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**Impacts of rock climbing on lichen and bryophyte communities at  
McLellan Rocks and Sharon Climbing Areas, Spokane County, WA**

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IMPACTS OF ROCK CLIMBING ON LICHEN AND BRYOPHYTE COMMUNITIES  
AT MCLELLAN ROCKS AND ROCKS OF SHARON CLIMBING AREAS,  
SPOKANE COUNTY, WA

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A Thesis  
Presented To  
Eastern Washington University  
Cheney, Washington

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In Partial Fulfillment of the Requirements  
for the Degree  
Master of Science in Biology

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By  
Giovanna M. Bishop  
Spring 2021

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## ABSTRACT

Saxicolous lichens and bryophytes dominate cliff communities of Eastern Washington State. A recent rise in the outdoor recreation of rock climbing has caused major concerns over its potential negative impacts on cliff-dwelling biodiversity. To better understand how rock climbing is impacting lichen, bryophyte and vascular plant communities in Spokane, WA, I surveyed two sites: McLellan Rocks and Rocks of Sharon, for the abundance, richness and diversity of lichens, bryophytes and vascular plants. Sixteen paired transects consisting of a climbed route and the unclimbed adjacent cliff face, with eight plots per transect for a total of 256, 0.5m<sup>2</sup> plots were surveyed for this study. Climbed and unclimbed communities overlapped, but were significantly different from one another. Overall, cover was significantly lower in climbed transects compared to unclimbed transects. Rock climbing routes at McLellan Rocks had reduced plant cover, richness and diversity. Climbing also decreased lichen cover, richness, and diversity, however, it was site specific: lichen cover and diversity decreasing at Rocks of Sharon, while lichen richness decreased at McLellan Rocks. Lichen morphogroups were differentially impacted. Crustose and endolithic lichen cover and richness exhibited a positive response to climbing pressure at McLellan Rocks, and crustose lichen richness was also higher in climbed vs. unclimbed areas at Rocks of Sharon. The remaining morphogroups decreased in cover, richness, and diversity in response to rock climbing. Specifically, foliose cover, fruticose cover, umbilicate cover, richness, and diversity, and leprose cover at Rocks of Sharon were lower on climbed routes, as was fruticose lichen cover at McLellan Rocks. In addition to climbed status, route age, route popularity, approach distance, slope, rock heterogeneity, plot height, and canopy cover significantly

influenced community composition. I found 118 lichen, 29 bryophyte and two vascular plant species. The most common species were crustose lichens within the genus *Rhizocarpon*, and the most diverse lichen groups were the foliose genus *Xanthoparmelia* and the umbilicate lichen genus *Umbilicaria*. At the McLellan Rocks site, bryophytes were extremely diverse and abundant, species included the mosses *Grimmia trichophylla*, *Antitrichia californica*, and *Syntrichia ruralis* as well as the liverwort *Porella cordaeana*. Based on my results, I conclude that rock climbing mainly impacts cliff-dwelling lichen, bryophyte and vascular plant communities at my studies sites in decreasing cover, richness, and diversity. However, different patterns of impacts were observed at the two sites surveyed here, suggesting that unique management plans must be developed for each climbing area.

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*IMPACTS OF ROCK CLIMBING ON LICHEN AND BRYOPHYTE  
COMMUNITIES AT MCLELLAN ROCKS AND ROCKS OF SHARON CLIMBING  
AREAS, SPOKANE COUNTY, WA*

Cliff Ecosystems

The biodiversity that inhabit cliffs makes them one of the most unique habitats on the planet. Cliffs are vertical faces of rock that include talus at the base and a plateau at the top. They are often located along coasts, rivers, and escarpments within mountainous areas (Larson et al. 2000). Historically, in North America cliffs have been viewed as ecosystems that are too extreme to harbor any biodiversity (Walker 1987; Larson et al. 2000). However, studies of cliffs in eastern Canada along the Niagara Escarpment suggest that cliffs are similar to old growth forests, due to the lack of anthropogenic influence and the presence of ancient trees (Walker 1987; Larson et al. 1999). Indeed, some *Thuja occidentalis* on the Niagara Escarpment reach 1,000 years old (Larson and Kelly 1991). Today, cliffs are seen as one of the least disturbed, ancient habitat types on the planet (Larson et al. 1999; Larson et al. 2000). In fact, cliffs are refuges that harbor a plethora of biodiversity that include vascular plants, bryophytes, lichens, fungi, invertebrates, birds and bats (Smith 1998; Graham and Knight 2004; Baur et al. 2017; Thiel and Spribille 2007; Adams and Zaniwski 2012; Boggess et al. 2017; Loeb and Jodice 2018; Covy et al. 2019; Wilson 2020).

Cliff faces contain many unique geological features that are formed over time through uplift, erosion, weathering, and climatic events. These features include cracks, ledges, crevices, joints, caves, and overhangs (Larson et al. 2000). Rock features on cliffs act as micro-habitats for many species, especially cliff vegetation. Cliff plant species often are high-light and high-stress specialists. They can tolerate extreme conditions, such as drought, temperature shifts, and high winds (Larson et al. 2000; Graham and Knight 2004). For many taxa this means they can compete against their terrestrial counterparts in cliffs despite the many abiotic factors they face including aspect, slope, rock heterogeneity, and canopy cover (Larson et al. 2000).

Considerable research has been done on plant cliff communities in North America, and Europe (Walker 1987; Clark 2012; Boggess et al. 2021). Many studies have found that cliffs harbor endemic, rare, and endangered species (John and Dale 1990; Matthes et al. 2000; Graham and Knight 2004; Clark 2012; Boggess et al. 2021). Common vascular plant communities include ferns, lycophytes, orchids, trees, cacti, and herbaceous eudicots (Larson et al. 2000). However, lichens and bryophytes often outcompete vascular plants on cliff faces and are the most diverse and abundant taxonomic groups due to their higher stress tolerance (Furness and Grime 1982; Hedderson and Brassard 1990; Glime 2017). Lichens are symbiotic organisms made of up a fungi and an alga and or cyanobacteria, and should not be confused with bryophytes, which are non-vascular plants. Recent studies on cliff plants have found new species records, and rare endemics (McMillan and Larson 2002; Thiel and Spribille 2007; Adams and Zaniewski 2012; Lorite et al. 2017; Boggess et al. 2017, Harrison 2020). Some examples include *Sarcocapnos pulcherrima*, a flowering plant endemic to limestone cliffs in Spain (Lorite et al. 2017), the lichen *Endocarpon latzelianum* Servít, a new species to cliffs in Europe, and the moss *Tetrodontium brownianum* (Dicks.) Schwägr., thought to be extirpated from cliffs in northern Germany (Thiel and Spribille 2007).

Cliffs are one of the few ecosystems with very few natural disturbances. Fires cannot easily reach them, and the only mammals to disturb them in North America are mountain goats and sheep (Larson et al. 2000). Even so, most sheer cliff faces receive little to no disturbance besides natural erosion, weathering and the past geological events that formed them. Although cliffs are culturally significant sites for Indigenous groups worldwide, and have been for thousands of years (McGrath 2016; Ahmad 2019), recently, rock climbing has become one of the main disturbances cliffs experience, and the rapid increase of the sport has quickly altered cliff habitats (Clark 2012; Holzchuh 2016; Boggess et al. 2021). Disturbances from climbing have not only raised concerns from cliff ecologists, but have directly impacted indigenous cultural sites and elicited large-scale efforts to protect them from rock climbing. For example the sites Devil's

Tower in Wyoming, USA and Uluru in Australia have led to court cases where Indigenous groups are fighting for climbing and permanent bolts to be illegal (Hanson and Chirinos 2001; McGrath 2016). The Access Fund has publicly acknowledged tribal lands, as many climbing areas in the United States are indigenous sites that still hold significance today (Ahmad 2019). Cliffs hold a bounty of biodiversity and human history and it is imperative that efforts are made through research and indigenous rights to conserve them for future generations.

### Rock Climbing

In North America climbing rock for sport first started in the late 1800's. Pitons were hammered into weaknesses in rock, cracks, as a way to protect climbers who fell off of a cliff face while attempting to climb to the top (American Alpine Club 2019). This method, however, scarred the rock, and more advanced safety equipment, including ropes and other tools have been incorporated over the past century. Safety and technology advancements have allowed climbing to develop into multiple sub-disciplines, including aid, traditional, sport, top rope, ice, bouldering and more (Attarian and Keith 2008).

The advent of sport climbing in the 1970's in western North America initiated an exponential rise in rock climbing. Sport climbing uses fixed bolts that are placed into the cliff and left permanently so that climbers may use them to easily clip their rope into as they climb a route (Boggess et al. 2021). Permanent bolts being left in the rock facilitated the congregation of climbers in specific areas for repeated climbs. The rapid increase in the popularity of climbing disciplines and climbing areas across the country means rock climbing is no longer a niche sport. There are over 35 million rock climbers worldwide (American Alpine Club 2019), and >200,000 currently developed routes in North America (mountainproject.com).

The rise of the popularity of rock climbing has inevitably led to negative impacts on cliff ecosystems (Holzchuh 2016; Boggess et al. 2021). One of the initial impacts before climbing starts is route development, which primarily involves scraping lichens and bryophytes off of the rock (Studlar et al. 2015), and cleaning the cliff of any loose rocks or vascular plants that might

hinder the safety and experience of the climber while on route. Seasonal cleaning along with continued climbing hinders the cliff biodiversity from recolonizing cleared space (Clark 2012). Because the popularity of climbing has increased so rapidly throughout North America it is essential to assess how exactly and extensively rock climbing is impacting cliff ecosystems (Boggess et al. 2021). Although management plans have been implemented at some climbing areas, most of the focus is on climber safety and trail maintenance, rather than conserving cliff ecosystems and the organisms that dwell there (Holzchuh 2016; American Alpine Club 2019; Boggess et al. 2021).

The impact of rock climbing on cliff ecosystems has been preliminarily studied worldwide (Boggess et al. 2021). Studies have shown that rock climbing negatively impacts overall abundance and diversity of birds, insects, bats and plant communities, however there is still much to learn about climbing impacts going forward (Camp and Knight 1998; Holzchuh 2016; Loeb and Jodice 2018; Covy et al. 2019; Wilson 2020; Boggess et al. 2021). Taxa vary in how they are impacted by climbing, with lichen abundance, richness, and diversity being decreased the most by rock climbing impacts when they are included in studies (Holzchuh 2016; Boggess et al. 2021). Ten peer-reviewed studies and two theses on the impacts of rock climbing in North America were included in a review by Boggess et al. (2021). Results from studies are conflicting: some finding no impacts to taxa (Kuntz and Larson 2006; Walker et al. 2004; Harrison 2020) and others finding significant impacts (Nuzzo 1996; Farris 1998; Camp and Knight 1998; McMillan and Larson 2002; Clark and Hessel 2015; Tessler and Clark 2016; Boggess et al. 2017; Covy et al. 2019). Locality, rock type, abiotic variables, climbing intensity, and study design are all factors that explain differences in results across studies (Boggess et al. 2021). A standard study design, including paired climbed and unclimbed transects is recommended in Boggess et al. (2021) to minimize abiotic variation among climbed and unclimbed transects. Overall, studies have shown that each cliff face is unique and in order to

fully understand rock climbing impacts to cliff plant communities, lichens and bryophytes must be included (Holzchuh 2016; Boggess et al. 2021).

*Pacific Northwest: Rock climbing, management, and previous research*

The Pacific Northwest (PNW) is home to some of the oldest rock climbing areas in North America. In total there are over 16,000 routes in Washington, Oregon and Idaho combined, with Washington alone having over 8,500 (mountainproject.com, Accessed: July 10<sup>th</sup>, 2021). The most popular climbing sites in the state are located east of the Cascade crest. Leavenworth, Vantage, Wenatchee, and Spokane, Washington all offer a plethora of climbing opportunities. Management plans for climbing areas in the PNW include re-bolting routes, trail maintenance, route development restrictions, and more depending on the area. The Bower Climbing Coalition has initiated and worked with many management plans at climbing areas across eastern Washington, and the Washington State Recreation and Funding Board provide grants to hire climbing rangers to help manage major climbing areas across the state (<https://rco.wa.gov/wp-content/uploads/2020/01/NEWS-178RecGrantAwards2018.pdf>, WA 2018). While multiple rock climbing areas in Washington have seasonal closures for raptor nesting (Hayes and Buchanan 2002), Beacon Rock State Park specifically includes a closure of one cliff face for two endangered vascular plant species: *Erigeron oregonus* and *Sullivantia oregano* (Beacon Rock 2017). However, to my knowledge, there have been no restrictions on climbing for any other organisms that dwell in rock climbing areas in Washington.

Landowners and managers are beginning to recognize the need to include vegetation surveys at climbing sites (American Alpine Club 2019). Preliminary biodiversity surveys have been initiated at some sites. Two peer-reviewed published studies from western North America were discussed in a review of rock climbing impacts (Boggess et al. 2021): a vascular plant study at Joshua Tree National Park in California, USA (Camp and Knight 1998) and a study that focused on cliff dwelling birds in the Flatirons of Colorado, USA that also included cliff dwelling plants (Covy et al. 2019). West of the Cascade crest in Washington along the Skagit River Gorge,

the U. S. Department of the Interior and the United States Geological Survey has funded non-vascular research in rock climbing areas for management purposes (Berkey 2019) as well as overall floristics work that did not focus on cliff habitats (Hutten et al. 2005). However, these are the only two known studies focused specifically on cliff dwelling lichens and bryophytes in the PNW. Moreover, a masters thesis on the effects of rock climbing on the rare plant *Silene seelyi* in climbing areas in Leavenworth, WA was found as the only rock climbing impacts study on vascular plants (Malkin 2002). Since, to my knowledge, no research has been published on rock climbing impacts in the PNW specifically, where biodiversity of lichens and bryophytes is especially unique, we do not know how rock climbing is impacting lichen and bryophyte cliff communities. With the increase of rock climbing in the PNW, it is imperative studies are done to better understand cliff floras and how rock climbing is impacting them.

### Lichens and Bryophytes

Lichens and bryophytes are relatively small, autotrophic and poikilohydric organisms that occur on every continent, usually in mixed communities (Proctor and Tuba 2002). Bryophytes are non-vascular plants that are comprised of three groups: mosses, liverworts, and hornworts (Leebens-Mack and Barker et al. 2019). Mosses are the most diverse group of bryophytes, with over 12,000 species. Liverworts are the second most diverse with 9,000 species and hornworts are the least diverse with only about 300 named species. Lichens are symbiotic organisms comprised of a fungi and an alga and/or cyanobacteria. Lichens are named after the fungal symbiont, which comprises the majority of the mass of the lichen, and there are approximately 20,000 described species worldwide (Grimm et al. 2021). Both lichens and bryophytes are sensitive indicators of human-caused changes to the environment like air pollution (Geiser 2004, Gatzliolis et al. 2016) and logging (Lesica et al. 1991; Vitt et al. 2019). While some lichen and bryophyte species are extremophiles and can withstand high-stress environments (Furness and Grime 1982; Armstrong and Bradwell 2010; Glime 2017), others are extremely sensitive to environmental change (Giordani et al. 2013; Glime 2017; Stark et al. 2017).

Grime (1977) created three life history classifications to explain environmental selection pressures of all groups of organisms. There are three main life history strategies: 1. Competitive species that dominate low stress and low disturbance environments, 2. Ruderal species that occur in low stress and high disturbance habitats, and 3. Stress-tolerant species that are predominant in high stress and low disturbance. Competitive species tend to grow quickly, while ruderal species specifically reproduce at faster rates (Grime 1977; Furness and Grime 1982; Glime 2017). Grime placed lichens in the stress-tolerant category and bryophytes between stress-tolerant and ruderal when explaining different life history strategies for different groups of organisms (Grime 1977; Glime 2017). Furthermore, Grime notes multiple examples of ruderal mosses, including *Funaria hygrometrica*, for its reproduction and weedy tendencies (Furness and Grime 1982). Overall many lichens and bryophytes are able to succeed in high-stress habitats that may be inhospitable to other organisms.

Responses to stress and disturbance vary among lichen and bryophyte functional traits and reproductive modes. Growth form, growth rate and reproductive strategy drive the distribution of bryophytes and lichens in the stressful environments in which they often succeed (Giordani et al. 2013). Most bryophytes require substantial moisture and lower light levels, yet some are stress tolerant and can withstand long periods of desiccation (Glime 2017; Stark et al. 2017). Under high stress, mosses often use fragments instead of sexual reproduction to reproduce and disperse (Zechmeister 1995). Spore size between ferns, lycophytes, mosses, liverworts, fungi, and lichens can also impact dispersal, smaller spores dispersing longer distances than larger spores (Giordani et al. 2013).

There are three main lichen growth forms: crustose, foliose, and fruticose (Nash 2008). These morphotypes contain numerous subgroups, which have different traits (i.e. reproduction, growth rate) that allow them to occupy specific microhabitats (Giordani et al. 2013). Crustose lichens are tightly attached to substrates and cannot be removed without destroying the lichen body. There are multiple subtypes of crustose lichens including leprose, which lack an outer layer



of dense hyphal protective tissue that is found in other lichen growth forms, and endoliths, which grow fully embedded within substrates (Brodo et al. 2001). Foliose lichens have distinct upper and lower surfaces, and grow in flat leaf-like forms (Nash 2008). There are a few specialized subtypes of foliose lichens, squamulose, which are small, and umbilicate, which attach to substrates at a single point. Foliose lichens grow faster than crustose lichens, most species growing 0.4-5mm/year in diameter, compared to crustose at 0.1-0.2mm/year (Armstrong and Bradwell 2010; Armstrong and Bradwell 2011). Foliose lichens are less tolerant to periods of desiccation and disturbance than crustose lichens. During dry periods, foliose lichens can crack or crumble, which lowers their growth rates, making them more susceptible to high stress (Armstrong and Bradwell 2011). Fruticose lichens are shrub-like or pendant, do not have distinct lower and upper surfaces, and are often attached at only one point (Brodo et al. 2001). Fruticose growth rates can be similar to crustose or foliose, growing very slow or much faster depending on the species (0.5- 11mm/year) (Pegau 1968; Dunford et al. 2006). Both foliose and fruticose lichens spread asexually by fragmentation, which can allow them to thrive in stressful or disturbed habitats when they may not be able to reach reproductive size and age (Hestmark et al. 2004; Armstrong and Bradwell 2011). Images of each morphogroup can be found in Figure 1.

