Rhizoplaca chrysoleuca as an Alternative Lichenometric Species: a Preliminary Investigation at the Lawn Lake Alluvial Fan, Rocky Mountain National Park, CO USA

Jennifer Shanteau[1]
Casey D. Allen[2]*, corresponding author*

[1] *GEI Consultants, Inc.*
4601 DTC Boulevard, Suite 900
Denver, CO 80237 USA
gentlepher@gmail.com

[2] *Western Governors University*
Salt Lake City, UT 84107
caseallen@gmail.com

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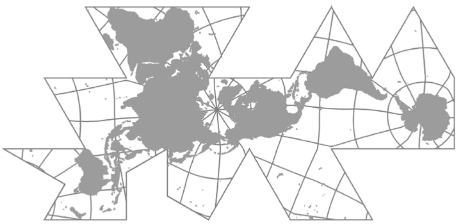
ABSTRACT

Lichenometry can be a useful tool to date past events when surface ages are unknown. As a method, lichenometry needs to overcome uncertainties in the understanding of lichen biology. Being fairly ubiquitous, Rhizocarpon geographicum is generally used for dating purposes. Other lichens can and have been used for studies, but are often used in conjunction with R. geographicum. This case study suggests that for areas lacking R. geographicum, Rhizoplaca chrysoleuca may be used as an alternate species if the substrate in question does not have substantial R. geographicum growth. While R. geographicum is well-studied, R. chrysoleuca is not, and growth curves have not been established to any extent close to those for R. geographicum. This study uses an alluvial fan in Rocky Mountain National Park created by a dam breach in 1982 as a preliminary baseline to establish a basic R. chrysoleuca growth curve. Age of the substrate is known and was previously unexposed inside a glacial moraine. Assuming lichen growth began soon after the exposure, and as R. chrysoleuca represents the majority species at the site, a basic growth curve can be established, at least in alpine environments. This initial assessment can potentially aid researchers using lichenometry in alpine environments and, more specifically, where sufficient R. geographicum is not present.

Keywords: lichenometry, alpine environments, fieldwork, Rocky Mountain National Park, Rhizoplaca chrysoleuca

INTRODUCTION

Lichens can be useful in environmental monitoring as they reflect changes in the environment (Seaward 2008), especially when that change is due to anthropogenic factors. Loss of specific species sensitive to particular environmental changes can help



identify those changes and aid in mitigating them. Some argue that to aid in assessments of glacial retreat rates, snowmelt rates, flooding, mass wasting event occurrence, and other factors, that lichenometry may be an appropriate assessment method (Noller and Locke 2000, Winchester and Harrison 2000, McCarroll 1993, Innes 1985, Gellally 1982, Innes 1981, Mottershead 1980, Lock, Andrews and Webber 1979). Along with mapping and remote-sensing, lichenometry can also aid in monitoring such changes in conjunction with other known environmental changes, allowing researchers to model future changes and recommend steps to mitigate further issues (Benedict 2009, Dabski 2007, Armstrong 2004, Goehring 2003, Refsnider 2003, Winchester and Harrison 2000, McCarthy 1999, McCarthy 1997).

While not all researchers agree on lichenometry as a valid dating tool (see Osborn et al. 2015 for a full review), it has been used to measure climate change via lichen responses. Lichenometric dating has shown that during periods of warming, glaciers recede rapidly, exposing new surfaces that are subsequently colonized by lichens, aiding in a better understanding climatic responses of surrounding biota. For example, Armstrong (2004) discusses lichenometry as a method for studying glacial fluctuations caused by rapid warming periods, and Trenbirth and Mathews (2010) speculated that lichen growth or survival was influenced by unspecified climatic changes during the Little Ice Age after monitoring a site for 25 years. Lichens are also useful for climate change studies in colder climates with harsh environmental conditions. As the first colonizers after glacial retreat (Sancho, Green and Pintado 2007), lichens tend to be the most abundant plant life in these areas, with their growth rates correlating favorably to environmental factors, including temperature and moisture. The studies Armstrong (2004) discusses (cf., McCarroll 1993, Harrison and Winchester 2000, Oerlemans 1994) contribute valuable data to further validate climate change impacts on glacial retreats over the last century by comparing growth rates of lichens with increasing temperatures associated with global climate change (see also Sancho et al. 2007).

Under-studied areas of lichen biology (Büdel and Scheidegger, 2008) hinder accurate growth curve production for lichen species (Armstrong 2011). Reproduction, transportation of propagules, morphogenesis, lag time of establishment on a substrate, and even understanding of lichen taxonomy are all areas that need further study. These uncertainties should not invalidate lichenometry, since some assumptions can be made using current knowledge to make a case for legitimacy. Lichenometry as a dating technique may not yet be an exact science, but the field is continuing to grow. With more research in these areas, the use of lichens can become a legitimate dating tool, useful in situations where other dating techniques will not yield results.

