IMPACT OF RECREATIONAL ROCK CLIMBING ON LICHEN DEVELOPMENT AT ENCHANTED ROCK STATE NATURAL AREA

BY HANK LEGAN, ALEXANDRA SMITH, AND CARLOS SANCHEZ

REVIEWED BY DR. CHRISTI TOWNSEND
EDITED BY TORIANN MOLIS

Lichen is a drought resistant, moss-like organism that plays an important foundational role in environmental systems. Lichen perpetuates chemical and physical weathering of rocky outcrops, initiating soil creation processes in arid environments such as Enchanted Rock State Natural Area (ERSNA), an exposed granite batholith in the Texas Hill Country between Fredericksburg and Llano. Recent increases in human outdoor recreation, such as rock climbing, increase the potential for human activity to negatively impact this environmentally significant organism. We sought to determine whether lichen development was being impacted by recreational rock climbing within ERSNA. Measurements of lichen colonies at popular climbing locations within the study area were compared to measurements of lichen colonies on non-climbing areas. No significant statistical difference was observed between these measurements, indicating that climbing is not having an adverse impact on park lichen colonies.

Background:

Farm to Market Road 965 north of Fredericksburg, Texas is not unlike any other road in the expansive region west of Austin and San Antonio known as the Texas Hill Country. The landscape is unmistakably Texan: stands of Ashe Juniper and Prickly Pear Cactus spread across a patchwork of ranches, vineyards, and the occasional residence. Eroded limestone bluffs cap the hills for which the region is named. It is scenic, to be sure, but not particularly noteworthy–until the road turns and drops downhill, and suddenly Enchanted Rock, a massive dome of pink granite standing 425 feet above the surrounding area comes into view (Reed 2011). The dome grows larger and larger in the windshield until one arrives at the entrance to Enchanted Rock State Natural Area (ERSNA), a 1,643-acre property that opened to the public in 1978 (Taylor & O'Kennon 2016). Its namesake dome is the "most prominent of several exfoliation domes and related granite features...in th[e] area" (Reed 2011, v). Administered as part of the state park system by Texas Parks and Wildlife Department (TPWD), the park hosts almost 300,000 visitors annually, making it one of the most popular parks within the Texas park system (Salinas 2016).

Enchanted Rock Park offers visitors a glimpse through the ages of geologic time to what geologists refer to as "some of the most important geological events in Earth's history" (Allred 2009, 68). The rock that would become the Enchanted Rock batholith began forming 1,255 million years ago during the Precambrian Mesoproterozoic Period – a long, long time ago, even in the context of geologic time scales. Since then, Texas has seen a mountain range of Himalayan proportions created and destroyed, and has been inundated several times by ocean waters – most recently during the Cretaceous Period (93-110 million years ago), when a sea stretched from today's Gulf of Mexico to the Arctic Ocean. These inundations laid the foundation of the region's limestone and sandstone deposits, covering Enchanted Rock with at least 2,500 feet of younger, softer rock. This softer rock is more susceptible to erosion than the hard granite and eventually revealed the granite underneath. Once revealed, chemical and physical weathering shaped the dome into its current state (Reed 2011).

The unique geological formations of the area attract two very different organisms: rock climbers and lichen. According to TPWD, "the granite domes and boulders at Enchanted Rock have enjoyed a long and ongoing history of traditional-style ascents" (para. 3).

MountainProject.com, a user-curated online rock climbing guidebook, lists 367 different climbing routes within the park. Routes range from short scrambles on scattered boulders to long, technical routes up the steep backside of the main dome itself. Rock climbers share these sheer faces of rock with colonies of lichen, fungi-like photosynthesizing growths, which cling to the bare granite cliffs. The lichen can be identified as the bright streaks of orange, yellow, and green along the cliffs that starkly contrast the dark granite.

Lichen and other plant species within the park are constantly adapting to the highly variable climate of Central Texas. The region experiences a humid sub-tropical climate, exhibiting seasonal variations in temperature from "January lows averaging 0.1 degrees Celsius (32.2 Fahrenheit) and August highs averaging 37 degrees Celsius (98.6 Fahrenheit)" and average annual rainfall of 31.2 inches (Taylor & O'Kennon 2016, 268). In these ever-changing conditions, the vegetation present is more susceptible to be damaged by human activity. For instance, in their 2016 survey, researchers Kimberly Taylor and Robert O'Kennon attributed the human introduction of goats to the property to be the main source of destruction of several rare plant species. They further note that "the abundance of human visitors to the park likely is the greatest threat to its vegetation" due to the constant trampling of feet everywhere (Taylor & O'Kennon 2016, 273). Recognizing the threat posed by ever-increasing visitation numbers, TPWD recently introduced new pet policies "to balance the need to better protect sensitive natural habitats atop the rock" (Salinas 2016, para. 1).