#### *Cliff dwelling lichens and bryophytes*

Bryophytes and lichens on cliffs are often rock specialists that are referred to as saxicolous or epilithic. Rock dwelling species are stress-tolerant and display slower rates of establishment, growth, and often reproduction (Grime 1977; Furness and Grime 1982; Zechmeister 1995). Saxicolous species usually have a strong affinity for specific rock chemistries, with most species growing on either calcareous or non-calcareous rock. Some species have an even higher degree of rock substrate specificity and grow only on one rock type, such as the lichen *Cladonia appalachensis*, which grows exclusively on iron-rich Anakeesta rock outcrops in the southeastern United States (Lendemer and Harris 2013). Research on lichen diversity and composition in cliff systems have always been restricted to one or as few rock types

as possible to reduce the potentially confounding factor of substrate specificity (Pentecost 1980; Thiel and Spribille 2007; Adams and Zaniewski 2012).

In addition to substrate composition, lichen and bryophyte cliff communities are influenced by slope, aspect, exposure, water availability, and micro-topography (John and Dale 1990; Hedderson and Brassard 1990; Zechmeister 1995; Giordani 2013). Many features within cliff faces, such as ledges, have the ability to aggregate soil, which then facilitates the growth of non-rock dwelling species in cliff ecosystems (Larson et al. 2000; Kuntz and Larson 2006; Boggess et al. 2017). Taxa in individual lichen morphology groups (foliose, fruticose, crustose), as well as bryophytes can respond differently to abiotic and environmental variables in cliffs (John and Dale 1989; John and Dale 1990; Giordani et al. 2013). For example, Matthes et al. (2000) found that crustose lichens were more prevalent higher up the cliff face, which often is associated with high exposure. Higher slopes on overhung cliffs tend to support higher lichen cover, while lower slopes have an abundance of bryophytes (Giordani et al. 2013). High light and high moisture areas are the perfect habitat for most foliose lichens (Giordani et al. 2013) while areas with higher canopy cover harbor more bryophytes (Furness and Grime 1982).

Mountain ranges influence the geographic distributions of all plants, and many lichen and bryophyte species have become stranded during interglacial retreats on mountain peaks. These 'glacial relicts' (Brodo et al. 2001; Sabovljević 2006) have very limited distributions and studying cliffs can reveal their presence. Since lichens and bryophytes are some of the most diverse organisms on cliffs (John and Dale 1990; Matthes et al. 2000), it is imperative that additional studies are conducted to better understand cliff lichen and bryophyte communities and the impacts they face from the increase of humans in the outdoors recreating.

#### *Impacts of rock climbing on lichen and bryophyte cliff communities*

The impact of rock climbing on lichen and bryophyte cliff communities has been studied in Europe and North America (Matthes et al. 2000; Thiel and Spribille 2007; Boggess et al. 2021). Route development and seasonal cleaning often impact lichen and bryophyte cliff

communities the most out of any taxa (Attarian and Keith 2008; Studler et al. 2015). Unclimbed transects frequently host higher bryophyte abundance and diversity compared to climbed transects (Thiel and Spribille 2007; Boggess et al. 2021). Recent studies suggest that lichens respond differently; unclimbed transects have higher abundance and climbed transects have similar species richness compared with unclimbed transects (Boggess et al. 2021). Climbed transects can typically have increased slope or cliff angle, which makes it harder for bryophytes to subsist, resulting in both lower diversity and overall cover (Holzchuh 2016; Boggess et al. 2021). This is the opposite for lichens, cliffs with higher slopes often supporting higher lichen cover (Boggess et al. 2021). Some crustose lichens specifically can persist on climbed routes, and are often more abundant than other groups within rock climbing areas (Smith 1998; Harrison 2020). When impacts of rock climbing studies include lichens and bryophytes it allows for ecologists to better understand cliff floras and how the abiotic factors that influence cliffs shape lichen and bryophyte communities that are successful there. Moreover, impacts of rock climbing studies have found many rare lichen and bryophyte species with poorly understood distributions (Matthes et al. 2000; Thiel and Spribille 2007; Boggess et al. 2021), making lichens and bryophytes essential groups to include in rock climbing impacts studies.

## **Objectives and Hypotheses**

The major goal of this study was to fill a significant knowledge gap regarding the impacts of rock climbing on cliff biodiversity for climbing locations in the inland PNW. My specific objectives were to: 1) Assess the impacts of rock climbing on granitic cliff bryophyte and lichen abundance and diversity in eastern Washington, and 2) Contribute to the improvement and development of management practices in rock climbing areas for lichens and bryophytes. I tested a suite of hypotheses using paired climbed and unclimbed cliff transects to determine which route variables and abiotic factors impacted lichen and bryophyte diversity, richness, and cover most by asking five study questions. Route variables were: age, difficulty, popularity (star value), and

approach distance. Abiotic variables were: plot height, slope, aspect, canopy cover, and rock heterogeneity, which were based upon the number and cover of features (cracks, pockets, and ledges) within plots. Management questions were also proposed in order to consider specific conservation solutions.

My specific study questions are:

- 1) Does climbing impact taxa cover, diversity and richness?
- 2) What abiotic variables explain unclimbed taxa cover, richness, diversity, and community composition?
- 3) What abiotic and route variables explain climbed taxa cover, richness, diversity, and community composition?
- 4) What species are dominant in climbed vs. unclimbed transects?
- 5) Are there indicator species for climbed vs. unclimbed transects?

My specific management questions are:

- 1) How are rock climbers in Eastern Washington impacting lichen and bryophyte communities?
- 2) Do sites need to implement management plans that include vegetation conservation?
- 3) Are there any species of concern at any of the sites within my study area?
- 4) Did I find any new county or state records, and are they species of concern?
- 5) Are there any specific routes with species of concern that should be monitored?

## **Methods**

This study took a paired approach by comparing unclimbed adjacent strips of cliff face to climbed rock climbing sport routes. Sites were selected from a variety of rock climbing areas within Spokane County, to ensure that sites had sport climbing routes and abundant unclimbed cliff face. The abiotic variables of slope, aspect, canopy cover, feature cover, feature number, and plot height were included. The climbing variables of route age, route difficulty, approach

distance, and popularity (star value) were used to better understand climbing intensity. A suite of statistical analyses were used to compare climbed and unclimbed transects and their lichen and bryophyte communities. Lichens were grouped by morphology for analyses and to better understand how individual growth types responded to climbing. Sites were further analyzed separately because of their differences in overall habitat and community type.

### Site Description

Two popular climbing sites were selected in Spokane County, Washington State: McLellan Rocks (MR) and Rocks of Sharon (ROS). MR is within Fisk State Park, south of the city of Tumtum along the Spokane River. ROS is in the Dishman Hills Conservancy within Spokane city limits. Both sites have abundant sport climbing routes and are popular destinations for local climbers and outdoor enthusiasts. The climate in the region is semi-arid, with an average annual precipitation of 528.32mm (Western Regional Climate Center). Temperatures range from -10°F to 104°F (-23.333°C to 40°C) with summer temperatures averaging 83.7°F (28.722°C) and winter temperatures averaging 22.1°F (-5.5°C) (NOAA). The dominant terrestrial plant community at ROS is a *Pinus ponderosa* savannah, which is characterized by sparse tree cover (predominately *Pinus ponderosa*) with a diverse grass and forb understory. Historically, Fisk State Park was also dominated by a *Pinus ponderosa* savannah, however, today, because of long-standing no fire policies, the habitat is mainly a closed canopy mixed conifer forest with scattered grassland meadows.

### *Geologic history of sites*

The Spokane River Valley has experienced many geological events that have resulted in several different rock types making up the landscape (Doughty et al. 2016). There are many types of rock in the Spokane River Valley, which are all associated with the western flank of the Priest River Complex: a series of lower parts of the crust that have been metamorphosed and uplifted about 50 million years ago towards the end of the development of the current Rocky Mountains. This rapid uplift also caused expansive melting of the crust, leading to many of the granite and

metamorphic climbing areas of the Spokane area (Doughty et al. 2016; Stevens et al. 2015). The Spokane Dome, a smaller portion of the Priest River Complex is generally composed of granite, granodiorite, Newman lake orthogneiss - metamorphosed Cretaceous Granite from the Mt. Spokane Batholith, and Chester Creek paragneiss (Doughty et al. 2016). MR is fractured granite, whereas ROS is a mix of granitic rock and orthogneiss (Schuster 2005). ROS is one of the highest elevation areas within the city of Spokane at over 3,500 ft, which allowed it to not be impacted by the Missoula Floods 16,000 years ago. However, MR is within the area here in Spokane where the floods did carve out and create the rock formations we see today at that site (O'Connor et al. 2020).

#### *Anthropogenic history of sites*

ROS it is one of the oldest climbing areas in Eastern Washington, with some of the first climbs being bolted in the 1950s (Loomis and Loomis 1983). MR has the most sport climbing routes in Spokane, with over 100 bolted routes in the past thirty years (mountainproject.com). MR has been developed by Eastern Washington University for their outdoor recreation program 'EPIC Adventures', which has used the rock climbing areas for programming for over a decade.

#### Study Design and Field Collection Methods

Sixteen climbing routes were surveyed with paired unclimbed transects directly adjacent to the route, for a total of thirty-two transects; sixteen climbed and sixteen unclimbed. Ten routes were surveyed at MR, and six were surveyed at ROS. At each site, routes were found within crags, three crags being chosen at ROS, and five crags being chosen at MR (Table 1). Crags are a small cliff, or the term for a climbing area where many routes are present. Routes were chosen based on direct field observations and communicating with local climbers, ensuring unclimbed cliff faces were wide enough for a transect adjacent to each climbed route and had never previously been climbed. Additional route selection criteria were difficulty, popularity, and safety. Unclimbed transects were placed no further than two meters and at least one meter to the left or right of climbed transects, to ensure no climbing impacts. Half meter squared plots were

placed on either side of the rope every three meters, starting at the base of the cliff, at four locations along climbed and unclimbed transects (Figure 2). Within each plot, the percent cover of every bryophyte, lichen, lycophyte and fern species was recorded. Samples were collected if field identification was not possible. Additionally, within each plot center slope was measured with a clinometer, and every major rock feature (pocket, ledge, crack) was recorded and measured (length, width, depth). The overall aspect of the cliff face was taken with a compass, and canopy cover was measured with photos that were later analyzed using Image-J software (Schneider et al. 2012). Route difficulty (Yosemite decimal system 5.4- 5.15) and popularity (star value) were recorded from mountainproject.com, local rock-climbing guidebooks and climbing site aids from local route developers. Route grade within this study ranged from 5.6- 5.11. Approach distance was calculated using maps of each site paired with Google Earth Pro and ranged from 0.25-1.25 miles. A climbing metric was then developed with approach distance, popularity, and difficulty to better understand climbing intensity for each route. Shorter approach distances, more popular routes (higher star values), and easier climbs were assigned larger numbers to correspond with accessibility, more likely to be climbed, and climb-ability of the route. Approaches for each site were categorized by distance: short, moderate, or long. Short was given a value of five, moderate distances were given a value of three, while the longest approaches for each site were given a value of one. Route grade was split into three difficulty categories, 5.6-5.8 = easy, 5.9-5.10 = moderate, and 5.11 = hard. Easy routes are worth the most at five, moderate climbs were given a value of three, while hard climbs were given a value of one. The star value of each route, which ranged from 1-3.1 out of five, was then multiplied with the value for approach distance and route difficulty to create the climbing use index (CUI) for each route. This then assumes the hardest, farthest away, least popular climbs are climbed the least, and the easiest, closest, most popular climbs are climbed the most.

### Identification methods

Mosses were identified using Lawton (1971) Moss Flora of the Pacific Northwest as well as the Bryophyta Flora of North America (vol. 27, 28). Liverworts were identified using Schuster (2002). Bryophyte taxa requiring species confirmation or further identification were sent to Dr. Terry McIntosh (University of British Columbia) and Dr. Daphne Stone (Oregon State University). Ferns and lycophytes were identified via Flora of the Pacific Northwest 2<sup>nd</sup> Edition (Hitchcock and Cronquist, 2018).

Bryophytes and vascular plants overall were kept as separate species but grouped for analyses as plants. Only two moss groups were formed based on identifications by myself, and Dr. Terry McIntosh: *Grimmia trichophylla* group and the ‘dark’ *Grimmia* group. A new moss species within the genus *Grimmia* is thought to have been collected as a common moss at both sites, as it did not fit any species description in the Bryophyte Flora of North America, thus being grouped as the ‘dark’ *Grimmia* for analyses along with the other dark *Grimmia* species thought to be present, *Grimmia montana* and *Grimmia alpestris*. Genera with multiple species, *Homalothecium*, *Syntrichia*, *Orthotrichum*, and *Racomitrium*, were kept together for analyses because of similar appearance in the field with the exception of *Polytrichum piliferum* and *Polytrichum juniperinum*. See Table 2 for the assigned taxon names for analyses and their corresponding species included in the study and Figure 3 for bryophyte examples.

Many keys were used for lichen identification (Brodo et al. 2001; Nash et al. 2001; Nash et al. 2004; McCune and Geiser 2009; McCune 2017a; McCune 2017b). Additionally chemical spot tests and thin layer chromatography using solvent C were implemented for lichen identifications. Dr. Jessica L. Allen (EWU) confirmed all lichen identifications, and helped to identify species in more taxonomically difficult groups such as *Caloplaca*. Dr. R. Troy McMullin (Canadian Museum of Nature) confirmed and identified *Chaenothecopsis subparoica* and Dr. Bruce McCune (Oregon State University) helped to confirm the collection of *Henrica americana*.



Additionally, Dr. James Lendemer (New York Botanical Garden) helped to confirm *Carbonea vorticosa*.

Lichen morphogroups were created to better understand climbing impacts on each individual group. Within this study three foliose morphogroups were recognized: squamulose, umbilicate, and foliose, with the latter group encompassing all foliose lichens that were not squamulose or umbilicate, thus the three groups included a mutually exclusive set of species. All fruticose lichens were considered together as a single group. Crustose lichens were divided into leprose (dust) lichens, endoliths, and crustose, the latter of which included all species that were not ascribable to the first two groups. See Figure 1 for lichen morphogroup examples, Table 3 for all species and how they were grouped for analyses, and Table 4 for which species were included in each lichen morphology group. Some crustose lichen species were grouped because of similar appearance in the field. Later identification revealed several species within groups. *Rhizocarpon* species were grouped by color: yellow, grey, and brown. Yellow *Rhizocarpon* species included *Rhizocarpon macrosporum*, *Rhizocarpon lecanorinum*, and the *Rhizocarpon geographicum* group. Grey *Rhizocarpon* species included *Rhizocarpon disporum* and *Rhizocarpon grande*. Brown *Lecidea* species were grouped with the brown *Rhizocarpon* species for their similar appearance in the field, species included: *Rhizocarpon bolanderi* and *Lecidea atrobrunnea*. *Candelariella* species were also grouped for analyses and included the *Candelariella vitellina* group as well as *Candelariella rosulans* and *Candelariella citrina*. Black apotheciate endolithic lichens were grouped in the field. Later, identification revealed five species: *Lecidella stigmatea*, *Lecidella patavina*, *Porpidia crustulata*, *Carbonea vorticosa*, and *Sarcogyne regularis*. Leprose lichens were grouped by genus based on TLC plate and spot test identifications. There were several *Lepraria* species, including multiple *Lepraria neglecta* chemotypes that were all grouped together for analyses. *Leprocaulon knudsenii* was a dominant species, while the other leprose lichens, including *Chrysothrix chlorina*, were uncommon. Foliose were also grouped in certain genera. Usnic-acid containing *Xanthoparmelia* species were grouped together for analyses

because of the need for TLC in order to correctly identify each individual. Brown foliose lichens within the genera *Xanthoparmelia*, *Montanelia*, *Melanohalea*, and *Melanolixia* were grouped for analyses because of species not being distinguishable in the field. Several *Physcia* species were also found in this study and were grouped, including: *Physcia biziana*, *Physcia caesia*, *Physcia tenella*, *Physcia magnusonii*, and *Physcia ascendens*. *Phaeophyscia* species were grouped together and included *Phaeophyscia decolor*, and *Phaeophyscia sciastra*. All *Physconia* species were grouped for analyses, as many were not distinguishable in the field, species included: *Physconia enteroxantha*, *Physconia perisidiosa*, and *Physconia muscigena*. The two *Parmelia* species found in the study; *Parmelia saxitalis* and *Parmelia sulcata* were also grouped for analyses. All other taxa were able to be clearly distinguished from one another in the field and were kept separate for analyses. For a list of taxon names for analyses and the species included in each, see Table 3.