Lichen growth rates applied to surface dating characterizes the basis for lichenometry and typically uses crustose lichens (Palmqvist et al. 2008), although foliose lichens have also been used (Noller and Locke 2000). Other dating techniques, such as radiocarbon or other elemental dating techniques, are less accurate at dating recent (<500 years) events (Armstrong 2004), and even less useful when rocks are the medium. While Palmqvist et al. (2008) suggest that lichens can grow on surfaces for up to 1000 years, this claim may be undermined by Osborn et al. (2015) who estimated annual lichen mortality rates at 0.38 to 5.09% based on a sample of 2774 marked *R. geographicum* thalli that were tracked over 19 yrs, concluding that *R. geographicum* seldom live for more than 160 years. Still, calibration with known dated surfaces remains key to growth curve formation, even if the odds of a lichen thallus living for 1000 years means a 2-3% die-off in all thallus size classes, as noted by Loso & Doak (2006). Since lichens usually grow in a circular formation, the diameter of the lichen can be used to determine the growth rate when the age of the substrate is known (Noller and Locke 2000), though there are many examples of asymmetric thallus growth reported in the field (cf., Benedict 2009, Loso and Doak 2006, Noller and Locke 2000, Winchester and Harrison 2000, Matthews 1994, Innes 1985, Mottershead 1980, Lock et al. 1979).

Many aspects of lichen biology remain poorly understood, and when it comes to using lichens as a dating mechanism, controversies are not rare (Osborn et al. 2015 give the most comprehensive account of this ongoing debate). In many instances, however, such as dating late-Holocene glacier fluctuations (Loso and Doak 2006), lichenometry represents the only appropriate method, and this case study, fledgling as it is, speculates that, given new species to work with, perhaps lichenometry as a dating technique still has some merit. Another related issue revolves around the accuracy of statistical analyses concerning lichen size and their growth rate determinations. However, if exact debris deposition times were known, establishing growth rates could be more feasible and reliable. Such an event occurred in Rocky Mountain National Park (RMNP) with the Lawn Lake flood in 1982. This flood washed-out a glacial moraine and deposited previously unexposed debris as a small alluvial fan. Because the exact date and time this flood occurred in RMNP was recorded, a number of previously unstudied factors about lichen growth and distribution, lichenometry dating, and climate change might be determined. Further, using such a young site with a precise time of exposure can give helpful insight into current lichenometry dating controversies. Even if calibrations could be created for a mere 30-year time interval, it could help developers and site managers in instances when environmental and landscape change events (e.g., mass wasting events such as landslides, avalanches, etc.) occur in previously-unstudied locales such as new housing subdivisions or highly touristed areas.

Taking advantage of the 1982 Lawn Lake Flood disaster in RMNP, and gathering data from the site in August 2010, this paper seeks to establish a baseline for using *Rhizoplaca chrysoleuca* as a lichenometric dating technique. First, a comparison of *Rhizocarpon geographicum* and *R. chrysoleuca* is offered before outlining the methods used in this study, including site selection, sampling methods, and study assumptions. Then, findings are discussed, noting such characteristics as general thallus size, thallus size versus boulder size, and lichen relationship to rock face aspect. With repeated measurements, these findings could be used to establish a preliminary growth curve for *R. chrysoleuca* based on a precisely-known substrate exposure date. Finally, after discussing the findings' implications, succinct concluding remarks are offered.

COMPARISON OF TWO LICHEN SPECIES

Rhizocarpon geographicum

Also known as yellow map lichen, *R. geographicum* is a crustose lichen classified as a cosmopolitan taxa (Galloway 2008) and found on all continents and most islands, but is not ubiquitous. Completely attaching itself to the substrate, *R. geographicum* is easily distinguishable with a patterned, map-like yellow and black thallus typically found growing on siliceous rocks, and favoring alpine and arctic habitats (Brodo, Sharnoff and Sharnoff 2001). Owing to these characteristics, *R. geographicum* is currently the lichen of choice when performing lichenometric studies. Bradwell & Armstrong (2007) reviewed multiple studies, giving *R. geographicum* growth rates of 0.1 mm yr^{-1} to 0.5 mm yr^{-1} depending upon the habitat the lichens were found, with their own study revealing a higher average growth rate (0.65 mm yr^{-1}). Their study also included differences between thallus size and growth rate, resulting in a parabolic growth rate as opposed to a linear growth rate assumed in many studies. Owing to this discrepancy, more studies into the relationship between thallus size and yearly growth are needed for *R. geographicum* (Fig. 1). Additionally, taxonomic complexities within this group can add to the problems of using this species and supports the use of alternatives (cf., Armstrong 2011, Bradwell and Armstrong 2007, Benedict 2009, Dabski 2007, Refsnider 2003)