Any list of sensitive organisms to be protected must certainly include lichen. These primitive lifeforms are a combination of at least two different organisms: an alga (a member of the plant phyla) and a fungus (a member of the fungi phyla). They are among the hardiest and most resistant of all plant organisms, able to withstand extreme temperatures and droughts (Hiller 1983). Will-Wolf and Lueking describe the genus as "quintessential stress-tolerators for natural environmental factors: most species can tolerate wide temperature fluctuations and complete desiccation for prolonged times" (2016, para. 1). In other words, they are perfectly suited for the arid, rocky environment of Enchanted Rock State Natural Area (ERSNA). Unfortunately, this same stress-tolerating strategy "renders them especially vulnerable to…anthropogenic stressors" (Will-Wolf & Lueking 2016, para. 1). Since they are able to survive in locations inhospitable to vascular plants, which have internal tissues to distribute water and nutrients throughout the plant, lichen play an important geological role: converting rocks into soil. They produce a weak acid which slowly dissolves the rock's minerals, forming tiny cracks in the surface of the rock (Hiller 1983). Over time, ice, wind, and water attack these cracks, eventually transforming the rocks into soil. Thus, the presence of lichen marks the difference between a plain of unbroken, inhospitable bedrock and a field of fertile farmland. Additionally, lichen colonies may serve as carbon sinks; research "suggests that colonization by lichens increases carbon sequestration over bare rock surfaces" (Zambell, Adams, Gorring, Schwartzman 2011, 172).

As noted above, research into lichen and its interaction with the environment is available, as is research on both the geologic history of ERSNA and its native flora and fauna. However, little research exists on the proliferation of lichen colonization of the numerous granite boulders and outcroppings present within the park boundaries. According to Lance Allred's *Enchanted Rock: A Natural and Human History*, lichen is "often... particular about its host, preferring granite over limestone...and so on" (2009, 191). Though Allred notes multiple types of lichens present in the park, Taylor and O'Kennon's 2016 survey of plant life within ERSNA notes that lichens are "in need of future study" (275).

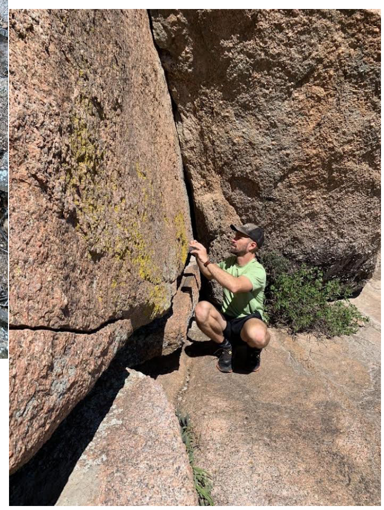
There is a lack of existing research on the extent of lichen development within ERSNA. As a result, little is known about the impact of recreational rock climbing on these lichen developments. If such an impact exists, it must be discovered now, as recreational rock climbing has exploded in recent years and projects to continue this growth pattern. A 2010 report from the United States Forest Service predicts that "challenge activities" such as rock climbing will see an eighteen percent increase in participation rate by 2060. The American Alpine Club's 2019 State of Climbing report supports this, stating that 7.7 million Americans participated in rock climbing activities in 2014, a staggering increase of almost 500,000 people from the year before. This increase in climbing activity can be expected to exacerbate any negative environmental impact that climbing has had on lichen colonies in the park. Therefore, we set out to determine the degree to which, if any, lichen is being impacted by climbing activities. This would provide data to help Texas Parks and Wildlife manage climbing activities in a manner which preserves the environmentally significant lichen colonies in the park.