### Statistical Methods

Initial NMDS analyses to better understand site differences and similarities were done with all taxa and revealed large site differences (Figure 4). This led to all analyses for this study to be done separately by site to not skew the results, as more transects were done at MR. To answer the study question of how rock climbing impacts taxa cover, richness, and diversity general linear mixed effects models (GLMM) were built with the package nlme (v3.1-152, Pinheiro et al. 2021). Species richness (SR) and Shannon's diversity (SD) were calculated for each plot for lichens, lichen morphology groups (crustose, leprose, endolith, fruticose, foliose, umbilicate, squamulose), plants, and all taxa using the program R (v3.1.2, R Core Team, 2019) and the vegan package (v2.5-6, Oksanen et al. 2019). Richness directly corresponded to how many species were within each plot, while Shannon's Diversity values were from 0-1, 0 meaning only one species occurred and 1 meaning every species was present possible. Climbing effect was tested with each lichen morphogroup and plants for cover, richness, and diversity. GLMM models were also built to answer the questions of what abiotic and route variables are significant and

important in explaining relationships for SR, SD, and percent cover for lichens and plants at each site. Data was combined between sites for analyses as well as done separately for each site to better understand differences and similarities. GLMM models for individual sites did not include aspect ordination and approach distance because they were highly collinear with crag, which was included in the model as a random intercept, along with route, which was nested within the crag parameter. Variable selection for each model was conducted using the dredge function in the MuMIn package (v1.13.15, Bartoń 2019). I tested the importance of predictor variables and their interactions using a Type II and Type III analysis of variance (Anova) for the best model. Anova Type III is used to better understand models that have variables interacting, while the Anova Type II is better suited for models with variables that do not interact. To test site differences and to see what variables best explained all taxa, lichens, and plants for all data and climbed data, non-metric multidimensional scaling (NMDS) was used. NMDS significance values were taken from *EnvFit*, which was better suited for these data than the traditional ADONIS, which tests for the effects of predictors sequentially. In order to run each NMDS, I sometimes had to remove species unique to specific plots or transects, otherwise those species dominated the ordination. Additionally the package BiodiversityR (v2.13-1, Kindt and Coe 2005) was applied to create ranked abundance species plots for climbed and unclimbed transects overall, at each site for all taxa, lichens, and plants to better understand dominant species. To further understand indicator species specifically, the package indicpecies (v1.7.8, De Caceres and Legendre 2009) was applied to lichen and plant climbed and unclimbed data for each site. Indicspecies through its analysis chooses species as indicators if they are both frequent in and specific to a particular group of sites. By using the function *mulipatt* across 999 permutations, climbed and unclimbed indicator species were calculated, assuming  $\alpha = \leq 0.1$ . Figures were prepared with Inkscape (<https://inkscape.org/>).

## Results

### Impact on taxa cover, diversity and richness

The results of the climbing effects GLMM show that climbing does influence all taxa considered in my study (Table 5; Figure 5). Total cover was significantly lower in climbed vs. unclimbed plots at both sites (MR  $\chi^2 = 71.834$ ,  $p < 0.0001$ ; ROS  $\chi^2 = 48.045$ ,  $p < 0.0001$ ). Plant cover, diversity, and richness were significantly lower in climbed plots at MR (cover:  $\chi^2 = 21.978$ ,  $p < 0.0001$ ; richness:  $\chi^2 = 17.733$ ,  $p < 0.0001$ ; diversity:  $\chi^2 = 25.472$ ,  $p < 0.0001$ ), but they were not significantly lower at ROS (cover:  $\chi^2 = 0.101$ ,  $p = 0.7507$ ; richness:  $\chi^2 = 0.5019$ ,  $p = 0.4787$ ; diversity:  $\chi^2 = 0.0001$ ,  $p = 0.9941$ ). Lichen cover and diversity was significantly lower in climbed plots at ROS ( $\chi^2 = 17.692$ ,  $p < 0.0001$ ;  $\chi^2 = 4.9325$ ,  $p = 0.02636$ ), but not at MR ( $\chi^2 = 0.0007$ ,  $p = 0.97873$ ;  $\chi^2 = 0.0961$ ,  $p = 0.7566$ ). Lichen richness was significantly higher in climbed plots than unclimbed plots at MR ( $\chi^2 = 6.2988$ ,  $p = 0.01208$ ), whereas at ROS there was no significant difference ( $\chi^2 = 0.0068$ ,  $p = 0.9343$ ).

Lichen morphogroup response to climbing is highly variable (Table 6). Crustose lichen cover, richness, and diversity at MR was significantly higher in climbed vs. unclimbed transects ( $\chi^2 = 19.439$ ,  $p < 0.000$ ;  $\chi^2 = 14.7379$ ,  $p = 0.00012$ ;  $\chi^2 = 31.243$ ,  $p < 0.0001$ ). At ROS, crustose richness was also higher in climbed plots ( $\chi^2 = 8.421$ ,  $p = 0.00371$ ). Endolithic lichen cover and richness at MR was significantly higher on climbed routes ( $\chi^2 = 9.7127$ ,  $p = 0.00183$ ;  $\chi^2 = 30.775$ ,  $p < 0.0001$ ), yet at ROS there was no significant difference in endolithic lichen response to climbing (cover:  $\chi^2 = 0.2974$ ,  $p = 0.5855$ ; richness:  $\chi^2 = 3.0497$ ,  $p = 0.08075$ ). At both sites climbing significantly lowered fruticose lichen richness (MR  $\chi^2 = 22.67$ ,  $p < 0.0001$ ; ROS  $\chi^2 = 17.984$ ,  $p < 0.0001$ ), and fruticose lichen cover was significantly lower in climbed vs. unclimbed plots at MR ( $\chi^2 = 12.3373$ ,  $p = 0.00044$ ). Foliose and leprose lichen cover was significantly lower in climbed plots at ROS ( $\chi^2 = 7.7392$ ,  $p = 0.0054$ ;  $\chi^2 = 26.073$ ,  $p < 0.0001$ ), as was umbilicate lichen cover, diversity, and richness ( $\chi^2 = 24.0334$ ,  $p < 0.0001$ ;  $\chi^2 = 5.9763$ ,  $p = 0.01450$ ;  $\chi^2 = 9.8626$ ,

$p=0.00169$ ). Squamulose lichen responses were not significantly different in climbed vs. unclimbed plots at either site (Table 6).

Abiotic variables explain unclimbed taxa cover, richness, diversity, and community composition

Responses of lichen and plant cover, richness, and diversity in unclimbed plots at MR and ROS to a suite of abiotic variables (i.e. slope, canopy cover, feature number, aspect degree, plot height) was investigated using GLMMs (Table 7). Transects with fewer features and lower slopes supported higher plant cover at MR. Slope was significant and important (Weight = 0.99,  $p<0.0001$ ) while feature number was almost significant and still fairly important (Weight = 0.55,  $p=0.05034$ ). The best model for plant cover at ROS only included feature number, however it was not significant and did not hold much importance. No variables were important enough for plant richness or diversity at either site for model responses. Canopy cover, and feature cover were included in the MR lichen cover model, while models with lichen diversity and richness as response variables only included the variable plot height. Plots that had more features, and less canopy cover, hosted higher lichen cover. Feature cover held more importance than canopy cover in plots (Weight= 0.66 vs. Weight= 0.3, respectively), and was significant ( $p<0.0001$ ). Lichen richness and diversity was highest in plots that were higher on the cliff face at MR. Plot height was significant for both lichen diversity ( $p<0.0001$ ) and lichen richness ( $p=0.0167$ ), the importance of plot height was higher for diversity compared to richness (0.32 vs. 0.221). The ROS lichen model with the response variable cover, included the abiotic variables of slope, feature number, and plot height. Plots placed highest on the cliff face, with overhung slopes, and higher feature cover, had the highest lichen cover at ROS. Plot height held the most variable importance (Weight= 1), while slope and feature number held less (Weight= 0.51, Weight= 0.53). Plot height was the most significant ( $p<0.0001$ ), followed by slope and feature number ( $p=0.0099$ ,  $p=0.0339$ ). No variables were important enough for ROS lichen richness or diversity for model responses.

The NMDS analysis for unclimbed lichens and plants at both sites revealed how communities are influenced by abiotic variables at each site (Table 8; Table 9; Figure 6). The factors aspect ordination, crag, and route (route here referring to the unclimbed strip of cliff face adjacent to said route) were significant and explanatory (Table 8). Lichen species variation within plots at MR was best explained by the variables slope ( $r^2 = 0.2461$ ,  $p=0.001$ ), feature cover ( $r^2 = 0.1052$ ,  $p=0.015$ ), and canopy cover ( $r^2 = 0.3995$ ,  $p=0.001$ ) (Figure 6). At ROS, lichen variation was explained 19.99% by slope ( $p=0.009$ ) and 49.01% by plot height ( $p=0.001$ ) (Figure 6). For plants at both sites plot height and canopy cover were significant and explained substantial variation (Table 9; Figure 6), yet MR plants additionally were explained by feature cover ( $r^2 = 0.1107$ ,  $p=0.009$ ) and aspect degree ( $r^2 = 0.3473$ ,  $p=0.001$ ), while ROS was further explained by slope ( $r^2 = 0.2816$ ,  $p=0.008$ ). The NMDS analysis of all taxa within unclimbed areas at both sites combined revealed significant differences between sites, and site explained 29.56% of variation in the data ( $p = 0.001$ ; Figure 4). NMDS results show site differences and how slope is explanatory for lichen species variation within plots, and how canopy cover and plot height are explanatory for plants.

#### Abiotic and route variables influence on climbed taxa cover, richness, diversity, and community composition

Climbing variables (i.e., route age, star, approach distance, difficulty, and the climbing metric) were important and significant to the addition of abiotic factors in the GLMM models for the response variables of lichen and plant cover, richness, and diversity along rock climbing routes (Table 7). The MR plant cover model included the variables route age, star, feature number, and plot height, while no variables were important enough for plant richness or diversity model responses. When plots were placed lower, on younger, more popular routes at MR with fewer features, plant cover was the highest. All variables within the model were significant except for route age (Table 7), while star and plot height held the most importance (Weight= 1), followed by feature number (Weight= 0.9) and route age (Weight= 0.54). Plants within plots at

ROS were extremely scarce, only a few moss species were present on climbed routes. No variables were important enough to include in a model for moss cover or diversity at ROS, however moss richness did respond to the variables slope, feature number, and plot height. When plots were placed lower on routes at ROS and had lower slopes and more features, moss richness was the highest. Plot height held the most importance (Weight= 1), while feature number and slope held less (Weight= 0.86, Weight= 0.57), slope and feature number being significant ( $p=0.01611$ ,  $p=0.00236$ ), and plot height almost being significant ( $p=0.06107$ ). The GLMM model for lichen cover at MR included the variables route age, star, feature number, and plot height. When plots were placed higher along older, less popular routes with more features at MR, lichen cover was the highest. Star, route age, and plot height were the most important, while feature number, plot height, and route age, were significant (Table 7). The MR lichen diversity model only had the variable feature number, while the richness model included feature number, star, and plot height. Feature number was significant for both richness and diversity ( $p=0.00012$ ,  $p=0.00415$ ), yet it was more important for richness (Weight= 0.97 vs. Weight= 0.164). Additionally, plot height was significant in the lichen richness model ( $p=0.00087$ ) while star was not, each variable holding less weight compared to feature number (Weight= 0.97 vs. Weight= 0.81 vs. Weight= 0.5). The ROS climbed lichen cover model included the variables route age, star, plot height, and the interactions between age x star as well as age x plot height. Lichen cover was highest in plots on younger, more popular routes towards the tops of cliffs. The only significant variable in the ROS lichen cover model was plot height, while every variable weight held an importance over 0.50 (Table 7). The models for lichen richness and diversity for ROS both included star. Star value was significant for lichen richness ( $p=0.00127$ ), but not for lichen diversity despite it holding more importance (Weight= 1 vs. Weight= 0.54).

Both route and abiotic variables were explanatory in climbed transects based on NMDS results (Tables 8-11; Figure 6). Similar to the unclimbed data, crag and route were significant and explanatory for lichens and plants at both sites, as well as aspect ordination (Table 10). MR lichen

variation was explained by the variables; route age ( $r^2 = 0.1487$ ,  $p=0.005$ ), canopy cover ( $r^2 = 0.1527$ ,  $p=0.005$ ), and plot height ( $r^2 = 0.1586$ ,  $p=0.002$ ). ROS lichen variability was also explained significantly by route age ( $r^2 = 0.1239$ ,  $p=0.050$ ), but was further explained by the variables star value ( $r^2 = 0.2272$ ,  $p=0.004$ ), slope ( $r^2 = 0.3335$ ,  $p=0.001$ ), feature cover ( $r^2 = 0.1788$ ,  $p=0.008$ ), and aspect degree ( $r^2 = 0.3338$ ,  $p=0.001$ ). Plants, conversely, did not have any similar significant or explanatory vectors between sites, ROS plant variation within plots being explained by star value ( $r^2 = 0.4134$ ,  $p=0.002$ ) and aspect degree ( $r^2 = 0.2597$ ,  $p=0.013$ ), while plants at MR were explained by several variables including: approach distance ( $r^2 = 0.0870$ ,  $p=0.02$ ), route age ( $r^2 = 0.102$ ,  $p=0.012$ ), plot height ( $r^2 = 0.2656$ ,  $p=0.001$ ), slope ( $r^2 = 0.0853$ ,  $p=0.044$ ) and canopy cover ( $r^2 = 0.1333$ ,  $p=0.044$ ). Additionally, the NMDS analysis of all taxa within climbed areas at both sites combined revealed significant differences between sites, and site explained 30.81% of variation in the data ( $p = 0.001$ ; Figure 4).

### Dominant Species

#### *Lichens*

In total, 118 lichen species were collected and identified. I grouped the species into 83 taxonomic categories ascribable to species or genera depending on their degree of field identifiability (Table 3). There were 63 total taxa at MR, and 50 taxa occurred in unclimbed transects while 47 occurred in climbed transects. 13 taxa were unique to climbed transects, and 16 unique to unclimbed, while 34 taxa occurred in both climbed or unclimbed transects at MR. I found 60 lichen taxa at ROS, and unclimbed transects at hosted 53 taxa while climbed routes hosted 46. There were seven taxa unique to climbed transects, and 11 unique to unclimbed, with 42 taxa that occurred in both climbed or unclimbed transects. There were 23 unique taxa and MR and 20 at ROS. Between both sites 40 taxa were shared.

The most common and abundant lichens varied both by site and by climbing status (Figure 7). The most common species between both sites, which also occurred on both climbed and unclimbed rock faces, were the grey *Rhizocarpon* group and the brown *Lecidea/Rhizocarpon*



species. The leprose lichen *Lepraria* was also very abundant at both sites, and *Leprocaulon knudsenii* was especially abundant at ROS. The most abundant foliose lichens were the ‘Mel’ group, which can be seen in both climbed and unclimbed transects at both sites in the ranked abundance plots. Squamulose lichens were not as abundant compared to other foliose lichen groups. Umbilicate foliose lichens were more abundant at ROS, yet each site had a unique species that the other did not. For example, *Umbilicaria vellea* was only collected at ROS, and *Umbilicaria torrefacta* was solely at MR. The only fruticose species that was of particular abundance was the *Cladonia* group at MR, which only occurred within unclimbed transects.

### *Plants*

Between both sites there were 25 plant taxa that represented 31 species (Table 2; Figure 8). MR was by far the most diverse with 24 taxa representing vascular plants, mosses, and liverworts compared to the only nine moss taxa present at ROS. ROS did not have any unique bryophyte species, while MR had several unique taxa, which included the vascular plant species, *Selaginella wallacei* and *Woodsia scopulina*, and both liverwort species, *Porella cordaeana* and *Frullania californica*. Both sites had three species unique to unclimbed transects; *Neckera menzeisii*, *Encalypta ciliata*, and the fern *Woodsia scopulina* at MR and *Polytrichum piliferum*, *Ceratodon purpureus*, and a *Schistidium* species that was not further identifiable because of lack of sporophytes at ROS. Unique taxa for climbed transects was minimal, ROS only having the *Homalothecium* group, and MR having a *Schistidium* spp.. The dominant species between both sites were the *Grimmia trichophylla* group, as well as the Dark *Grimmia* group.

### *Indicator Species*

Indicator species for climbed routes at MR were all crustose species (Table 12). The black endolithic lichens were represented by the species *Sarcogyne regularis*, *Lecidella patavina*, *Carbonea vorticosa*, *Porpidia crustulata*, and *Lecidella stigmatea*. The ‘green crust’ lichen was not identifiable as it wasn’t mature and lacked enough identifiable features. *Henrica americana* was recently collected for the first time in North America (Breuss 2002) and is a new species for

the state of Washington. Unclimbed transects were best indicated by both fruticose and foliose lichen species, including species that use bryophytes as their main substrate (Table 12). *Leptochidium albociliatum*, *Massalongia carnosa*, and *Polychidium muscicola*. *Parmelia saxatilis* and *Parmelia sulcata* were also often growing on top of mosses at MR, and many *Cladonia* species were only found on built up soil on small ledges and on bryophytes. MR did not have any plant indicator species for climbed transects. However, there were indicators for unclimbed transects (Table 12). *Antitrichia californica*, *Selaginella wallacei*, *Pseudobraunia californica*, *Syntrichia ruralis/norvegica* and *Dicranum* were all found as indicators for unclimbed transects. *Antitrichia californica* and *Pseudobraunia californica* are both pleurocarpus mosses, and are much more fragile and easy to remove as they grow in carpets along the cliff face along with *Selaginella wallacei*. *Syntrichia ruralis/norvegica* grew in very large clumps that have clearly been growing for several years in unclimbed areas, compared to growing in small bunches on climbed transects.

Climbed routes at ROS for both lichens and mosses did not have any indicator species. However, unclimbed transects did have representative indicators within both groups (Table 12). For mosses, the *Grimmia trichophylla* group was the sole indicator species. For lichens, fruticose, foliose, and umbilicate foliose lichens were all indicator species. The rock dwelling wolf lichen, *Letharia vulpia*, two *Umbilicaria* species, *Umbilicaria americana* and *Umbilicaria hyperborea*, as well as *Rhizoplaca melanothphalma*, and *Massalongia carnosa* were indicators. In climbed transects the *Umbilicaria* species were often very small and damaged, with no individuals growing larger than two inches across. *Rhizoplaca melanothphalma* was fairly abundant at ROS, and because of its natural crumbly appearance, was rarely seen within climbed plots. *Massalongia carnosa* relies on mosses for its substrate, making it a unique indicator for ROS since its bryophyte cover is not very high.