Rhizoplaca chrysoleuca

Commonly called orange rock-posy, *Rhizoplaca chrysoleuca* is typically found on granitic rock and fairly ubiquitous across western North America (Brodo et al. 2001). A foliose lichen, the thallus can be pale yellow-green to yellow-grey in color, with apothecia disks of pale to dark orange. *R. chrysoleuca* attaches to the substrate by a central holdfast rather than completely attaching itself like *R. geographicum*, but can sometimes appear similar to a crustose lichen (Armstrong 2011, Weber 1962). Very few studies have been conducted with *R. chrysoleuca*, as it is not as cosmopolitan as *R. geographicum*. Timoney and Marsh (2004), however, use multiple species to establish growth curves to determine water level changes, and report growth rates for *R. chrysoleuca* between 0.32 – 0.89 mm yr^{-1} when a lag time of 5.9 years is used. Their study also references three unpublished studies for these growth rates. Given this lack of data regarding the use of *R. chrysoleuca*, especially where *R. geographicum* is not found, it becomes apparent that more study is needed for *R. chrysoleuca*, and can be useful in lichenometric studies if other lichens are not present in abundance (Fig. 2).

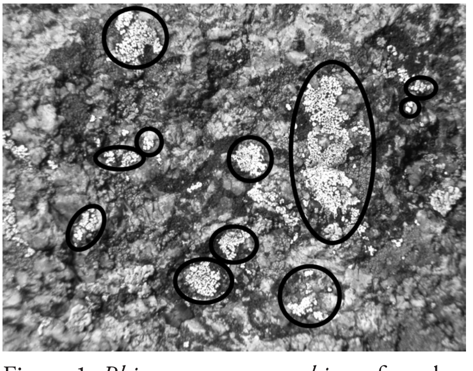


Figure 1. *Rhizocarpon geographicum* found at site. Note the patchy, map-like appearance in the circled areas that gives this species its name. Usually a greenish-yellow color, it can vary from vibrant yellow to bright or dull green. Photo by J. Shanteau.

METHODS

Study Site Location and Justification

On 15 July 1982 after years of disrepair, the Lawn Lake Dam in RMNP, an earthen dam constructed in 1903, failed. The resultant breach sent 219 million gallons of water into the Roaring River (Estes 2010). This torrent of water broke through a glacial moraine, intact from the last ice age, sending tons of debris – including large granite boulders from the glacial till – down to what is now called Horseshoe Park (elevation ~2600 m, Fig. 3). Though water continued to wash down through the Cascade Lake Dam, flooding the town of Estes Park and finally stopping in Estes Lake, most debris was deposited at Horseshoe Park (Estes 2010). Many washed-down boulders were part of a glacial moraine that the flood destroyed and, as such, were previously unexposed to lichens,

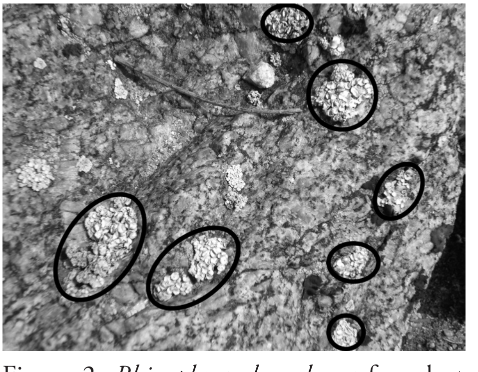


Figure 2. *Rhizoplaca chrysoleuca* found at site and used for this study in the circles. Though sometimes a dusty green in color, R. chrycoleuca can also be a soft yellow to vibrant orange, and even a yellowish orange, but most often denoted by its defined and raised ledges, typical of a foliose lichen. Photo by J. Shanteau.