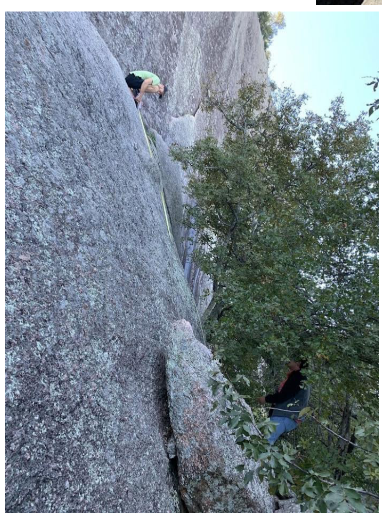
Research Methods:

We used MountainProject.com, a popular

user-maintained online listing of rock climbing routes and areas, to select climbing routes at various areas within ERSNA. In selecting sampling areas, we endeavored to select those used for each main climbing discipline (bouldering, sport, and traditional) at multiple locations across the park to ensure a representative sample. At each climbing area, we identified lichen colonies by sight and classified these colonies as either *on a route*, and therefore potentially impacted by climbing activity, or *off a route*, and therefore not likely to be impacted by climbing activity. To round out our sample, we also collected measurements from one area beside a main trail of the park to act as a control group completely unimpacted by any climbing activity. Measurements were obtained in inches via tape measure based on the following process: 1) we recorded the length and width of the largest continuous patch of lichen development on the rock face, 2) we recorded the overall length and width of the rock face, 3) we used the iPhone application "GPS & Maps: Location Tracker" to record the latitude and longitude of the sample location, and 4) we used the iPhone compass to identify the aspect of the rock face (to determine if sun exposure might play a confounding role in any significant variation among samples).

The measurements were used to establish a ratio of lichen colony size to rock face size. These ratios were then compared against each other using a T-test to determine the statistical significance of any among the samples. Since we recorded data for the aspect of each sample, we also categorized each sample by aspect into either northeast (0–89 degrees), southeast (90–179 degrees), southwest (180–269 degrees), or northwest (270–359 degrees) groups and ran an ANOVA test to determine whether aspect played a significant role in lichen development.





Figures 1–3,: measuring lichen colonies at Buzzard's Roost, Cheap Wine Wall, and Devil's Slide.

Study Areas:

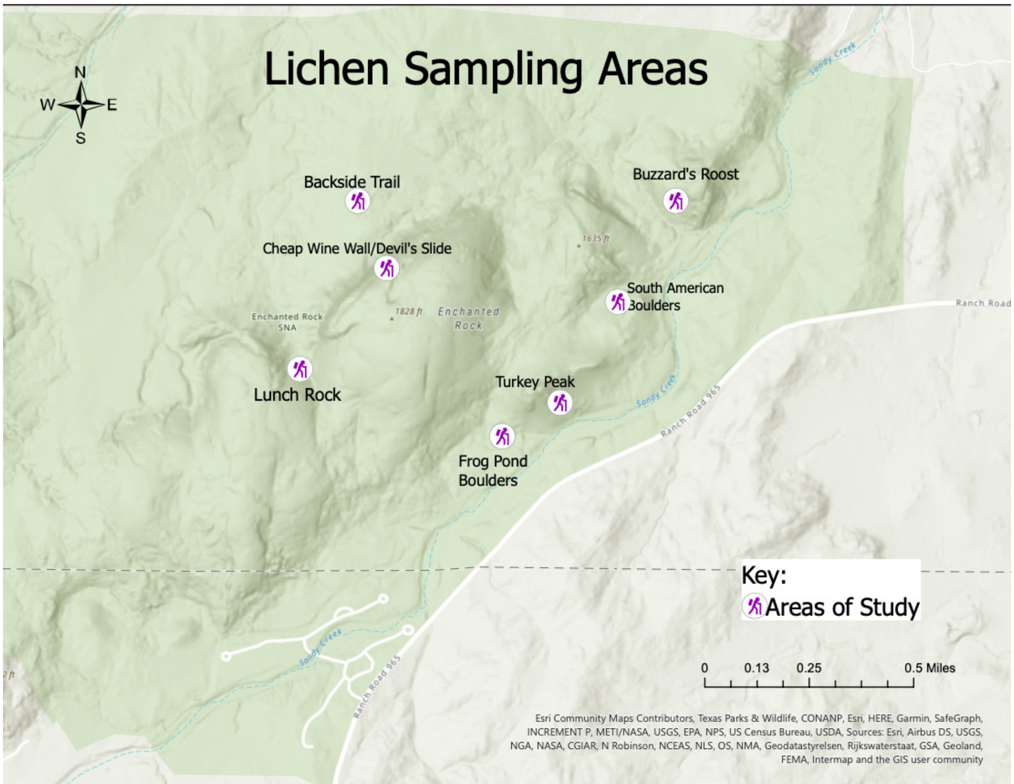


Figure 4: Locations of Sampling Areas within ERSNA

Data and Analysis:

We collected 41 measurements, 20 of which were from control (non-climbing/off-route) locations and 21 from areas potentially impacted by rock climbing activities. The total area of lichen colonies measured on non-climbing areas was 17,519.25 square inches and the total area of these faces was 133,688 square inches, for a colony:face ratio of non-climbing samples of 13.1%. The total area of lichen colonies measured on climbing areas was 23,117.5 square inches and the total area of climbing faces measured was 265,753 square inches, for a colony:face ratio of 8.7%. In other words, non-climbed faces exhibit 4.4% more lichen colonization. However, this contrasts with the average ratio of each group. Colonization ratios for non-climbed faces range from a minimum of 0.14% to a maximum of 72.69%; ratios for climbed faces range from 0.01% to 100%. The average colonization ratio of non-climbing samples was 20.79% (standard deviation of 17.87%) and 21.83% for climbing samples (standard deviation of 23.16%), indicating that on a sample-by-sample basis, climbed faces exhibit slightly higher lichen colonization. A t-test comparing the colonization ratios of each measured sample resulted in a p-value of 0.89, indicating no significant statistical difference in lichen colonization between climbing and non-climbing faces at a 95% confidence interval. Therefore, we were unable to reject the null hypothesis of our study, indicating there is no significant statistical difference between lichen colonization of climbing vs. non-climbing surfaces in ERSNA.

Table 1: Measurements and orientation data for collected samples.