## Discussion

This study revealed diverse lichen and plant communities on both climbed and unclimbed cliff sections. Climbing both increased and decreased individual taxa cover, richness, and diversity (Table 5 and Table 6). My study sites hosted distinct communities that were both significantly impacted by rock climbing, which is consistent with numerous past studies (Boggess et al. 2021). Climbing route variables (i.e., age, popularity) explained most of the variation among communities on climbed rock faces at both sites. Therefore, each site exhibited consistent impacts from rock climbing. These results suggest that climbing management should be guided by minimal disturbance during route development, cliff community composition (as characterized by morphogroups), and species indicative of unclimbed areas.

*Does climbing impact taxa cover, diversity and richness?*

Rock climbing significantly reduces the abundance and diversity of most cliff-dwelling organisms. Lichen richness was significantly lower on climbed rock faces than on unclimbed rock faces at MR, and lichen cover and diversity were significantly lower on climbed rock faces than unclimbed rock faces at ROS (Table 5). Plant cover, richness and diversity was lower on climbing routes at MR, but not at ROS (Table 5). Previous studies on the impact of rock climbing have observed similar trends for lichens (Nuzzo 1996; Kuntz and Larson 2006; Adams and Zaniewski 2012; Clark and Hessel 2015; Tessler and Clark 2016; Reding 2019) and bryophytes (McMillan and Larson 2002; Tessler and Clark 2016; Boggess et al. 2017) and vascular plants (Schmera 2018; March-Salas et al. 2018; Lorite et al. 2017; Tessler and Clark 2016; Clark and Hessel 2015; Müller et al. 2004; Rusterholz et al. 2004; McMillan and Larson 2002; Camp and Knight 1998).

Organismal responses to environmental stress and disturbance are often discussed in the context of Grime's life history strategies (Grime 1977). Cliffs are stressful environments, making them challenging places for many groups of organisms to succeed (Larson et al. 2000). Lack of competition, along with adaptations to high-stress environments (Grime 1977), results in

lichens and bryophytes being some of the most successful components of cliff communities. The addition of rock climbing as a disturbance to cliffs drastically shifts the dynamics in these systems, resulting in both a high stress and high disturbance environment. Responses to such drastic shifts in disturbance regimes on cliffs vary substantially among morphogroups. Here I subdivided groups of lichens, bryophytes and vascular plants into Grime's life history strategies based on their response to the stress of the cliff and the disturbance of climbing (Figure 9). Significant decreases in cover, richness, and/or diversity in rock climbing areas were recorded for the least disturbance-tolerant groups (i.e., foliose, leprose, fruticose, umbilicate, most plants; Table 5 and Table 6). Conversely, significantly higher cover, richness, and/or diversity in climbed areas were recorded for the most disturbance-tolerant groups (i.e., crustose and endolithic lichens; Table 6). Previous research on lichen morphogroup responses to climbing impacts similarly found that crustose lichens were more abundant on climbed routes (Smith 1989; Harrison 2020). Harrison (2020) also found that leprose lichens had significantly higher cover in unclimbed areas at both their sites compared to climbed routes, which was only seen at ROS in my study (Table 6). Reding (2019) found that crustose lichens were the most abundant functional group overall in their study, but did not perform any specific analyses on morphogroups for rock climbing impacts. Kuntz and Larson (2006) did not split their lichens into morphogroups, however they did specifically note that foliose and fruticose species decreased in richness and abundance in climbed areas, while crustose species increased, which is similar to my study results (Table 6).

*Abiotic variables influence on unclimbed taxa cover, richness, diversity, and community composition*

Slope, plot height, and rock heterogeneity were the most important factors shaping lichen cover, richness, and diversity in my study, and canopy cover, slope, plot height, and rock heterogeneity were most important for plants (Table 7, Table 9, and Table 11). These results illustrate the previously observed trend that lichens and bryophytes often exhibit opposite environmental preferences (Zechmeister 1995; Giordani et al. 2013; Glime 2017). A specific

example of opposite responses is evident when light availability (plot height + canopy cover), slope, and rock heterogeneity are considered. Base plots, which have lower light levels had the highest bryophyte cover, whereas lichens were more abundant on the upper cliff in higher light conditions (Table 7). Higher slopes (vertical or overhanging) supported higher lichen cover, especially crustose and leprose lichens, whereas lower sloped areas supported higher plant cover (Furness and Grime 1982; Zechmesiter 1995; Kuntz and Larson 2006; Glime 2017; Table 7). Similar trends for slope and light availability have been reported in numerous other studies (Kuntz and Larson 2006; Clark and Hessel 2015; Boggess et al. 2017; Reding 2019) as lichens prefer areas with high light and bryophytes can succeed in areas with lower light (Glime 2017). Bryophytes and vascular plants had higher cover and richness in areas with fewer features (Table 7; Figure 5), while all lichens across both sites were more abundant in areas with higher rock heterogeneity. One previously proposed explanation for this phenomenon is that lower slopes and areas with higher rock heterogeneity tend to capture more water, soil, and bryophyte fragments than higher slopes, and that lichens, especially crustose species as they are embedded within the rock, can persist in higher slopes that are less heterogeneous (Furness and Grime 1982; Zechmesiter 1995; Kuntz and Larson 2006; Glime 2017). Therefore, when considering environmental variables controlling climbed and unclimbed cliff lichen and plant communities, it is critical to incorporate numerous, related environmental variables as these all interact to shape cliff vegetation. Abiotic and route variables influence on climbed taxa cover, richness, diversity, and community composition

Route age and popularity had the most significant impacts on lichens and plants in my study system (Table 11; Figure 6). At MR, plant cover was highest on younger, less popular routes, possibly due to the ease at which older routes are seasonally cleaned, as mats of bryophytes are easy to remove. Similarly, Schmera (2018) saw higher plant cover on less popular routes within their study. At ROS, younger more popular routes had higher lichen cover, richness, and diversity. This is opposite of expected trends, and is likely explained by lichen morphogroup

stress tolerances, route age, and climbing use over time. This result is likely explained by the fact that youngest routes at ROS are actually relatively old (11-20 years old compared to MR at 5-10 years old), and constant climbing on more popular routes may be removing low disturbance tolerant species, allowing disturbance tolerant species, especially crustose lichens, to thrive on rock climbing routes. Route age has not been fully included in past studies (Boggess et al. 2021), thus my results are preliminary and need to be further investigated to inform management. Quantifying how often climbers use routes, or its popularity, is challenging, which is why a climbing use index (CUI) has been calculated based on route variables in past studies (Boggess et al. 2021). Both Schmera et al. (2018) and Clark and Hessel (2015) created a CUI similar to my study and also found it was not a significant predictor. Schmera (2018) focused on vascular plants, their results showed that routes with higher CUIs had less cover overall. Clark and Hessel (2015), whose study was conducted in the New River Gorge, West Virginia, specifically found that their NMDS including star, approach distance, difficulty, and their CUI were all not explanatory for lichen or plant variation, canopy cover and aspect, instead, were the major driver of cliff community composition. I similarly found that canopy cover and aspect were frequently significant and explanatory within my analyses (Table 7, Table 9, and Table 11; Figure 6). In contrast to Clark and Hessel (2015) I found that multiple route variables were explanatory. For instance, star alone explaining over 40% of the moss variation at ROS.

#### *Dominant and Indicator Species*

Ranked abundance plots revealed dominant species in climbed and unclimbed transects for each site, plants dominating plots at MR, and lichens dominating plots at ROS (Tables 12-15; Figure 7 and Figure 8). Boggess et al. (2017) similarly used ranked abundance plots and found that the leprose lichen *Lepraria* was the most abundant lichen species overall. Within my study *Lepraria* was abundant on both climbed and unclimbed transects, especially at MR (Table 13 and Table 14). Crustose lichens in the genus *Rhizocarpon* were the most abundant in my study overall, and dominated the rocks at both sites (Table 12-15). Several moss species were included

in the MR plot height rank abundance for both unclimbed and climbed transects. Plants were also included in Boggess et al. (2017) rank abundance plots, however lichens dominated overall.

Indicator species were highly site-specific, and the only unclimbed lichen indicator shared by both sites was *Massalongia carnosa*. Climbed indicator species were only crustose lichens, while unclimbed indicator species were mosses, fruticose, and foliose lichens (Table 16). Harrison (2020), whose study was conducted in a region with very different climatic conditions, the Southern Appalachian Mountains, also performed indicator species analyses, which revealed similar trends of low stress and disturbance tolerant taxa in unclimbed areas, as well as opposite trends to my study when looking specifically at morphogroups. Harrison (2020) had crustose, foliose and leprose species as climbed indicators, and several crustose and *Cladonia* species as unclimbed indicators at her sites. *Cladonia* was also an unclimbed indicator at one of my sites (Table 16). Indicator species can be used as ecological indicators of habitat type, environmental conditions, and community present (De Cáceres et al. 2010; Carpenter et al. 2012). The National Forest Service implemented management indicator species (MIS) into conservation initiatives in 1984 (Patton 1987) as management practices that involve the use of indicator species can better understand how disturbance impacts diversity, and a community's ability to recover. This directly corresponds to my study and how unclimbed indicator species can be used to conserve undeveloped areas, and how climbed indicators can be used to seek out cliffs for development that already harbor species that prefer routes and that can persist through the disturbance of rock climbing.

### Management Recommendations

Rock climbing significantly decreases lichen and plant cover, richness and diversity (Table 5 and Table 6; Nuzzo 1996; Farris 1998; Camp and Knight 1998; McMillan and Larson 2002; Rusterholz et al. 2004; Müller et al. 2004; Kuntz and Larson 2006; Adams and Zaniewski 2012; Clark and Hessel 2015; Tessler and Clark 2016; Lorite et al. 2017; Boggess et al. 2017; March-Salas et al. 2018; Schmera 2018; Covy et al. 2019; Reding 2019). The specific

outcomes for biodiversity in climbing areas varies by site, and by morphogroup (Kuntz and Larson 2006; Boggess et al. 2017; Harrison 2020). In my study, sites with dense canopy cover, such as MR, harbor a much higher plant cover compared to climbing areas with low canopy cover, and highly exposed cliffs, such as ROS, which harbor more lichens. Because climbing reduces cover and diversity of almost all groups regardless of site, cliffs that have a high plant and lichen cover should be reconsidered for development. All macrolichen groups (i.e., fruticose, foliose, umbilicate) were less abundant on climbed routes, thus routes with high macrolichen abundance should also be avoided during route development.

*Implementing management plans that include vegetation conservation*

I have two management suggestions that apply to both sites, and a suite of site-specific suggestions. First, route development should be undertaken only if the route will actually be climbed. I noticed many instances of permanent bolts and cleaned routes on cliff faces that are clearly not regularly climbed. Second, the indicator species recovered in this study are easily field identifiable (Table 16) and surveys should be conducted for the indicators before route development is undertaken. MR should implement a guideline for seasonal cleaning, and future development based on results for the decrease of plant cover, richness, and diversity and the abundance of lichens that rely on bryophytes as their substrate within the cliffs. Specifically, areas that have high bryophyte and lichen cover should not be developed for future climbing, and it is important that future crags are surveyed for unclimbed indicator species before the establishment of more routes. ROS is a much older site than MR, and many routes have been climbed for 30+ years. No further development is planned to my knowledge. As the lichen communities are diverse at ROS, and less routes were surveyed than at MR, more studies on the lichen flora at the site should be done to better characterize the complete lichen community. Moreover, seasonal cleaning should be reduced, and focus solely on foot and handholds, as many lichens do not interfere with climbing routes.



### *Interesting Species*

I collected multiple interesting species throughout my study, some of which may be the first record for the site, Spokane County, or Eastern Washington. However, I did not collect any of the 52 lichens or six bryophytes on Washington's rare and threatened species lists (Washington Natural Heritage Program Lichen List 2011, Washington Natural Heritage Program Bryophyte List 1996). As much remains to be discovered about the lichen and bryophyte cliff communities in Spokane County, additional surveys would need to be done to assess if any species within my study are actually rare, endangered, or of concern.

At ROS some notable lichen species were: *Umbilicaria vellea*, *Chaenothecopsis subparoica*, and *Scharaeria fuscocinerea*. At MR similarly several lichens were notable: *Henrica americana*, *Dermatocarpon miniatum*, *Vestergrenopsis sonomensis*, and *Normandina pulchella*. *Henrica americana* is only known from one site in North America in Montana where it was collected by Dr. Bruce McCune (Breuss 2002). My collection is the second record of the species in North America. MR bryophyte species of interest included: *Zygodon rupestris*, *Pseudobraunia californica*, the thought to be un-described dark *Grimmia*, and both liverwort species (*Porella cordeana*, *Frullania californica*). *Frullania californica* may be a new county record as a review of literature (Hong 2002) and a review of herbarium records (Heinlen 2021), has it listed under the state of Washington, but not under Spokane County.

### *Management and the future of rock climbing in Spokane County*

Because of the increased popularity of rock climbing and significant impacts on cliff-dwelling organisms, biodiversity-focused management plans are urgently needed at all climbing areas throughout Spokane County. Pursuing multiple, specific lines of research are critical to developing data-driven management plans. The "urban" crags in Spokane County, like Minnehaha and Little Dishman, need baseline surveys, as well as sites that have ongoing development like Tumtum. Additionally, bouldering impacts should be investigated to better understand how different climbing disciplines impact lichen and bryophyte communities in

Spokane. The only study to date on bouldering impacts that has been published is Tessler and Clark (2016), and they found significant reductions in both lichen and bryophyte abundance. From 2019 to 2021 over 100 routes were added to the Spokane area on Mountainproject.com and even more routes are planned at places like Tumtum where local climbers have purchased land for development. A guidebook for the Spokane area is being published and released soon and includes all the updated and newly developed routes at MR, which has not had a publicly available guide before. This means even more people will be going to MR to climb, as routes will be easier to find and access with the guidebook. Thus, increases in climbing intensity throughout Spokane are likely, and right now is a critical moment to implement thoughtful development plans.

#### Future Studies

##### *Important variables to include in future studies*

The pace of research on rock climbing impacts lags behind the skyrocketing popularity of the sport. Many more studies are needed in order to understand how the rapid increase in rock climbers and the popularity of the sport is going to impact cliff communities in the future. Incorporating lichen morphogroups into analyses and studies will better contribute to how lichens are being impacted by rock climbing, since most studies have had lichens as the most abundant and diverse taxa within their sites with no subdivisions of lichens into smaller taxonomic or morphological groupings (Boggess et al. 2021). Even if there is no one on the research team with expertise in lichen identification, morphogroups can still be easily assessed by non-experts. Paired transects are also important for studies, since past studies that compared full cliff faces often did not have significant results due to abiotic variables not being comparable among the sampled climbed transects. Additionally, chalk has been mentioned as a concern, many climbers leaving chalk behind on routes. Hepenstrick et al. (2020) looked at how chalk impacted bryophytes and ferns at climbing sites, and did find significant chalk leaching in areas where chalk was not visible, and that chalk presence was decreasing fern and bryophyte abundance.

Future studies should note and try to include chalk as a contributing route factor that impacts climbed cliff communities to determine if the findings by Hepenstrick et al. (2020) are generalizable. CUI has not been recovered as a significant variable in my study or previous studies. However, this is likely due to how CUI is calculated, and direct measures of route use will likely be much more useful than *ad hoc* indices. A better approach would be to incorporate the use of surveys of climbers at study sites, wherein route use and cleaning activities are directly recorded throughout one or multiple seasons. While star value, approach distance, and route grade can roughly approximate popularity, having a direct measure through surveys would add greater detail and power to CUI analyses.

### **Conclusion**

Here I found that the impact of rock climbing mainly decreases cover, richness, and diversity of lichen and plant cliff communities in Eastern Washington. Splitting lichens into separate morphogroups resulted in a clear picture of climbing effects, and this approach should be formalized for future impacts of rock-climbing research. This study will provide both sites, MR and ROS, with a baseline and better understanding of the impact climbing is having on lichen and plant cliff communities as well as what species make up the cliffs. Additional surveys in unclimbed areas, continued studies over time as climbing increases, and keeping some areas from being developed is recommended to preserve the unique lichen, bryophyte, and vascular plant cliff communities of eastern Washington.

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### Giovanna Bishop

Graduate Fellow, Eastern Washington University  
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#### Profile

Environmental Science Graduate with research, outreach, and collections experience. Currently looking for permanent employment as a collections manager, curatorial assistant or researcher of cryptogams. Research interests include: taxonomy, biodiversity, and conservation of lichens, bryophytes, fungi, and algae; floristics; cliff ecology; and natural history collections-based research. Outreach activities include forays, Bioblitz's, leading hikes on lichens and bryophytes, and educating youth about the importance of the environment and different ecosystems.

#### Education

**M.S. in Biology, Eastern Washington University, Cheney, WA** Sep 2019- Jun 2021  
Thesis: Impacts of Rock Climbing on Lichen and Bryophyte Cliff Communities in Northwestern North America  
Advisor: Dr. Jessica Allen  
Cumulative GPA: 4.0

**B.A., Wheaton College, Norton, MA** Sep 2013- Jun 2017  
Major: Environmental Science with a concentration in Biology  
Minor: Studio Art  
Advisor: Dr. Scott Shumway  
Cumulative GPA: 3.0

#### Advanced Coursework and Workshops

**Eagle Hill Institute, Steuben, ME** Jun 2017  
Introduction to Bryophytes and Lichens, taught by Dr. Fred Olday  
Structure, Ecology, and Identification of Mosses, taught by Dr. Jerry Jenkins, and Sue Williams

#### Peer-reviewed publications and manuscripts

- Boggess, L., Harrison, G., **Bishop, GM.** 2021. Impacts of rock climbing on cliff vegetation: a methods review and best-practices. *Applied Vegetation Science*. <https://doi.org/10.1111/avsc.12583>
- Allen, J., Beeching, S., **Bishop, GM.**, Dal Forno, M., Hodges, M., Lendemer, J., McMullin, T., Paquette, H. & Yahr, R. 2020. *Flavoparmelia caperata*. *The IUCN Red List of Threatened Species* 2020: e.T180096947A180096996. <https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T180096947A180096996.en>.
- Allen, J., **Bishop, GM.** *In prep.* Preliminary checklist of the saxicolous lichens of granite rock in Spokane, County, USA. To be submitted to (unknown).
- **Bishop, GM.**, Harrison, G., Magori, K., O'Quinn, R., Allen, J. *In prep.* Impacts of rock climbing on lichen and bryophyte cliff communities in northwestern North America. To be submitted to *The Bryologist*.
- Kittredge WT, **Bishop GM** & Lubin D. *In prep.* A comparison of the cryptogam floras of Harold Parker State Forest and the Middlesex Fells Reservation, Essex and Middlesex Counties, Massachusetts, U.S.A. To be submitted to *Phytoneuron*.
- **Bishop GM.** *In prep.* Description of *Pohlia nutans* fo. *decepiens*: ecology and morphology of the lost forma. To be submitted to *Evansia*.