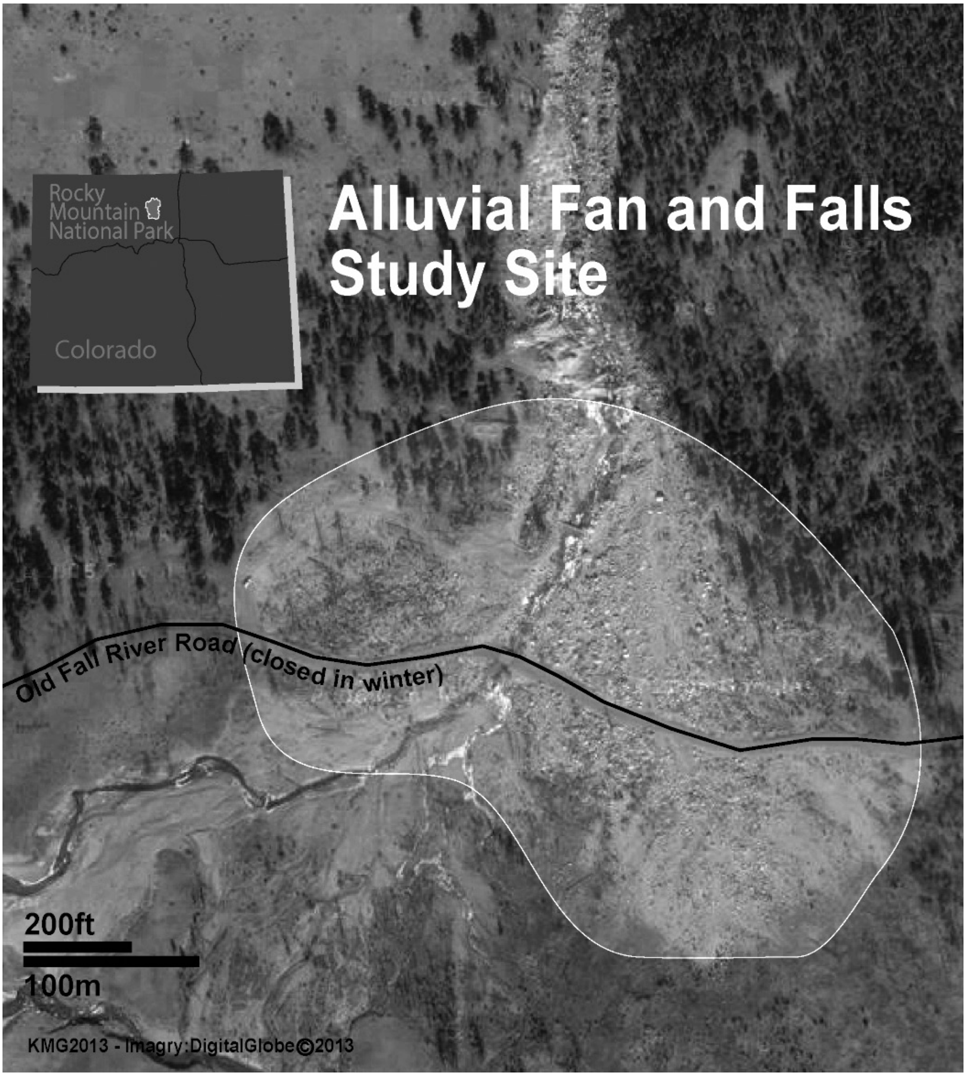


Figure 3. Approximate site location (shaded) in Rocky Mountain National Park, Colorado USA. Map by Kaelin M. Groom.

allowing for a well-defined, time-established study of lichen colonization (Fig. 4).

Although *R. geographicum* is the better-established species for conducting lichenometric studies, almost none were found within the study's boundaries. While Timoney & Marsh's (2004) multiple species technique was considered because of *Xanthoparmelia* and *Umbilicaria* (as well as unidentified brown, grey/black, and orange crustose lichens) being present at the study site (Fig. 5), the most abundant lichen that could be identified definitively to the species level was *Rhizoplaca chrysoleuca*. Because *R. chrysoleuca*

Figure 4. On-the-ground view of the debris field just above the sampling area, showing the deposition of boulders after the 1982 flood event. Photo by J. Shanteau.

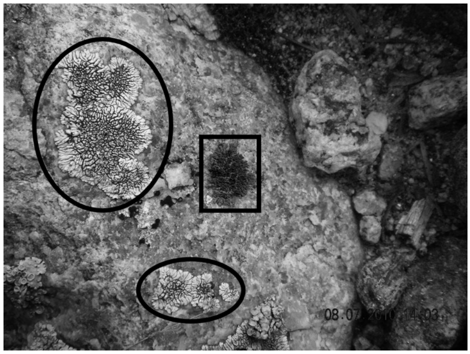


Figure 5. Other species were considered for the study, such as *Xanthoparmelia* (a usually bright-orange/rust-colored foliose species – rectangle outline, center) and *Umbilicaria* (most often light-green, though sometimes brown-to-gray-colored species, sometimes referred to as "rock tripe" because of its fluid-looking, foliose structure – round outlines, left and bottom center-left), but *Rhizoplaca* was more abundant.

is easily identified and was found in all areas sampled, the decision was made to lay the groundwork for establishing its growth curve as an alternative to *R. geographicum*, especially for sites lacking *R. geographicum*.

