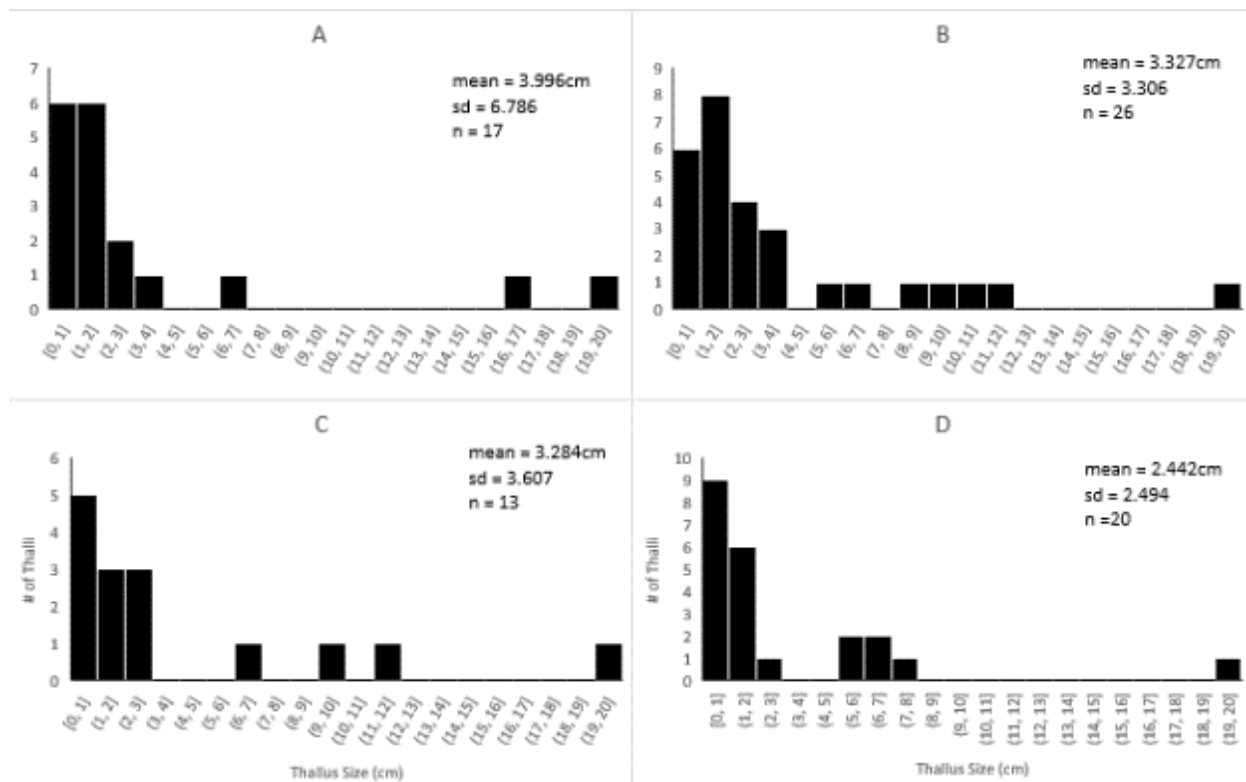


Figure 10. The size, number of thalli, mean thallus size and standard deviation of *X. plittii* across sites 1-4. Low South **A.** Low North **B.** Mid South **C.** Mid North **D.**

Table 1. Description of sites sampled in this study: aspect, elevation, the distance from Gothic and collection date are given.

Site #	Aspect	Location	Distance From Gothic	Date of Collection
1	South	Copper Creek (3,053 - 3,109 m)	~1.5 km	7/8/2017
2	North	Copper Creek (2,908 - 3,007 m)	~1.5 km	7/9/2017
3	South	Virginia Basin (3,316 - 3,394 m)	~2.4 km	7/14/2017
4	North	Virginia Basin (3,316 - 3,468 m)	~2.4 km	7/15/2017
5	South	Queen Basin (3,481 - 3,588 m)	~5 km	7/28/2017
6	North	Queen Basin (3,385 - 3,456 m)	~5 km	7/29/2017

Table 2. Results of pairwise t-tests for differences in Shannon-Wiener Diversity Index among sites.

	Site 1 (South, Low)	Site 2 (North, Low)	Site 3 (South, Mid)	Site 4 (North, Mid)	Site 5 (South, High)	Site 6 (North, High)
Site 1 (South, Low)		(T = 3.004, p = .003506)	(T = -0.716, p = .240958)	(T = -3.666, p = .000826)	(T = -7.421, p = .00001)	(T = -22.07, p = .00001)
Site 2 (North, Low)	(T = 3.004, p = .003506)		(T = -4.121, p = .000293)	(T = -7.005, p = .00001)	(T = -11.28, p = .00001)	(T = -27.95, p = .00001)
Site 3 (South, Mid)	(T = -0.716, p = .240958)	(T = -4.121, p = .000293)		(T = -3.351, p = .00184)	(T = -7.660, p = .00001)	(T = -25.74, p = .00001)
Site 4 (North, Mid)	(T = -3.666, p = .000826)	(T = -7.005, p = .00001)	(T = -3.351, p = .00184)		(T = -3.674, p = .001077)	(T = -18.95, p = .00001)
Site 5 (South, High)	(T = -7.421, p = .00001)	(T = -11.28, p = .00001)	(T = -7.660, p = .00001)	(T = -3.674, p = .001077)		(T = -16.949, p = .00001)
Site 6 (North, High)	(T = -22.07, p = .00001)	(T = -27.95, p = .00001)	(T = -25.74, p = .00001)	(T = -18.95, p = .00001)	(T = -16.949, p = .00001)	

Table 3. Shannon Diversity Index values with evenness for each site.

	Shannon Diversity Index	Evenness (n)
Site 1	-1.139064902	11
Site 2	-1.321089401	9
Site 3	-1.098148184	11
Site 4	-0.917179324	8
Site 5	-0.722717587	8
Site 6	-0.073078587	2