## Natural History Collections Experience

**Graduate Curatorial Assistant**, Eastern Washington University Herbarium, Cheney, WA  
Present

- Accession, database, and file specimens.
- Identify indet. material, re-identify or confirm bryophyte, lichen, fungi, and algae identifications.
- Preserve and maintain specimens through standard curation practices.
- Collaborate with professors/volunteers to pull specimens from collection for undergraduate courses.
- Mentor and train undergraduate students about herbaria practices and collections.

**Intern**, The Farlow, Harvard Herbarium, Cambridge, MA Jan 2019- Jul 2019

- Worked on Anna Marie Murphy Reid's Bryophyte collection of over 10,000 specimens.
- Re-packaged and labeled, databased, and filed over 3,500 bryophyte, and fungi specimens.
- Identified indet. bryophytes and verified identifications.
- Lead and developed tours for the public about the collections.
- Nomenclature course taken, offered by Kanchi Nata. Ghandi.

**Temporary Curatorial Assistant**, The Farlow, Harvard Herbarium, Cambridge, MA Nov 2017- Apr 2018

- Curated fungi, bryophytes, lichens, vascular plants, and algae.
- Identified bryophytes, lichens, and algae that needed verification before being added to the collections as well as databased and digitized specimens using Specify and Rapid.
- Certified to mount vascular and algae specimens from head mounter at Harvard Herbaria.

**Lab Assistant**, Wheaton College: Norton, MA Fall 2016- Spring 2017

Worked with Dr. Scott Shumway to identify and digitize a lost collection of marine mollusks.

- Keyed over 100 species of marine mollusks.
- Digitized collection of marine species and curated specimens for open access resources through Wheaton.

## Research Experience

**Field Assistant**, Eastern Washington University, Cheney, WA Aug 2019  
Assisted Dr. Jessica Allen and Dr. R. Troy McMullin in collecting Lichens for the North Cascades Flora Project

- Collected, identified and deposited over 100 lichen collections to EWU Herbarium.

**Cryptogamic Botanist**, Friends of the Fells and Walter Kittredge, Boston, MA Summer 2018  
Identified mosses, lichens, liverworts, and algae for Walter Kittredge to help create a Flora for both The Middlesex Fells Reservation and Harold Parker State Park.

- Scouted areas for new species of bryophytes and lichens, collected specimens, identified vouchers at Harvard Herbaria.

**Field Research Assistant**, University of Florida, Gainesville, FL Summer 2017

Assisted PhD candidate, Christopher Krieg, to find what traits the polyploidy fern *Polystichum scopulinum* has evolved from its parents, *P. imbricans* and *P. lemmonii*.

- Utilized a LICOR to collect physiological data.
- Collected pinna of ferns for dry weight mass vs. area measurement and for isotopic processing.
- Collected soil samples at each site to differentiate soil types in which the ferns were found.

- Collected voucher specimens for deposition at to the UF Herbarium.

**Independent Research**, Wheaton College, Norton, MA

Spring 2017

Worked under Dr. Deborah Cato to learn more about Lichens and Bryophytes.

- Collected lichen and bryophyte samples in the field around New England.
- Identified and created a personal herbarium of over 100 Lichen, and Bryophyte species from NH, CT, MA, RI, and ME.

**Lab Assistant**, Oregon State University, Corvallis, OR

Summer 2016

Worked with Dr. Kim Bernard to enhance my lab skills.

- Discovered the relative impact of fishing routes on krill populations and their overall impact on the Western Antarctic Peninsula. Employing Antarctic Krill Fishing vessel data, I utilized Excel, Google Earth Pro, and GIS to examine the data and found that these vessels could be affecting penguin populations as well as other forms of marine life in the Western Antarctic Peninsula.
- Prepared Krill samples for analysis of stable isotopes to look at the diet of *Euphasia superba* in the last thirty years, to determine how their diet has changed and if there has been a shift in the trophic food web.
- Sorted plankton net tow samples and selected *Euphasia superba*.

### Relevant Job Experience

**Teaching Assistant**, Biology Dept. Eastern Washington University

Fall 2019- Spring 2021

- Assisted teaching undergraduate students for several courses: Intro Biology Series (171-173), Mycology, Botany, Field Botany, Climate Change Senior Seminar
- Created course material, graded assignments, setup/broke down labs, oversaw labs as well as held office hours weekly.

**IUCN Red List Lichen Intern**, Lichenologist Dr. Jessica Allen

Summer 2020

- Assisted in writing reports for several lichen species globally for the IUCN Redlist Lichen Initiative
- Attended specific IUCN training to learn how species become a part of the redlist

**Educator**, The Ecology School, Saco, ME

Sep 2018- Nov 2018

- Taught students K-8 about the ecology of several different ecosystems and how they interact with one another.
- Created lesson plans and taught about ecosystems from Forest, Beach and Dunes, to Salt Marsh.

**Greenhouse Assistant**, Wheaton College Greenhouse, Norton, MA

Summer 2015- 2016

- Provided tours that required knowledge of the plants to students, parents, and children.
- Removed pests from plants: mites, red-scale, and other diseases.
- Maintained healthy plants and safe, clean greenhouse.

### Community Outreach

**No Child Left Inside Volunteer**, Betz Elementary School, Cheney, WA

Nov 07, 2019

- Helped elementary students get outside and learn about native plants and the importance of restoration for the Palouse Prairie (0.01% left in fragmented chunks).
- Facilitated planting for each student of native grasses, wildflowers, and other plants of their choice.

**Spooky Science Volunteer**, Eastern Washington University, Cheney, WA

Oct 31, 2019

Event for local children in the town of Cheney to trick-or-treat in the science building and learn about science on Halloween.

- Explained to children and parents what lichens are and their importance.
- Taught kids about how lichens are 'spooky' because some species are UV+.

**Bryophyte/Lichen/Myxomycete Expert**, E.O.Wilson Bioblitz, Walden Pond, MA Jul 06, 2019

- Collected and identified lichens, bryophytes, and slime molds for the BioBlitz, was one of 3 experts.
- Myxomycete list included the most species ever for any Massachusetts BioBlitz in history.

**Bryophyte Expert**, Rhode Island BioBlitz, Camp Fuller- South Kingston, RI Jun 09, 2018

- Collected and identified bryophytes, was one of 4 experts.
- Bryophyte list included 47 mosses, and 6 liverworts.

**Lichen and Bryophyte Hike Leader**, Middlesex Fells Reservation, Medford, MA Summer 2018

- Lead hike to introduce public to mosses and lichens of Massachusetts.
- Taught those interested about the basic morphology of groups as well as how to identify common species.

**Founder**, WheaFarm, Wheaton College, Norton, MA Summer 2015- May 2017

- Recruited four students to assist in founding the Wheaton College Farm. Applied for a themed house on campus and established the Farm.
- President of both the Farm and the themed house, “Farm House”, for two years on campus.
- Built raised beds for Headstart preschool, donated grown food to local food bank, ran farmers markets in community, and created Farm Fest Community Event for Wheaton students and the town of Norton, MA.

**Intern**, Bristol Commons Community Garden, Taunton, MA Summer 2015

- Designed, planted and helped sustain the garden throughout the summer.
- Worked with community members to better their gardens.
- Experimented with permaculture, and different crops.

### Grants and Awards

**Honorable Mention, A.J. Sharp Award: Best Student Presentation BL2021**, ABLS July 2021  
**Graduate Conference Presentation Grant**, Eastern Washington University Spring 2021  
**Society of Herbarium Curators (SHC) Student Research Award**, SHC Spring 2021  
**American Alpine Club Research Grant**, American Alpine Club Spring 2020  
**Anderson and Crum Grant for Field Research in Bryology**, ABLS Spring 2020  
**Climbing Conservation Grant Program**, Access Fund Spring 2020  
**Northwest Environmental Research Institute (NERI) 2020 Grant**, NERI Winter 2020  
**Biology Department Mini-Grant**, Eastern Washington University Fall 2019  
**Graduate Teaching Assistantship**, Eastern Washington University Fall 2019- Spring 2021  
**Clinton V. MacCoy Prize in Ecology**, Wheaton College Spring 2017  
**Community Scholar**, Wheaton College Fall 2013- Spring 2017

### Co-Curricular Activities

**Graduate Representative, American Bryological and Lichenological Society** Present  
**Member**, Eastern Washington University Climbing Team Fall 2019- Spring 2020  
**Athlete**, Wheaton College Women’s Varsity Lacrosse Fall 2013- Spring 2017  
**President/Founder**, Farm House and WheaFarm at Wheaton College Spring 2015- Spring 2017  
**Trip Leader**, Wheaton Outdoor Orientation Program Summer 2015

### Professional References

Dr. Don Pfister, Professor of Mycology  
 Curator of the Farlow Library and Herbarium of Cryptogamic Botany  
 Asa Gray Professor of Systematic Botany  
 Harvard University, Cambridge, MA  
 617.495.2368 | dpfister@oeb.harvard.edu

Dr. Michaela Schnull, Director of Collections  
Harvard University Herbaria, Cambridge, MA  
617.495.0665 | [mschnull@oeb.harvard.edu](mailto:mschnull@oeb.harvard.edu)

Dr. Jessica Allen, Professor of Biology  
ICUN Lichen Specialist Group Co-Chair  
Eastern Washington University, Cheney, WA  
509.359.4727 | [jallen73@ewu.edu](mailto:jallen73@ewu.edu)

**Table 1.** Information about each site pertaining to route age, number of rock climbing routes, transects per site, and what routes were within each crag within sites.

	<b>McLellan</b>	<b>Rocks of Sharon</b>
<b>Route Age</b>	5-20+ years	11-35+ years
<b>Routes/Sport Routes</b>	115/84	61/47
<b>Climbed/Unclimbed Transects</b>	10/10	6/6
<b>Crags included in study with associated routes</b>	<p><u>The Burbs</u>: So much for the Afterglow  <u>Crisis Wall</u>: I am McLovin' It, Eura Sport Climber Now, Unknown 5.9, Two for Tuesday  <u>Dishonorable Wall</u>: Slick Shoes, Bourbon Legend  <u>Rock Candy</u>: Project Ivy, Happy Slow Boys  <u>Snake Slab</u>: Man in a Bear Suit</p>	<p><u>Big Rock, West Face</u>: Iron Wolf, The Timeless Bound  <u>Bird Watching Boulder</u>: Early Bird, Turkey Heads  <u>Triplets</u>: Nothin' but a Breeze, Upchuck the Boogie</p>



**Table 2.** Bryophyte and vascular plant taxon names for analyses and the included species.

<b>Taxon Code</b>	<b>Species</b>
ANTITRICHIA	<i>Antitrichia californica</i>
BRYUM	<i>Rosulabryum cf. capillare</i>
BUCKLANDIELLA	<i>Bucklandiella heterosticha</i>
CERATODON	<i>Ceratodon purpureus</i>
DICRANUM	<i>Dicranum sp.</i>
DIDYMODON	<i>Didymodon vinealis</i>
ENCALYPTA	<i>Encalypta ciliata</i>
FRULLANIA	<i>Frullania californica</i>
DARK_GRIMMIA	<i>Grimmia alpestris/montana</i> Group, <i>Grimmia sp.</i> (New)
GREEN_GRIMMIA	<i>Grimmia trichophylla</i> Group
HOMALOTHECIUM	<i>Homalothecium pinnatifidum</i> , <i>Homalothecium aureum</i>
NECKERA_MENZ	<i>Neckera menziesii</i>
NIPHOTRICHUM	<i>Niphotrichum elongatum</i>
ORTHOTRICHUM	<i>Orthotrichum laevigatum</i> , <i>Orthotrichum lyellii</i> , <i>Orthotrichum rupestre</i>
POLYTRI_PILIF	<i>Polytrichum piliferum</i>
POLYTRI_JUNI	<i>Polytrichum juniperinum</i>
PORELLA	<i>Porella cordaeana</i>
PSEUDOBRAUNIA	<i>Pseudobraunia californica</i>
PTERIGYNANDRUM	<i>Pterigynandrum filiforme</i>
RACOMITRIUM	<i>Bucklandiella affinis</i> ( <i>Racomitrium affine</i> ), <i>Racomitrium sp.</i>
SCHISTIDIUM	<i>Schistidium sp.</i>
SELAGINELLA	<i>Selaginella wallacei</i>
SYNTRICHIA	<i>Syntrichia norvegica</i> , <i>Syntrichia ruralis</i>
WOODSIA_SCOP	<i>Woodsia scopulina</i>
ZYGODON	<i>Zygodon rupestris</i>

**Table 3.** Lichen taxon names for analyses and their corresponding included species.

<b>Taxon Code</b>	<b>Species</b>
ACAROSPORA	<i>Acarospora</i> sp.
ASPICILIA	<i>Aspicilia contorta</i> , <i>Aspicilia cinerea</i>
BLACK_ENDOLITH	<i>Carbonea vorticosa</i> , <i>Lecidella patavina</i> , <i>Lecidella stigmatea</i> , <i>Porpidia crustulata</i> , <i>Sarcogyne regularis</i>
BROWN_CRUST	Indet. Lichen #1
BRYORIA	<i>Nodobryoria</i> sp.
BUELLIA	<i>Buella dispersa</i>
CALOPLACA	<i>Caloplaca biatorina</i> , <i>Caloplaca citrina</i> , <i>Caloplaca trachyphylla</i>
CALOPLACA_ARENARIA	<i>Caloplaca arenaria</i>
CALOPLACA_ARNOLDII	<i>Caloplaca arnoldii</i> subsp. <i>obliterata</i>
CANDELARIA	<i>Candelaria pacifica</i>
CANDELARIELLA	<i>Candelariella citrina</i> , <i>Candelariella rosulans</i> , <i>Candelariella vitellina</i>
CHAENOTHECOPSIS	<i>Chaenothecopsis subparioca</i>
CHRYSOTHRIX	<i>Chrysothrix chlorina</i>
CLADONIA	<i>Cladonia</i> sp. (1-5)
CREAMY_TAN_CRUST	Indet. Lichen #2
DERMATOCARPON	<i>Dermatocarpon miniatum</i>
DIMELAENA_OREINA	<i>Dimelaena oreina</i>
DIPLOSCHISTES	<i>Diploschistes muscorum</i> , <i>Diploschistes scruposus</i>
ESSLINGERIANA	<i>Esslingeriana idahoensis</i>
FRUTIDELLA	<i>Frutidella casioatra</i> ( <i>Lecidella carpathica</i> )
FUSCOPANNARIA	cf. <i>Fuscopannaria aurita</i>
GREEN_CRUST	Indet. Lichen #3
GREY_BLUE_CRUST	Indet. Lichen #4
GREY_CRUST	Indet. Lichen #5
GREEN_BROWN_CRUST	Indet. Lichen #6
GREEN_GREY_CRUST	Indet. Lichen #7
GREY_TAN_CRUST	Indet. Lichen #8
HENRICA_AMERICANA	<i>Henrica americana</i>
HYPOGYMNIA	<i>Hypogymnia austeroidea</i> , <i>Hypogymnia tubulosa</i>
LECANORA_BICINCTA	<i>Lecanora bicincta</i>
LECANORA_CENISIA	<i>Lecanora cenisia</i>
LECANORA_DISPERSA	<i>Lecanora dispersa</i>
LECANORA_DUST	<i>Lecanora</i> sp. #1
LECANORA_MUR	<i>Protoparmeliopsis muralis</i> , <i>Protoparmeliopsis garovaglii</i>
LECANORA_POLYTROPA	<i>Lecanora polytropha</i>
LECANORA_RUPICOLA	<i>Lecanora rupicola</i>
LECIDEA_TESSELATA	<i>Lecidea tessellata</i>
LEPRARIA	<i>Lepraria neglecta</i> (Psoromic, Norstictic, Stictic), <i>Lepraria elobata</i> , <i>Lepraria rigidula</i> , <i>Lepraria eburnea</i>
LEPROCAULON	<i>Leprocaulon knudsenii</i>
LEPTOCHIDIUM	<i>Leptochidium albociliatum</i>

LEPTOGIUM	<i>Leptogium</i> sp.
LEPTOGIUM_GELAT	<i>Leptogium gelatinosum</i>
LEPTOGIUM_LICHEN	<i>Leptogium lichenoides</i>
LEPTOGIUM_PALMATUM	<i>Leptogium palmatum</i>
LEPTOGIUM_RARE	<i>Leptogium</i> sp. A (potentially new species)
LETHARIA	<i>Letharia vulpina</i>
MASSLONG_CARN	<i>Massalongia carnosa</i>
MEL GROUP	<i>Melanelia hepatizon, Melanohalea infumata, Melanohalea subelegantula, Montanelia disjuncta, Montanelia panniformis, Montanelia soreliata</i>
MICAREA	<i>Micarea xanthonica</i>
MIRIQUIDICA	cf. <i>Miriquidica</i> sp.
MYCOBLASTUS_SANG	<i>Mycoblastus sanguinarius</i>
PARMELIA	<i>Parmelia sulcata, Parmelia saxatilis</i>
PELTIGERA	<i>Peltigera collina</i>
PHAEOPHYSCIA	<i>Phaeophyscia decolor, Phaeophyscia sciastra</i>
PHYLCTIS	<i>Phylctis argeana</i>
PHYSCIA	<i>Physcia caesia, Physcia biziana, Physcia dubia, Physcia magnusonii, Physcia phaea, Physcia tenella</i>
PHYSCONIA	<i>Physconia enteroxantha, Physconia muscigena, Physconia perisidiosa</i>
PIMPLE_CRUST	cf. <i>Verrucaria</i> sp.
PLATISMATIA	<i>Platismatia wheeleri</i>
PLEOPSIDIUM	<i>Pleopsidium flavum</i>
POLYCHIDIUM	<i>Polychidium muscicola</i>
PSEUDEPHEBE	<i>Pseudephebe pubescens</i>
PSORA_NIPPONICA	<i>Psora nipponica</i>
RHIZO_LECID_BRWN	<i>Lecidea atrobrunnea, Rhizocarpon bolanderi</i>
RHIZOCARP_GRY	<i>Rhizocarpon disporum, Rhizocarpon grande</i>
RHIZOCARP_YL	<i>Rhizocarpon geographicum</i> Group, <i>Rhizocarpon lecanorinum, Rhizocarpon macrosporum</i>
RHIZOPLACA	<i>Rhizoplaca melanothphalma</i>
RINODINA	<i>Rinodina confragosa</i>
SCHAER_FUSCO	<i>Schaeraria fuscocinerea</i>
STERILE_CRUST	<i>Lecanora</i> cf. <i>chloroleprosa</i>
TAN_BUMPY_CRUST	Indet. Lichen #9
TAN_CRUST_CRUMBLE	Indet. Lichen #10
UMBILICARIA_AMERI	<i>Umbilicaria americana</i>
UMBILICARIA_HYPER	<i>Umbilicaria hyperborea</i>
UMBILICARIA_PHAEA	<i>Umbilicaria phaea</i>
UMBILICARIA_POLYPHY	<i>Umbilicaria polyphylla</i>
UMBILICARIA_POLYRH	<i>Umbilicaria polyrrhiza</i>
UMBILICARIA_SP	<i>Umbilicaria</i> sp.
UMBILICARIA_TOR	<i>Umbilicaria torrefacta</i>
UMBILICARIA_VELLEA	<i>Umbilicaria vellea</i>
VESTERGRENOPSIS	<i>Vestergrenopsis sonomensis</i>
XANTHOMENDOZA	<i>Xanthomendoza</i> sp.