Sampling

Given that all the granitic boulders in Horseshoe Park came from *inside* a glacial moraine, it is safe to say that the substrate had not been colonized by lichens before final deposition on the alluvial fan. Further, since no majors floods have been recorded in Horseshoe Park since, it also stands to reason that the boulders on which the lichens are located have not been significantly moved. With those assumptions in mind, thirteen 8m x 8m plots were randomly selected within the boundaries of the alluvial fan at Horseshoe Park, based on boulder cover. The entire site was segmented into four main quadrants (i.e., northeast, southeast, northwest, southwest) using the mainly north-to-south flowing Roaring River and the generally east-and-west Old Fall River Road as the vertical and horizontal Cartesian axes, respectively (Fig. 3). A 4 m buffer between the sampling sites and any hiking paths or roads was used to minimize potential anthropogenic influence on lichen growth, since this site is a popular hiking area and easily accessible for all levels of hikers, lichen colonization would likely be inhibited or influenced by people climbing on boulders – unlike *R. geographicum*, *R. chrysoleuca* is only held by a central holdfast, and even minor disturbances could presumably compromise its long-term survival on a rock surface. Boulder sizes less than 30 cm were not sampled, as they appeared to have little or no *R. chrysoleuca* present. Close to the Roaring River, no lichens were found, and it is suspected that this is either due to seasonal flooding and/or the small debris size. Any *R. chrysoleuca* that was growing closely with another *R. chrysoleuca* was not measured unless there was a clear delineation between the two stands. Since *R. chrysoleuca* does not completely attach to the substrate, it was usually possible to distinguish a separation between two lichens. In the cases where it seemed they were growing together, they were excluded from sampling, as per previous studies (cf., Refsnider and Brugger 2007).

For each sampling site, GPS coordinates were taken at the four corners of the plot, the thallus measured from end-to-end along the longest axis using digital calipers, the approximate size of each boulder's "face" diameter along the longest axis (e.g., north-facing, south-facing, west-facing, etc.) was recorded, as well as the lichen's aspect (north, south, east, west, top of boulder). Further, the location of each boulder, and each thalli measured on each boulder, were recorded using a Trimble Juno GPS unit, as well as a corresponding photograph of each thallus. (Note: these data are contained in a large Excel spreadsheet and a large file folder – for each image – and will be made freely available to any researcher who requests it). Although there is no acceptable strategy to measure lichen, this study followed Refsnider and Brugger (2007) – who followed Innes' (1984) model – where the largest lichens were measured within each plot, rather than utilizing the repeated weighing method outlined by Gauslaa et al. (2009), as the authors were not allowed to gather samples from RMNP. The majority of sampling sites had numerous lichens, and up to 14 thalli in each sampling site were recorded. In some sampling sites, few lichens were encountered, and in these cases, only the largest five were recorded and subsequently averaged.

FINDINGS

Lichen Size

The average size *of R. chrysoleuca* from all 13 sites, with 65 total lichens measured, is 32.35 mm ± 3.22 mm (Fig. 6, last point). The averages of lichen diameter per site have a median of 31.92 ± 3.22 mm (Fig. 6, second to last point). Thus, using the averages of all samples is not significantly different than using the average of the means of each site, and following the recommendation of Innes

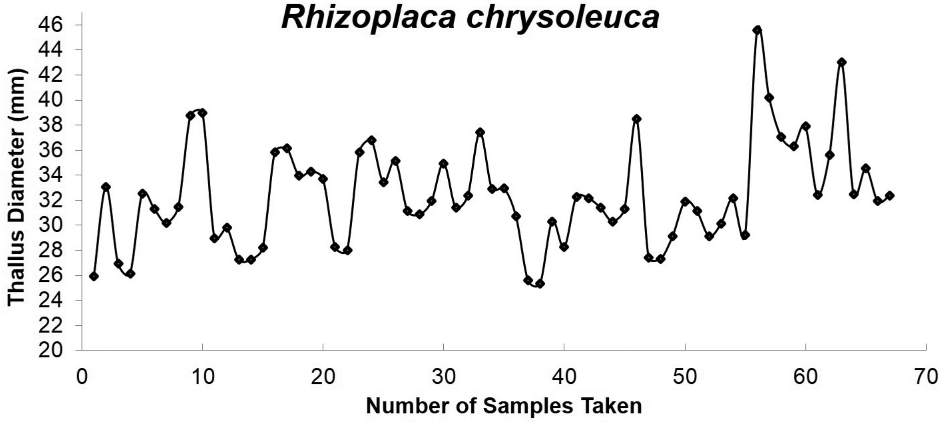


Figure 6. Thallus sizes of all *R. chrysoleuca* samples taken. A total of 65 samples were taken, though this image shows 67. The final two measurements (numbers 66 and 67) represent thallus median and mean across all samples, respectively. Connecting line does *not* represent continuous data, but is used instead for ease of reference between individual thalli measurements.

(1984), the mean of the five largest thalli of each sample site was used for final analyses (Fig. 7). Across quadrants, thalli sizes varied only a few mm: 30.12 mm for the northeast, 33.35 for the southeast, 34.69 for the northwest, and 30.45 for the southwest.

Thallus Diameter and Boulder Size

There was a varying degree of boulder size among the sampling sites, and all thallus measurements were compared against the size of boulder on which it was found. While McCarroll (1994) did find a slight correlation between thallus size and boulder size (using *R. geographicum*) he also notes that sampling a variety of boulder sizes has no significant effect on mean thallus size. Though admittedly the Horseshoe Canyon site has different lithologies (chiefly granitic in RMNP) than McCarroll's study, comparison of thallus size to boulder size revealed similar findings, as no significant correlation was found between thallus diameter and boulder size in this case study (Fig. 8).

Boulder Aspect

Rock facet aspect is known to affect lichen growth (Hall et al. 2005, Dabski 2007, Bailey 1976, Gellally 1982, McCarroll 1993, McCarthy 1997), and reviewing *R. chrysoleuca* growth at the Horseshoe Canyon site, this fact remains true. For the Horseshoe Canyon site, thallus size was correlated with the eight cardinal directions, as well as a "top" aspect for those boulders with flat tops and thus no direct aspect or orientation, since lichens may colonize a surface at the top, perhaps by propagules carried by birds, and then spreads down the face over time (Armstrong 1978). Results show that thalli located on the north, east, south, northeast, or top of the boulder, were substantially larger than those located on the southwest, southeast, northwest, or west facing lichen (Fig. 9). This is similar to Armstrong's (2005) findings in the Cascades (Washington state, USA), where the smallest growth was found on north-northwest aspects. At the Horseshoe Canyon site, the most abundant growth is found with lichens growing on the top of the boulders with an average growth of 33.41 mm, and the southwest aspect had the least growth with an average of 30.11 mm.

Quadrants

Though many lichenometric studies state that the largest lichens represent the idealized specimens for a particular habitat because they demonstrate fast growth rates and are the therefore the quickest to establish themselves on the substrate (cf., Noller and Locke 2000, Innes 1984, McCarroll 1994, Dabski 2007), Osborn et al.'s (2015: 4) review counter these studies' findings, noting specifically that, "These observations do not well support three of the most important lichenometric assumptions: i) the largest thalli began growth soon after the surface became stable and exposed, ii) the original colonists are long lived, and iii) the original colonists are the largest in the population." Still, for those who desire to continue and strive for including lichenometric techniques in their dating applications, fast growth rates and quick establishment times would tend to give the best possible growth curve to estimate substrate age, as previous researchers have noted (cf., Noller and Locke 2000, Innes 1984, McCarroll 1994, Dabski 2007). Differences seen in the growth of different quadrants at the Horseshoe Canyon site may be an indication of earlier colonization, but for purposes of growth curve construction, it is assumed that colonization takes place shortly after the substrates initial exposure. This is not necessarily what happens, as Timoney and Marsh (2004) note, but even their review of other studies show that lag time is inconsistent.

Another possible reason for dichotomy between sites may be that climactic conditions in those areas differ enough to affect growth. At Horseshoe Canyon, vegetation was similar across the site; it is suspected that this was not a factor affecting the lichen growth-aspect