XANTHOPARMELIA	<i>Xanthoparmelia angustiphylla</i> , <i>Xanthoparmelia</i> cf. <i>hypofusca</i> , <i>Xanthoparmelia</i> cf. <i>vagans</i> , <i>Xanthoparmelia coloradoensis</i> , <i>Xanthoparmelia cumberlandia</i> , <i>Xanthoparmelia</i> cf. <i>loxodes</i> , <i>Xanthoparmelia mexicana</i> , <i>Xanthoparmelia mougeotii</i> , <i>Xanthoparmelia plittii</i> , <i>Xanthoparmelia subhosseana</i>
XANTHORIA	<i>Xanthoria elegans</i> , <i>Xanthoria candelaria</i>

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**Table 4.** Species assignments for each lichen morphogroup.

Lichen Morphogroup	Species
Crustose	<i>Acarospora</i> sp., <i>Aspicilia contorta</i> , <i>Aspicilia cinerea</i> , Indet. Lichen #1-10, <i>Buella dispersa</i> , <i>Caloplaca biatorina</i> , <i>Caloplaca citrina</i> , <i>Caloplaca trachyphylla</i> , <i>Caloplaca arnoldii</i> subsp. <i>obliterata</i> , <i>Candelariella citrina</i> , <i>Candelariella rosulans</i> , <i>Candelariella vitellina</i> , <i>Dimelaena oreina</i> , <i>Diploschistes muscorum</i> , <i>Diploschistes scruposus</i> , <i>Frutidella casioatra</i> ( <i>Lecidella carpathica</i> ), <i>Henrica americana</i> , <i>Lecanora bicincta</i> , <i>Lecanora cenisia</i> , <i>Lecanora rupicola</i> , <i>Lecanora muralis</i> Group, <i>Lecidea tessellata</i> , cf. <i>Miriquidica</i> sp., <i>Mycoblastus sanguinarius</i> , <i>Verrucaria</i> sp., <i>Pleopsidium flavum</i> , <i>Lecidea atrobrunnea</i> , <i>Rhizocarpon bolanderi</i> , <i>Rhizocarpon disporum</i> , <i>Rhizocarpon grande</i> , <i>Rhizocarpon geographicum</i> Group, <i>Rhizocarpon lecanorinum</i> , <i>Rhizocarpon macrosporum</i> , <i>Rinodina confragosa</i> , <i>Schaeraria fuscocinerea</i> , <i>Phylctis argeana</i> , <i>Micarea xanthonica</i> , <i>Lecanora</i> cf. <i>chloroleprosa</i>
Endolithic	<i>Caloplaca arenaria</i> , <i>Lecanora dispersa</i> , <i>Lecanora polytropa</i> , <i>Carbonea vorticosa</i> , <i>Lecidella stigmatea</i> , <i>Lecidella patavina</i> , <i>Porpidia crustulata</i> , <i>Sarcogyne regularis</i>
Leprose	<i>Chrysothrix chlorina</i> , <i>Lecanora</i> sp. #1, <i>Lepraria neglecta</i> , <i>Lepraria eburnea</i> , <i>Lepraria elobata</i> , <i>Lepraria rigidula</i> , <i>Leprocaulon knudsenii</i>
Foliose	<i>Esslingeriana idahoensis</i> , <i>Hypogymnia austeroides</i> , <i>Hypogymnia tubulosa</i> , <i>Leptochidium albociliatum</i> , <i>Leptogium</i> sp., <i>Leptogium lichenoides</i> , <i>Leptogium palmatum</i> , <i>Leptogium gelatinosum</i> , <i>Leptogium</i> sp. #1, <i>Massalongia carnosa</i> , <i>Melanelia hepatizon</i> , <i>Melanohalea infumata</i> , <i>Melanohalea subelegantula</i> , <i>Montanelia disjuncta</i> , <i>Montanelia panniformis</i> , <i>Montanelia sorediata</i> , <i>Parmelia sulcata</i> , <i>Parmelia saxatilis</i> , <i>Phaeophyscia decolor</i> , <i>Phaeophyscia sciastra</i> , <i>Peltigera collina</i> , <i>Physcia caesia</i> , <i>Physcia biziana</i> , <i>Physcia dubia</i> , <i>Physcia magnusonii</i> , <i>Physcia phaea</i> , <i>Physcia tenella</i> , <i>Physconia</i> cf. <i>enteroxantha</i> , <i>Physconia</i> cf. <i>muscigena</i> , <i>Physconia</i> cf. <i>perisidiosa</i> , <i>Platismatia wheeleri</i> , <i>Vestergrenopsis sonomensis</i> , <i>Xanthoparmelia angustiphylla</i> , <i>Xanthoparmelia</i> cf. <i>hypofusca</i> , <i>Xanthoparmelia</i> cf. <i>vagans</i> , <i>Xanthoparmelia coloradoensis</i> , <i>Xanthoparmelia cumberlandia</i> , <i>Xanthoparmelia</i> cf. <i>loxodes</i> , <i>Xanthoparmelia mexicana</i> , <i>Xanthoparmelia mougeotii</i> , <i>Xanthoparmelia plittii</i> , <i>Xanthoparmelia subhosseana</i>
Fruticose	<i>Cladonia</i> species, <i>Letharia vulpina</i> , <i>Polychidium muscicola</i> , <i>Pseudephebe pubescens</i> , <i>Nodobryoria</i> sp.
Umbilicate	<i>Dermatopcarpon miniatum</i> , <i>Rhizoplaca melanophthalma</i> , <i>Umbilicaria americana</i> , <i>Umbilicaria hyperborea</i> , <i>Umbilicaria polyphylla</i> , <i>Umbilicaria polyrrhiza</i> , <i>Umbilicaria phaea</i> , <i>Umbilicaria torrefacta</i> , <i>Umbilicaria vellea</i>
Squamulose	<i>Psora nipponica</i> , (the next species listed were recognized as squamulose for analyses despite being foliose) <i>Xanthomendoza</i> sp., <i>Xanthoria candelaria</i> , <i>Xanthoria elegans</i> , <i>Candelaria pacifica</i>

**Table 5.** GLMM results for climbing effect between both sites and each individually for total taxa, plants, and lichens. Anova Type III test Chisq and Degrees of Freedom values are reported, a p-value less than 0.05 in bold were considered significant. C= cover, SD= Shannon's Diversity, SR= Species Richness.

Site, Taxa	C/SD/SR	Climbed Mean	Unclimbed Mean	Chisq	DF	Pr(>Chisq)
ROS, All Taxa	C	40.63	64.21	48.045	1	<b>&lt;0.0001</b>
	SD	1.8	1.86	0.6334	1	0.42610
	SR	12.09	12.17	0.0219	1	0.88230
MR, All Taxa	C	39.64	63.88	71.834	1	<b>&lt;0.0001</b>
	SD	1.55	1.66	2.9537	1	0.08568
	SR	9.77	10.04	0.3401	1	0.55980
ROS, Plants	C	5.1	5.32	0.101	1	0.7507
	SD	0.22	0.21	0.0001	1	0.9941
	SR	1.42	1.54	0.5019	1	0.47870
MR, Plants	C	20.85	29.77	21.978	1	<b>&lt;0.0001</b>
	SD	0.64	0.94	25.472	1	<b>&lt;0.0001</b>
	SR	2.93	3.67	17.733	1	<b>&lt;0.0001</b>
ROS, Lichens	C	38.91	54.88	17.692	1	<b>&lt;0.0001</b>
	SD	1.69	1.86	4.9325	1	<b>0.02636</b>
	SR	11.08	11.12	0.0068	1	0.93430
MR, Lichens	C	26.39	26.34	0.0007	1	0.97873
	SD	1.23	1.21	0.0961	1	0.75660
	SR	7.37	6.41	6.2988	1	<b>0.01208</b>

**Table 6.** GLMM results for climbing effect between both sites and each individually for each lichen morphogroup. P-values less than 0.05 in bold were considered significant and pertain to the Anova Type II test. C= cover, SD= Shannon's Diversity, SR= Species Richness.

Site, Lichen Morphogroup	C/SD/SR	Climbed Mean	Unclimbed Mean	Chisq	Df	Pr(>Chisq)
ROS, Crustose	C	26.09	24.58	0.0525	1	0.81870
	SD	1.23	1.13	2.1918	1	0.13870
	SR	6.27	5.21	8.421	1	<b>0.00371</b>
MR, Crustose	C	14.01	7.88	19.439	1	<b>&lt;0.0001</b>
	SD	0.74	0.56	14.7397	1	<b>0.00012</b>
	SR	3.49	2.42	31.243	1	<b>&lt;0.0001</b>
ROS, Foliose	C	3.15	5.68	7.7392	1	<b>0.00540</b>
	SD	0.36	0.36	0.0038	1	0.95079
	SR	1.66	1.7	0.0573	1	0.81080
MR, Foliose	C	5.05	6.06	0.7982	1	0.37163
	SD	0.36	0.37	0.117	1	0.73230
	SR	1.8	1.79	0.0011	1	0.97390
ROS, Leprose	C	5.04	8.87	26.073	1	<b>&lt;0.0001</b>
	SD	N/A	N/A	N/A	N/A	N/A
	SR	N/A	N/A	N/A	N/A	N/A
MR, Leprose	C	3.71	3.75	0.2235	1	0.63637
	SD	N/A	N/A	N/A	N/A	N/A
	SR	N/A	N/A	N/A	N/A	N/A
ROS, Endolith	C	0.03	0.02	0.2974	1	0.58550
	SD	N/A	N/A	N/A	N/A	N/A
	SR	0.26	0.11	3.0497	1	0.08075
MR, Endolith	C	0.87	0.25	9.7127	1	<b>0.00183</b>
	SD	N/A	N/A	N/A	N/A	N/A
	SR	0.48	0.08	30.775	1	<b>&lt;0.0001</b>
ROS, Fruticose	C	0.22	0.37	1.498	1	0.22098
	SD	N/A	N/A	N/A	N/A	N/A
	SR	0.18	0.6	17.984	1	<b>&lt;0.0001</b>
MR, Fruticose	C	0.01	0.17	12.3373	1	<b>0.00044</b>
	SD	N/A	N/A	N/A	N/A	N/A
	SR	0.29	0.58	22.67	1	<b>&lt;0.0001</b>
ROS, Squamulose	C	0.51	0.68	3.0962	1	0.07848
	SD	N/A	N/A	N/A	N/A	N/A
	SR	0.3	0.39	0.7948	1	0.37265
MR, Squamulose	C	0	0.1	0.8625	1	0.35300
	SD	N/A	N/A	N/A	N/A	N/A
	SR	0.17	0.14	0.1663	1	0.68341
ROS, Umbilicate	C	1.64	7.67	24.0334	1	<b>&lt;0.0001</b>

	SD	0.22	0.38	5.9763	1	<b>0.01450</b>
	SR	1.15	1.74	9.8626	1	<b>0.00169</b>
MR, Umbilicate	C	0.15	0.13	0.134	1	0.71436
	SD	N/A	N/A	N/A	N/A	N/A
	SR	0.22	0.32	3.218	1	0.07283



**Table 7.** GLMM results for climbed and unclimbed lichen and plants within each individual site. C= cover, SR= Species Richness, SD= Shannon's Diversity. P-values are from Anova Type II or III, those in bold are significant.

Site, Taxa	CL/UNCL	C/SR/SD	AICc	Variables	Slope	Weight	Anova Type II	Anova Type III
MR, Plants	CL	C	632.11	Age	-	0.54	0.17007	0.12425
				Star	-	1	<b>0.04890</b>	0.47112
				Feature Number	-	0.9	<b>0.03193</b>	0.97739
				Plot Height	-	1	<b>&lt;0.0001</b>	0.44581
MR, Plants	UNCL	C	705.90	Slope	-	0.99	<b>&lt;0.0001</b>	0.00958
				Feature Number	-	0.55	0.05034	0.16987
ROS, Plants	CL	SR	104.09	Slope	-	0.57	<b>0.01611</b>	0.70860
				Feature Number	+	0.86	<b>0.00236</b>	0.63020
				Plot Height	-	1	0.06107	0.86950
ROS, Plants	UNCL	C	348.93	Feature Number	-	0.044	0.4694	0.46940
MR, Lichens	CL	C	664.50	Age	+	0.97	<b>0.00404</b>	<b>0.02739</b>
				Star	-	0.93	0.83178	0.07163
				Feature Number	+	0.79	<b>&lt;0.0001</b>	0.05727
				Plot Height	+	0.98	<b>0.01645</b>	0.06245
MR, Lichens	CL	SD	134.97	Feature Number	+	0.164	<b>0.00415</b>	<b>0.00415</b>
MR, Lichens	CL	SR	419.53	Star	+	0.5	0.51048	0.66470
				Feature Number	+	0.97	<b>0.00012</b>	0.65860
				Plot Height	+	0.81	<b>0.00087</b>	0.42900
MR, Lichens	UNCL	C	676.02	Feature Cover	+	0.66	<b>&lt;0.0001</b>	0.36530
				Canopy Cover	-	0.3	0.49196	<b>0.01652</b>
MR, Lichens	UNCL	SD	169.33	Plot Height	+	0.32	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
MR, Lichens	UNCL	SR	424.56	Plot Height	+	0.221	<b>0.01673</b>	<b>0.01673</b>
ROS, Lichens	CL	C	397.42	Age	-	0.88	0.74310	0.31070
				Star	+	0.95	0.20020	0.11780
				Plot Height	+	0.86	<b>&lt;0.0001</b>	0.52430

				Age: Star	- : +	0.56	0.12910	0.13440
				Age: Plot Height	- : +	0.6	<b>&lt;0.0001</b>	0.50750
ROS, Lichens	CL	SD	71.650	Star	+	1	0.54700	0.54700
ROS, Lichens	CL	SR	256.49	Star	+	0.54	<b>0.00127</b>	<b>0.00127</b>
ROS, Lichens	UNCL	C	422.45	Slope	+	0.51	<b>0.01000</b>	0.96360
				Feature Number	+	0.53	<b>0.03400</b>	0.98380
				Plot Height	+	1	<b>&lt;0.0001</b>	0.73150

**Table 8.** Unclimbed transect NMDS results for factors for lichens, and bryophytes and plants for each site individually.  $R^2$  values are reported, bolded values had a significant p-value  $p < 0.005$ .

<b>Site, Taxa</b>	<b>Crag</b>	<b>Route</b>	<b>Aspect Ordination</b>	<b>Stress</b>	<b>K</b>
MR, Plants	<b>0.4357</b>	<b>0.5467</b>	<b>0.2742</b>	0.046	10
ROS, Plants	<b>0.2847</b>	<b>0.5252</b>	<b>0.4658</b>	0.039	4
MR, Lichens	<b>0.4607</b>	<b>0.6068</b>	<b>0.2361</b>	0.045	10
ROS, Lichens	<b>0.2621</b>	<b>0.4434</b>	<b>0.3331</b>	0.047	8

**Table 9.** Unclimbed transect NMDS results for vectors for lichens and bryophytes and plants for each site individually. Bolded p-values are significant ( $p < 0.05$ ). Stress and K values are included in Table 8 for each NMDS below.

Site, Taxa	Variable	NMDS1	NMDS2	r <sup>2</sup>	p-value
MR, Plants	Plot Height	-0.67323	0.73944	0.0808	<b>0.028</b>
	Feature Number	0.98929	-0.14599	0.0024	0.898
	Feature Cover	0.93064	-0.36594	0.1107	<b>0.009</b>
	Aspect Degree	0.31574	0.94884	0.3473	<b>0.001</b>
	Slope	0.74247	0.66988	0.0127	0.589
	Canopy Cover	0.77802	-0.62824	0.4684	<b>0.001</b>
ROS, Plants	Plot Height	0.66156	0.74989	0.1994	<b>0.049</b>
	Feature Number	-0.66226	0.74927	0.1018	0.237
	Feature Cover	0.02712	0.99963	0.0876	0.305
	Aspect Degree	0.80086	-0.59885	0.0297	0.676
	Slope	0.48792	0.87289	0.2816	<b>0.008</b>
	Canopy Cover	0.97852	-0.20613	0.3025	<b>0.011</b>
MR, Lichens	Plot Height	-0.61115	-0.79152	0.0797	0.060
	Slope	-0.53351	0.84580	0.2461	<b>0.001</b>
	Feature Number	-0.07440	0.99723	0.0275	0.349
	Feature Cover	0.71397	0.70018	0.1052	<b>0.015</b>
	Aspect Degree	-0.52569	0.85068	0.0491	0.157
	Canopy Cover	0.78530	-0.61912	0.3995	<b>0.001</b>
ROS, Lichens	Plot Height	0.04104	-0.99916	0.4901	<b>0.001</b>
	Slope	0.97845	-0.20650	0.1999	<b>0.009</b>
	Feature Number	-0.12588	-0.99204	0.0341	0.486
	Feature Cover	0.07571	0.99713	0.0075	0.858
	Aspect Degree	-0.97414	-0.22595	0.0870	0.134
	Canopy Cover	-0.98543	-0.17006	0.0248	0.550

**Table 10.** Climbed transect NMDS results for factors for lichens, and bryophytes and plants for each site individually.  $R^2$  values are reported, bolded values had a significant p-value  $p < 0.05$ .

<b>Site, Taxa</b>	<b>Crag</b>	<b>Route</b>	<b>Aspect Ordination</b>	<b>Difficulty</b>	<b>Stress</b>	<b>K</b>
MR, Plants	<b>0.1458</b>	<b>0.2958</b>	<b>0.1302</b>	<b>0.1298</b>	0.043	7
ROS, Plants	0.0211	0.2028	0.1058	0.1171	0.039	4
MR, Lichens	<b>0.1595</b>	<b>0.2730</b>	<b>0.0817</b>	<b>0.0856</b>	0.046	10
ROS, Lichens	<b>0.1389</b>	<b>0.4510</b>	<b>0.3849</b>	<b>0.2543</b>	0.046	9

**Table 11.** NMDS results for vectors for lichens and bryophytes and plants for each site individually for climbed transects. Bolded p-values are significant. Stress and K values can be found in Table 9 for each NMDS below.

Site, Taxa	Variable	NMDS1	NMDS2	r <sup>2</sup>	p-value
MR, Plants	Approach Distance	0.72678	-0.68687	0.0870	<b>0.020</b>
	Star	-0.99729	-0.07354	0.0708	0.074
	Climbing Intensity	-0.09626	0.99536	0.0563	0.094
	Route Age	-0.74321	-0.66906	0.1020	<b>0.019</b>
	Plot Height	-0.90178	-0.43220	0.2656	<b>0.001</b>
	Feature Number	-0.99650	-0.08364	0.0264	0.331
	Feature Cover	-0.58099	0.81319	0.0195	0.487
	Aspect Degree	0.13299	0.99112	0.0260	0.369
	Slope	0.99881	0.04878	0.0853	<b>0.044</b>
	Canopy Cover	1.00000	-0.00235	0.1333	<b>0.044</b>
ROS, Plants	Approach Distance	-0.43903	0.89847	0.0401	0.540
	Star	0.31891	-0.94779	0.4134	<b>0.002</b>
	Climbing Intensity	0.03459	-0.99940	0.0947	0.240
	Route Age	0.64228	-0.76647	0.0644	0.374
	Plot Height	-0.22307	0.97480	0.0251	0.714
	Feature Number	-0.08003	-0.99679	0.0683	0.339
	Feature Cover	0.98384	-0.17903	0.0154	0.825
	Aspect Degree	-0.24462	0.96962	0.2597	<b>0.013</b>
	Slope	-0.55622	0.83103	0.0179	0.780
	Canopy Cover	-0.13943	0.99023	0.1514	0.097
MR, Lichens	Approach Distance	0.72678	0.81139	0.0009	0.966
	Star	-0.63800	0.77004	0.0213	0.443
	Climbing Intensity	-0.14621	-0.98925	0.0045	0.840
	Route Age	-0.51450	0.85749	0.1487	<b>0.005</b>
	Plot Height	-0.32765	0.94480	0.1586	<b>0.002</b>
	Slope	-0.11042	-0.99389	0.0604	0.104
	Feature Number	-0.99839	0.05664	0.0096	0.717
	Feature Cover	-0.89984	-0.43623	0.0605	0.098
	Aspect Degree	-0.57125	-0.82077	0.0195	0.481
	Canopy Cover	0.94203	-0.33552	0.1527	<b>0.005</b>
ROS, Lichens	Approach Distance	0.40612	0.91382	0.0643	0.212

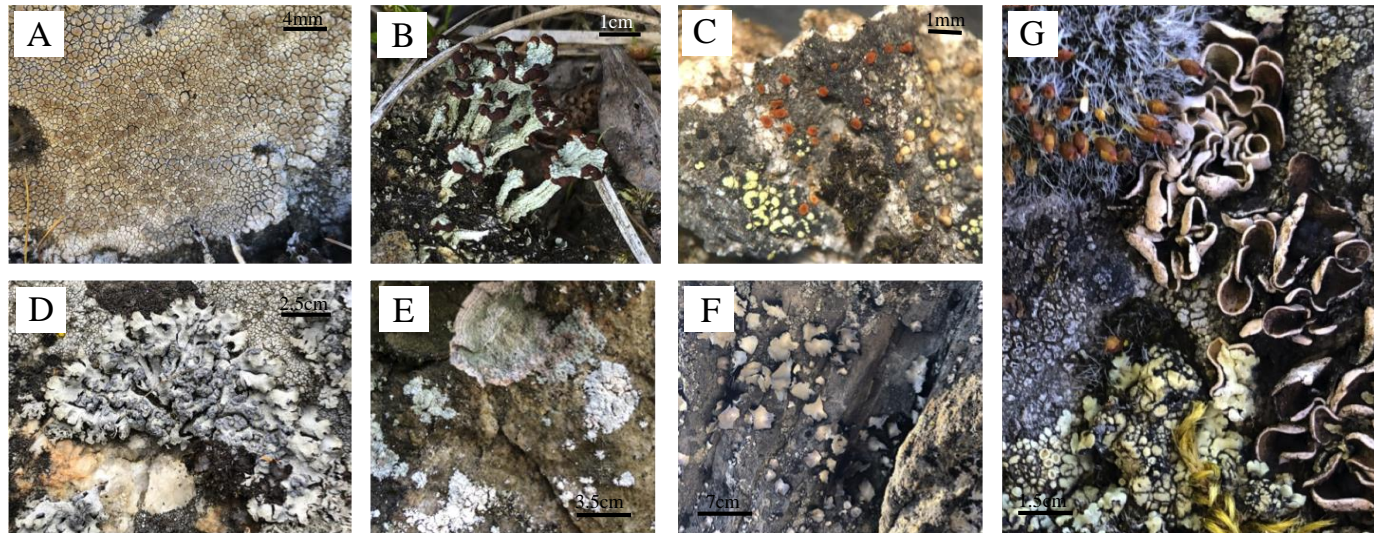
Star	0.59967	0.80024	0.2272	<b>0.004</b>
Climbing Intensity	-0.66743	-0.74467	0.0215	0.600
Route Age	-0.40808	0.91295	0.1239	<b>0.050</b>
Plot Height	-0.37518	0.92695	0.0947	0.112
Slope	0.99933	-0.03656	0.3335	<b>0.001</b>
Feature Number	0.66249	-0.74907	0.0124	0.759
Feature Cover	0.65311	-0.75726	0.1788	<b>0.008</b>
Aspect Degree	-0.44333	-0.89636	0.3338	<b>0.001</b>
Canopy Cover	-0.99589	-0.09055	0.1029	0.077

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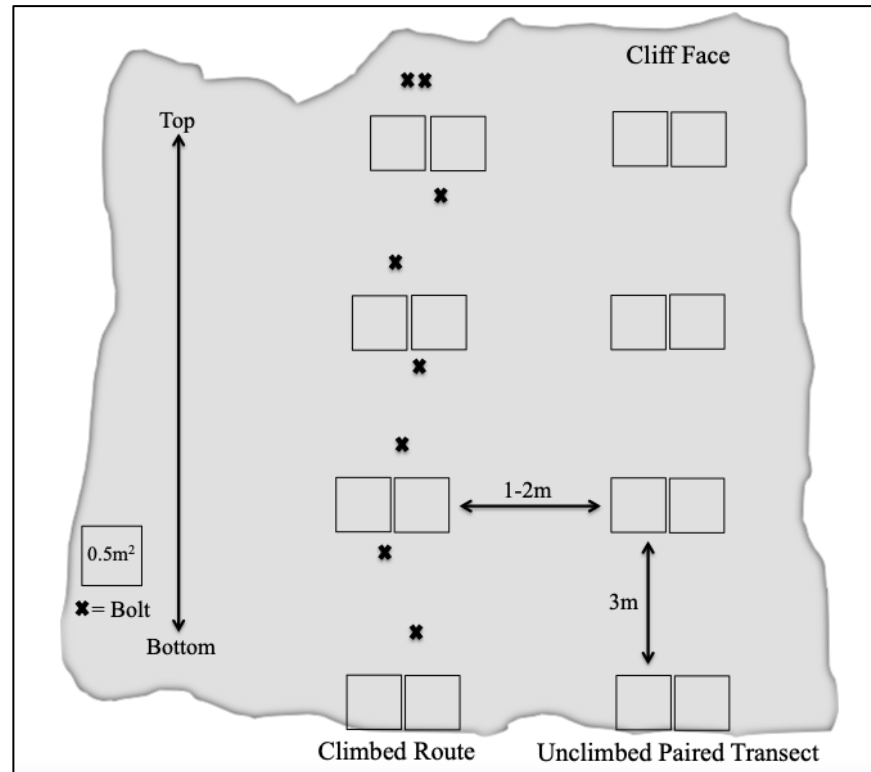
**Table 16:** Indicator species for each site, climbed and unclimbed for both lichens, and plants.

Site, Taxa	Climbing	Species	Stat	P-value
MR, Lichens	Climbed	Blk Endolith	0.535	0.0099
		<i>Lecanora polytropa</i>	0.428	0.0099
		Green Crust #1	0.342	0.0099
		<i>Henrica americana</i>	0.279	0.0495
		<i>Buellia dispersa</i>	0.279	0.0297
	Unclimbed	<i>Cladonia</i>	0.684	0.0099
		<i>Parmelia saxatilis/sulcata</i>	0.583	0.0198
		<i>Polychidium muscicola</i>	0.356	0.0198
		<i>Massalongia carnosa</i>	0.281	0.0198
		<i>Leptochidium albociliatum</i>	0.229	0.0396
MR, Plants	Unclimbed	<i>Antitrichia californica</i>	0.607	0.0099
		<i>Selaginella wallacei</i>	0.524	0.0099
		<i>Pseudobraunia californica</i>	0.495	0.0198
		<i>Syntrichia ruralis/norvegica</i>	0.490	0.0099
		<i>Dicranum sp.</i>	0.249	0.0495
ROS, Lichens	Unclimbed	<i>Letharia vulpina</i>	0.623	0.0099
		<i>Umbilicaria americana</i>	0.586	0.0099
		<i>Umbilicaria hyperborea</i>	0.573	0.0099
		<i>Rhizoplaca melanophthalma</i>	0.476	0.0495
		<i>Massalongia carnosa</i>	0.398	0.0297
ROS, Moss	Unclimbed	<i>Grimmia trichophylla</i>	0.554	0.0198



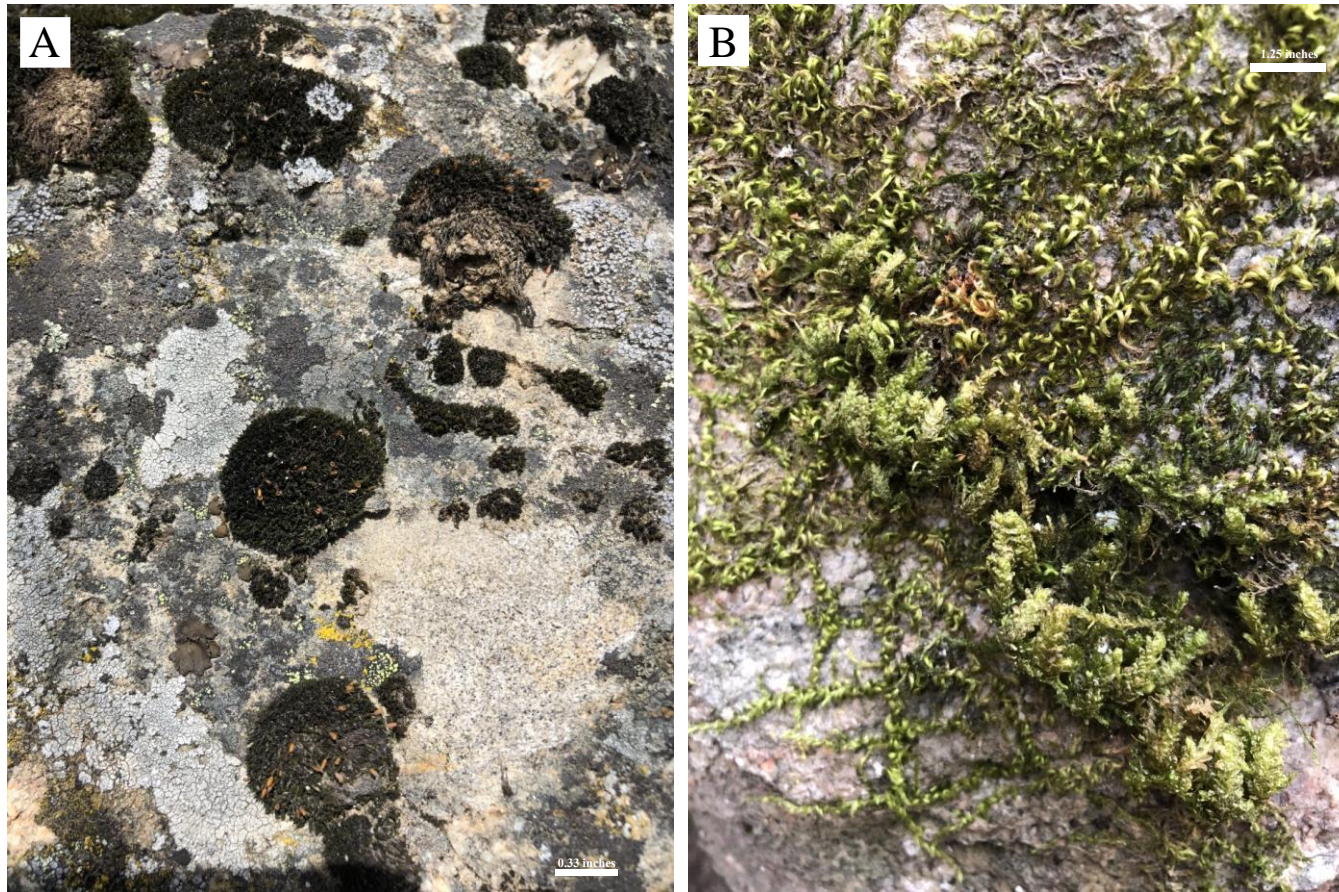


**Figure 1.** Examples of each lichen morphogroup included within this study. All photos were taken of lichens within climbed and unclimbed transects at both sites. A) Crustose, *Lecanora rupicola*; B) Fruticose, *Cladonia* spp.; C) Endolith, *Caloplaca arenaria*; D) Foliose, *Physcia caesia*; E) Leprose, *Lepraria* spp.; F) Umbilicate, *Umbilicaria americana*; G) Squamulose, *Psora nipponica*.

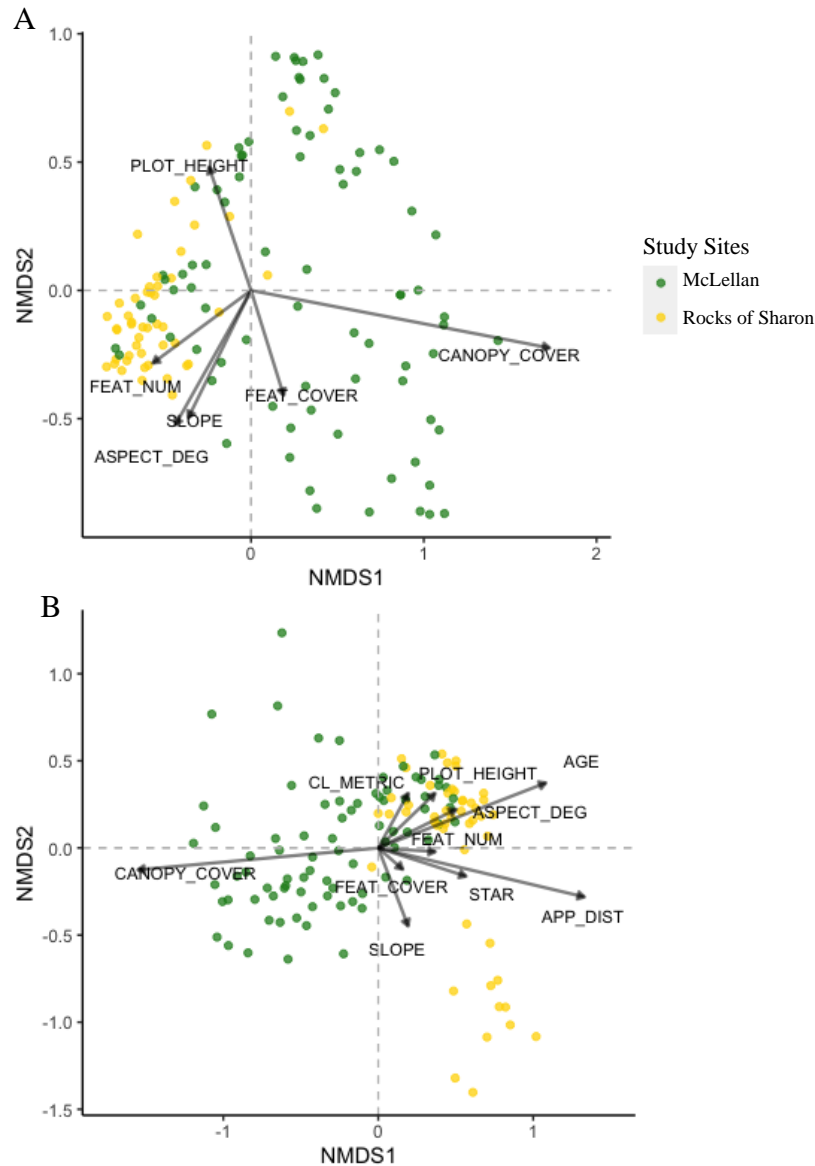


**Figure 2.** Study design illustrating two 0.5m<sup>2</sup> plots placed side by side every three meters a total of four times starting at the bottom of the cliff face. The sport-climbing route can be seen with X's as permanent bolts next to an unclimbed transect that it is paired with.