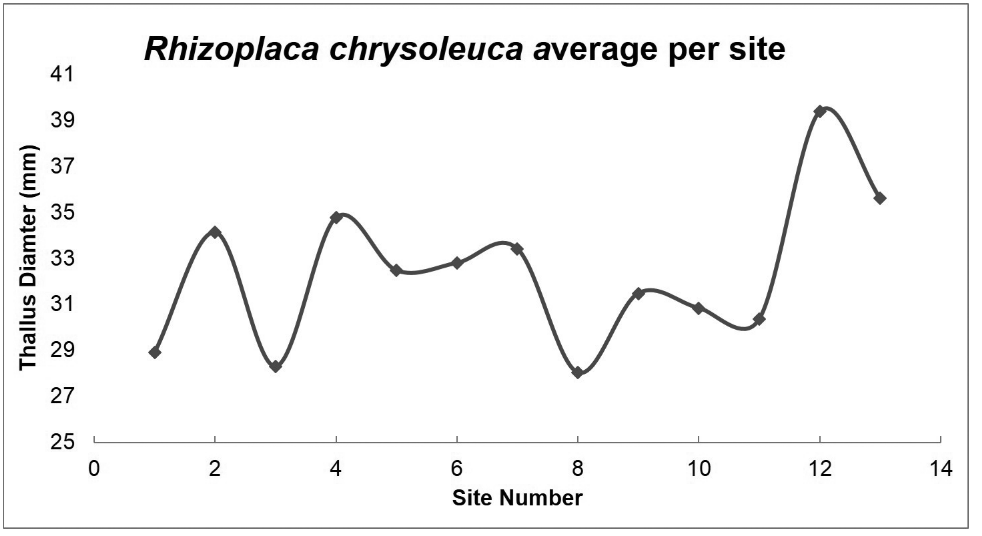


Figure 7. Averages of *R. chrysoleuca* thallus diameter by site (5 samples per site, after Innes 1984). Connecting line does *not* represent continuous data, but is used instead for each of reference between thalli averages and site numbers.

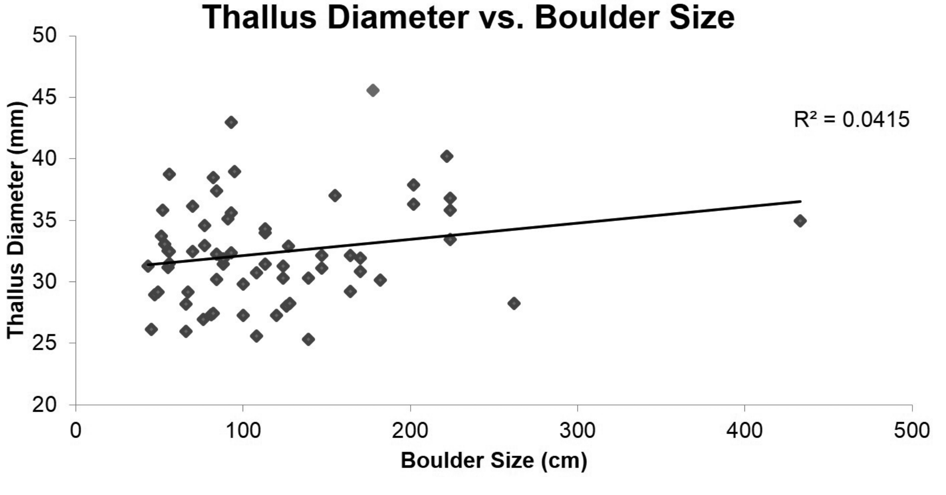


Figure 8. Spatial relationship between lichen thallus diameter and size of each boulder sampled. Boulder size in this instance is the length of its long axis.

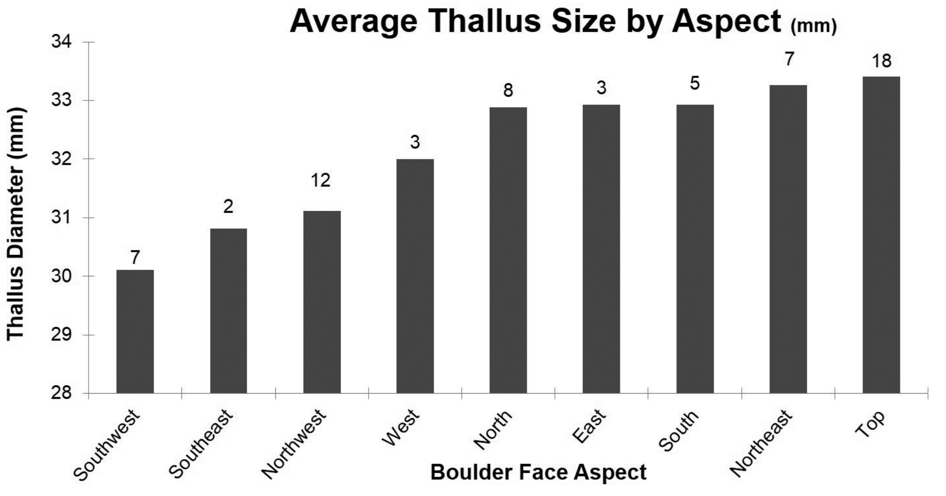


Figure 9. A comparison of sample aspect (as exposed on host-rock facies – directionally, as north, south, southwest, etc., as well as the "top"-facing side of the bulder) to sample size. Numbers above bars represent the number of samples measured and used for calculating average thallus size.