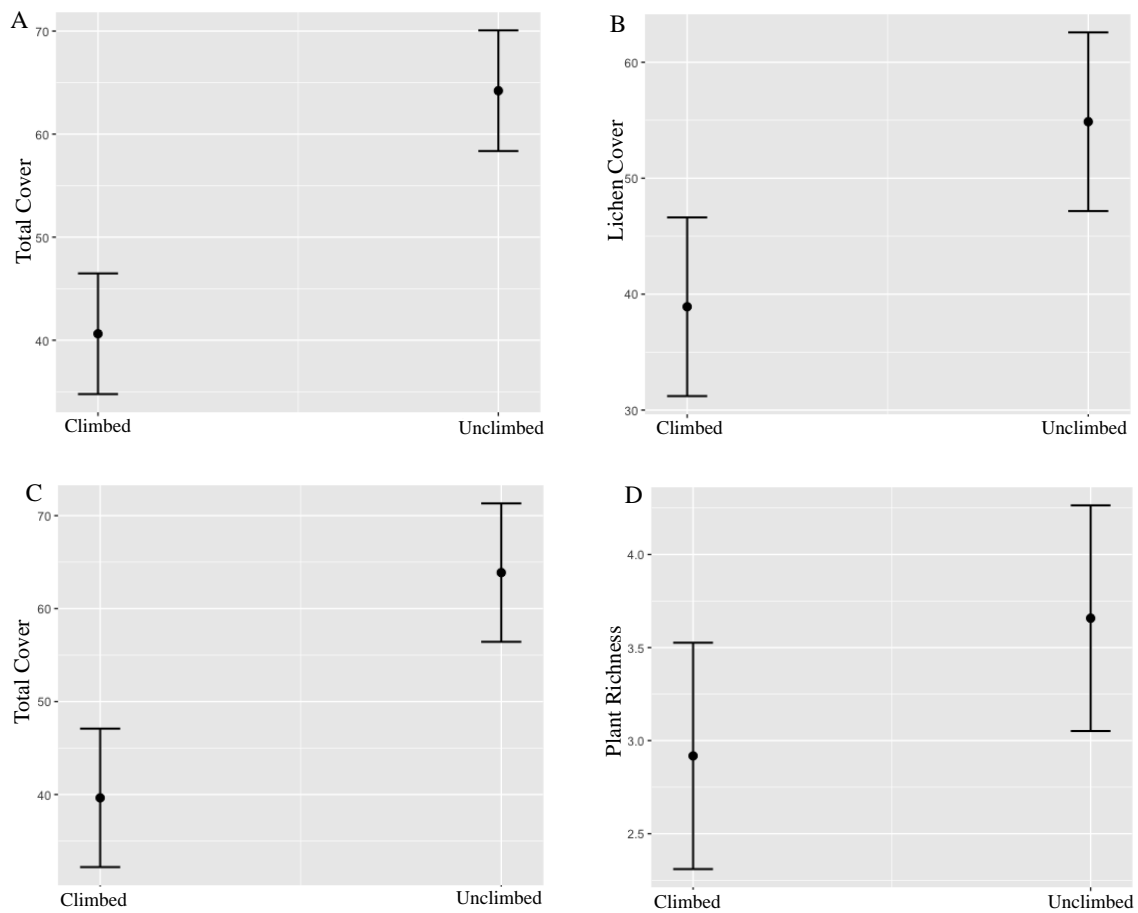




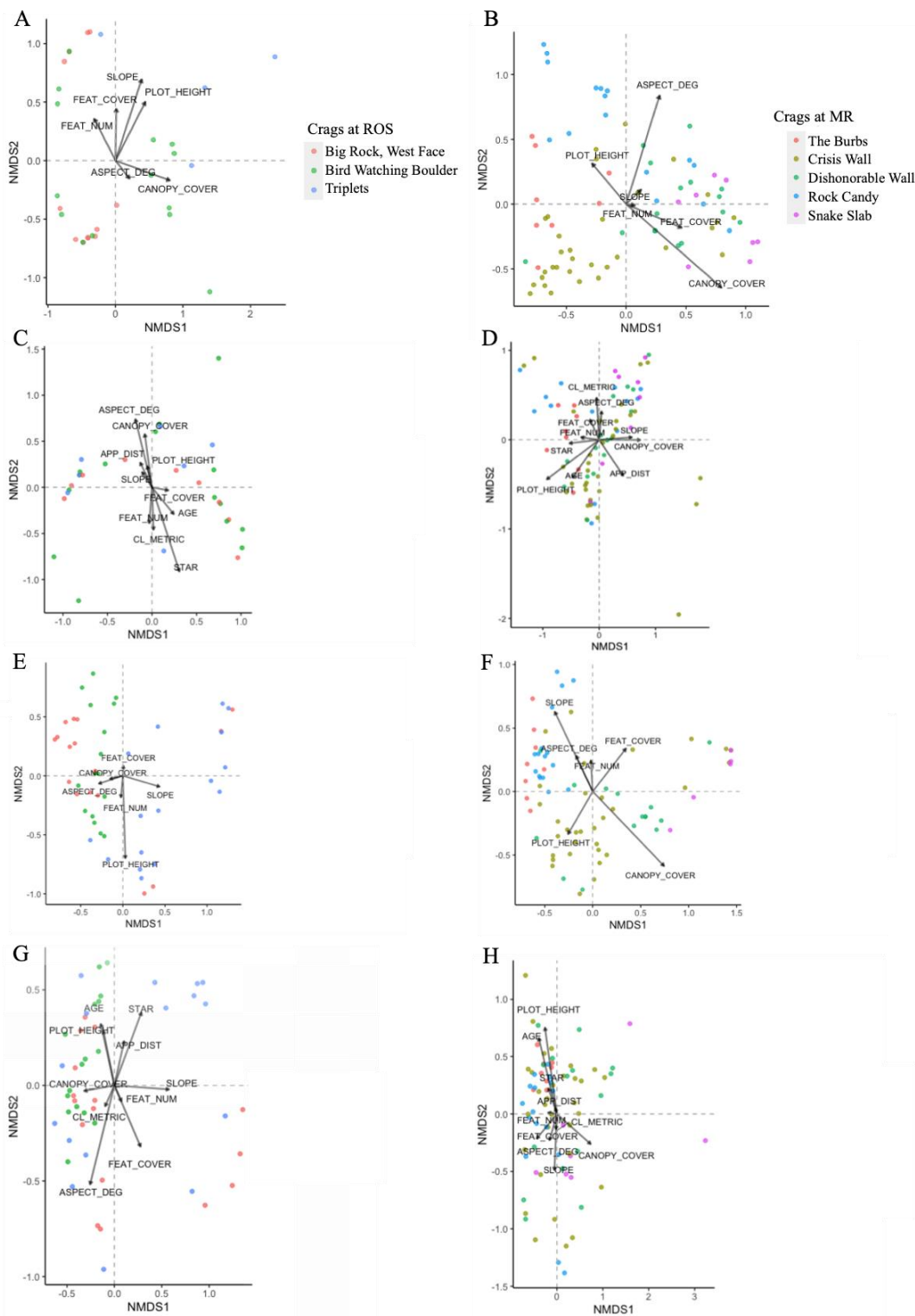
**Figure 3.** Examples of Bryophyte growth forms. Both photos were taken in unclimbed areas. A) Dark cushions illustrate the acrocarpus growth form of the moss *Grimmia alpestris/montana* growing together with crustose lichens at the Rocks of Sharon site; B) *Neckera menziesii* and *Homalothecium* sp. are examples of the pleurocarpus growth form of mosses at the McLellan Rocks site.



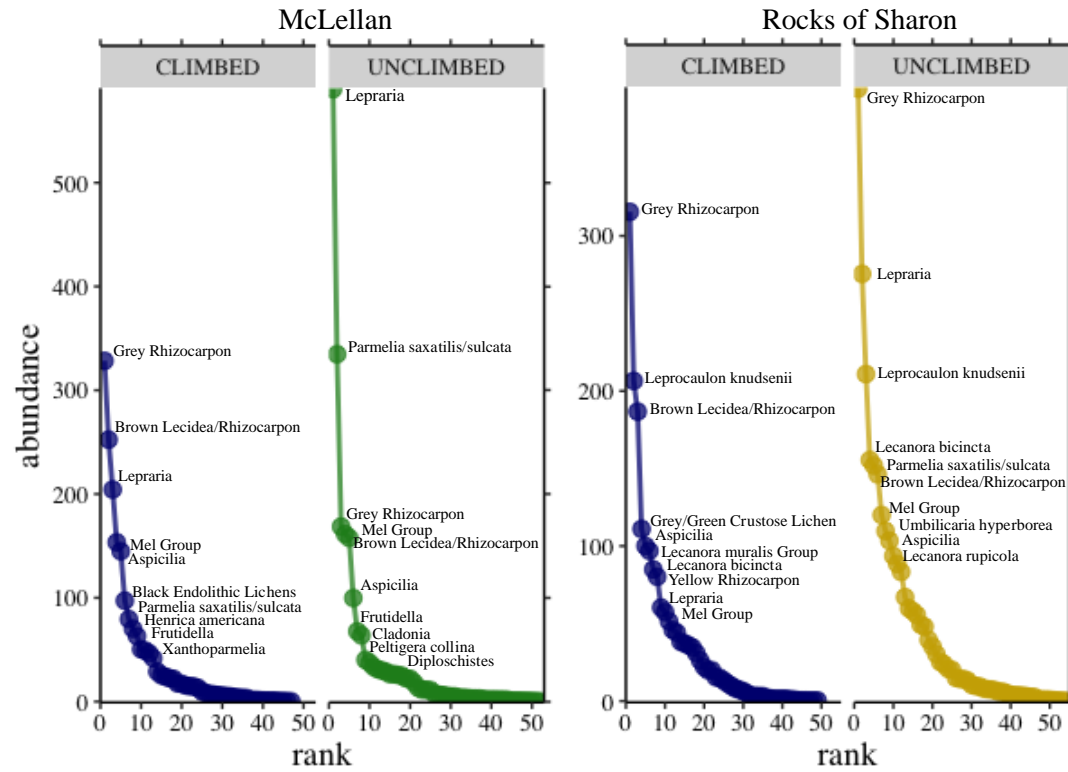
**Figure 4.** Climbed and unclimbed NMDS results for All Taxa between both sites combined. Unclimbed variables included plot height, slope, feature number, feature cover, canopy cover, and aspect degree, while unclimbed included all of the abiotic variables mentioned as well as the route variables route age, star value, CUI, and approach distance. A) Unclimbed plots, B) Climbed plots. Vectors were multiplied by 1.5 to better see variables effects on communities. Canopy cover can be seen dominating both NMDSs, as well as clear site differences between all taxa.



**Figure 5.** GLMM Climbing effect plots for All Taxa, Lichens and Plants. Climbed and unclimbed means are based upon values in Table 5. Graphs here show how climbing effected total taxa cover as well as one response variable for the taxa most dominant at each site, lichens at ROS and plants at MR. A) ROS All Taxa Cover; B) ROS Lichen Cover; C) MR All Taxa Cover; D) MR Plant Richness.

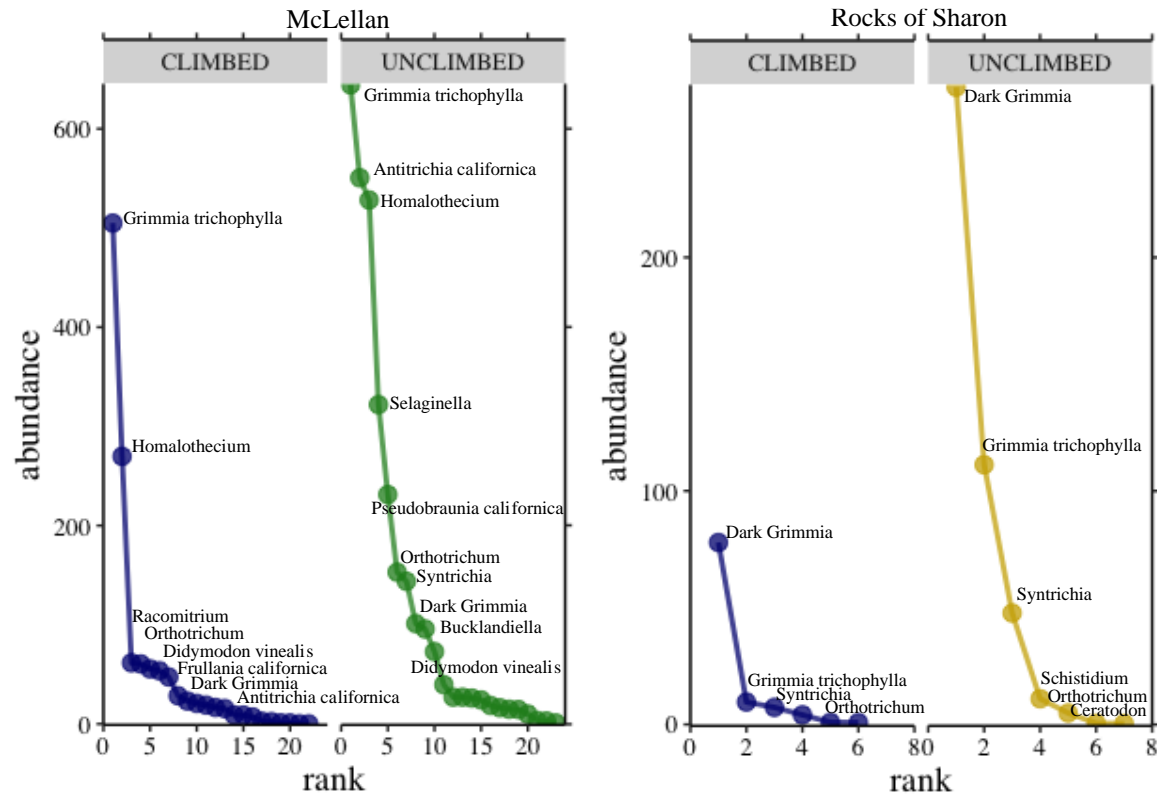


**Figure 6.** Climbed and unclimbed NMDS results for lichens and plants at each site. A) ROS Unclimbed Plants, B) MR Unclimbed Plants, C) ROS Climbed Plants, D) MR Climbed Plants, E) ROS Unclimbed Lichens, F) MCL Unclimbed Lichens, G) ROS Climbed Lichens, H) MR Climbed Lichens. Each vector was multiplied by 1.5 to better see variable effects on communities. Refer to Tables 9 and 11 for  $r^2$  and p-values for each variable.



**Figure 7.** Rank abundance plots for lichens climbed and unclimbed for McLellan Rocks (Left) and Rocks of Sharon (Right). Note abundance scales are different for each site.





**Figure 8.** Rank abundance plots for bryophytes and vascular plants climbed and unclimbed for McLellan Rocks (Left) and Rocks of Sharon (Right). Note abundance scales are different for each site.



*Ruderal* - high disturbance and low stress:

No groups fit here as cliffs are high stress environments and most lichens and bryophytes do not respond well to disturbance.

*Between Ruderal and Stress Tolerant* - high disturbance and high stress:

Crustose and endolithic lichens can persist in the most stressful cliff-face conditions, and continue growing despite disturbances, likely due to all or part of their tissues growing embedded within the rock.

*Stress Tolerant* - low disturbance and high stress:

Dessication tolerant mosses (e.g., Dark *Grimmia* group and *Syntrichia ruralis/norvegica*), withstand the most stressful cliff conditions, but cannot persist through disturbance. Umbilicate and foliose-green algal lichens, which are not able to withstand the disturbance of climbing or reside on high sloped cliffs due to their relatively loose attachment to rocks compared to crustose species.

*Competitive* - low disturbance and low stress:

Most bryophytes and vascular plants, cyanobacterial-associated foliose lichens, leprose, squamulose, fruticose, and other bryophilous lichens. None of these groups can withstand climbing disturbance and were most successful in fully unclimbed areas. Scaling the degree of stress for the scope experienced on cliff faces, these groups of species are less stress tolerant than other cliff-dwelling groups.

**Figure 9:** Grime Life History Strategy placements for cliff-dwelling bryophytes, vascular plants, and lichen morphogroups. Groups were placed within *Ruderal*, *Stress Tolerant*, *Competitive*, and between *Ruderal* and *Stress Tolerant*.