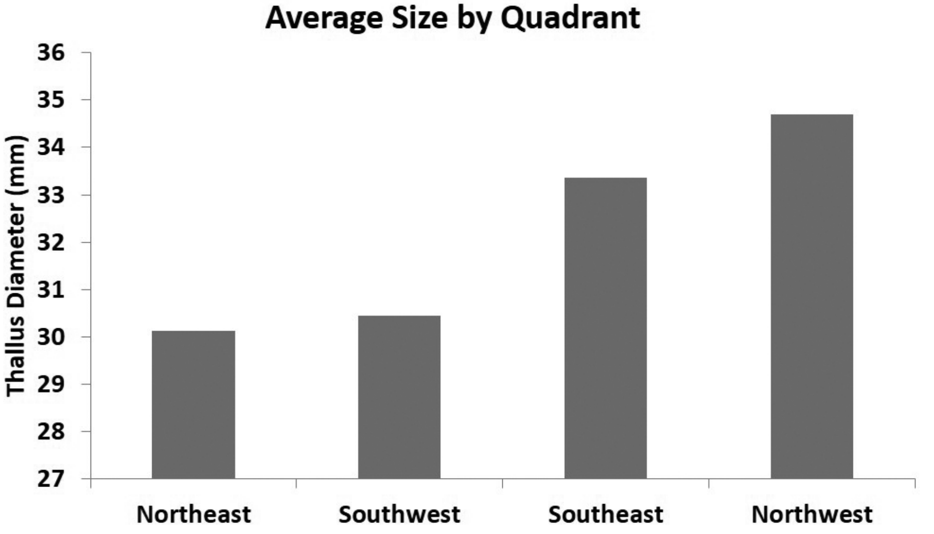


Figure 10. Thallus diameter by quadrant sampled.

connection. However, the two quadrants with lower growth may not receive the same amount of sunlight, precipitation, or the substrate may have different composition than the two quadrants with higher growth. The fact that neither the lower or higher growth quadrants are adjacent to each other makes it difficult to infer the cause for the significant difference seen in growth, unless microclimatic factors are vastly different in each area. Yet at the Horseshoe Canyon site, the largest growth quadrant (northwest) has an average of 34.69 mm, while the smallest growth quadrant (northeast) has an average of 30.12 mm (Fig. 10).

Discussion and Conclusion

In order to understand lichenometry better and validate its usefulness as a dating method when other methods cannot be used, generating lichen growth data beginning with a known substrate exposure date seems like a reasonable method. While this study is by no means complete, it represents a starting place to finding alternative lichens for sites that do not have established *Rhizocarpon geographicum*. There is no documentation of the growth limit or average lifespan for *R. chrysoleuca*, and only one reference to annual growth is mentioned by Timoney and Marsh (2004). The ability to use multiple species for a location would aid in establishing a more concrete time of exposure for deposition or substrate.

Since both aspect and quadrant can be ruled out as having an effect on the growth of *R. chrysoleuca* at the Horseshoe Canyon site, other locations with similar habitat and climate should be able to use this preliminary data to help construct a more robust growth curve for *R. chrysoleuca.* Since less is known of *R. chrysoleuca's* growth rate than *R. geographicum*, it is difficult to draw precise conclusions. Still, based on this preliminary study, using *R. chrysoleuca* may be a good alternative where *R. geographicum* is not found.

Since this study only has data from one point in time, it is not reasonable to expect construction of an overly-reliable growth curve. Still, many questions can be answered about *R. chrysoleuca's* growth by re-visiting the site and repeating measurements in the same areas. With repeated sampling, a more accurate and reliable growth curve could be constructed, allowing accurate dating to take place at other alpine sites with unknown ages where *R. geographicum* is not present. Further studies may also help answer the question of whether *R. chrysoleuca* experiences linear or parabolic growth. Continued monitoring may also produce more observations of other species, resulting in better understanding of lag times (if any exist for *R. chrysoleuca*) and also addressing questions about climate change impacts on both lichen growth and the surrounding environment. With ongoing studies of lichen biology, such as morphogenesis, reproduction, and taxonomy, growth studies such as this case study serve to enhance the potential applicability of lichenometry. Establishing more consistent methodologies of research for those that conduct these studies will invariably bring more validity to the field and streamline the process of gathering data so future lichenometric studies are more widely accepted as a useful and accurate dating technique.

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