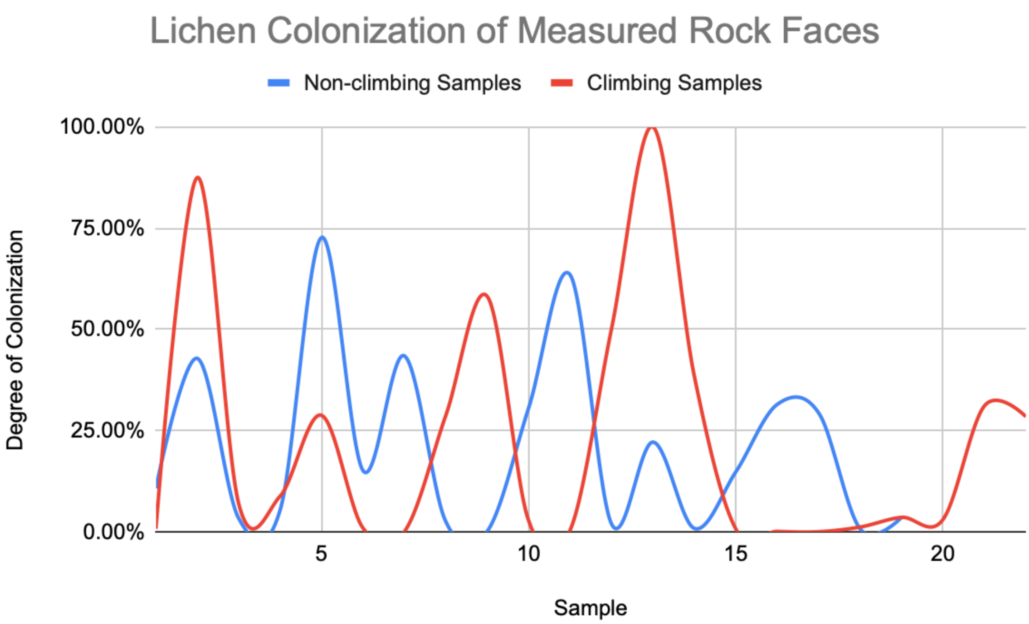
Location	X,Y	Type	Sample #	Aspect	Aspect	S Width	S Length	S Area	F Width	F Length	F Area	Area S:Area F
Lunch Rock	30.505, -98.822	Off-route	1	274	WNW	34	15	510	82	58	4756	10.72%
Lunch Rock	30.505, -98.822	Off-route	2	354	NNW	55	48	2640	92	67	6164	42.83%
Lunch Rock	30.505, -98.822	Off-route	4	135	SE	20	9	180	73	75	5475	3.29%
Lunch Rock	30.505, -98.822	Off-route	5	16	NNE	39	17	663	120	102	12240	5.42%
Cheap Wine Wall	30.508, -98.819	Off-route	10	322	NNW	21	22.5	472.5	26	25	650	72.69%
Devil's Slide	30.508, -98.819	Off-route	11	282	WNW	49	63	3087	143	143	20449	15.10%
Backside Trail	30.510, -98.820	Off-route	16	283	WNW	71.5	42.5	3038.75	53	132	6996	43.44%
Backside Trail	30.510, -98.820	Off-route	17	296	WNW	21	7	147	142	42	5964	2.46%
Backside Trail	30.510, -98.820	Off-route	18	178	SSE	2.5	1	2.5	19	91	1729	0.14%
Backside Trail	30.510, -98.820	Off-route	19	126	ESE	22	12	264	41	21	861	30.66%
Backside Trail	30.510, -98.820	Off-route	20	108	ESE	33	36	1188	36	52	1872	63.46%
Buzzard's Roost	30.501, -98,810	Off-route	21	67	ENE	17	19	323	130	130	16900	1.91%
Buzzard's Roost	30.501, -98,810	Off-route	23	173	SSE	40	15.5	620	40	70	2800	22.14%
South American Boulders	30.507, -98.811	Off-route	*30	232	WSW	9.5	25	237.5	120	240	28800	0.82%
Turkey Peak	30.504, -98.813	Off-route	31	2	NNE	14	40	560	60	63	3780	14.81%
Turkey Peak	30.504, -98.813	Off-route	32	199	SSW	39	43	1677	74	72	5328	31.48%
Frog Pond Boulders	30.503, -98.815	Off-route	36	0	N	36.5	51	1861.5	104	61	6344	29.34%
Frog Pond Boulders	30.503, -98.815	Off-route	38	9	NNE	4.5	2.5	11.25	29	54	1566	0.72%
Frog Pond Boulders	30.503, -98.815	Off-route	41	323	NNW	7.25	5	36.25	26	39	1014	3.57%
Lunch Rock	30.505, -98.822	On-route	3	105	ESE	28	5	140	137	137	18769	0.75%
Cheap Wine Wall	30.508, -98.819	On-route	6	7	NNE	37.5	28	1050	37.5	32	1200	87.50%
Cheap Wine Wall	30.508, -98.819	On-route	7	298	WNW	51	74	3774	265	207	54855	6.88%
Cheap Wine Wall	30.508, -98.819	On-route	8	318	NNW	19	13.75	261.25	52	57	2964	8.81%
Cheap Wine Wall	30.508, -98.819	On-route	9*	318	NNW	69	120	8280	120	240	28800	28.75%
Devil's Slide	30.508, -98.819	On-route	12	295	WNW	6.5	9	58.5	67	97	6499	0.90%
Devil's Slide	30.508, -98.819	On-route	13	306	WNW	3.25	2	6.5	103	104	10712	0.06%
Devil's Slide	30.508, -98.819	On-route	14	308	WNW	42	23	966	61	55	3355	28.79%
Devil's Slide	30.508, -98.819	On-route	15	142	SSE	31	13.5	418.5	45	16	720	58.13%
Buzzard's Roost	30.501, -98,810	On-route	22	67	ENE	32.5	14	455	130	130	16900	2.69%
Buzzard's Roost	30.501, -98,810	On-route	24	256	WSW	3	2.5	7.5	32	56	1792	0.42%
Buzzard's Roost	30.501, -98,810	On-route	25	155	SSE	71	64	4544	87	104	9048	50.22%
South American Boulders	30.507, -98.811	On-route	26	102	ESE	23	40	920	23	40	920	100.00%
South American Boulders	30.507, -98.811	On-route	27	116	ESE	13.5	47.5	641.25	31	54	1674	38.31%
South American Boulders	30.507, -98.811	On-route	*28	40	NNE	22.5	8.5	191.25	120	240	28800	0.66%
South American Boulders	30.507, -98.811	On-route	*29	30	NNE	6	4	24	120	240	28800	0.08%
Turkey Peak	30.504, -98.813	On-route	*33	226	WSW	2.5	1	2.5	120	240	28800	0.01%
Turkey Peak	30.504, -98.813	On-route	34	166	SSE	5	3.5	17.5	25	60	1500	1.17%
Turkey Peak	30.504, -98.813	On-route	35	180	S	5	17	85	52	46	2392	3.55%
Frog Pond Boulders	30.503, -98.815	On-route	37	53	ENE	46	9.5	437	94	153	14382	3.04%
Frog Pond Boulders	30.503, -98.815	On-route	39	196	SSW	27	9.25	249.75	11	73	803	31.10%
Frog Pond Boulders	30.503, -98.815	On-route	40	315	NW	28	21	588	44	47	2068	28.43%

Concerning the aspect of each lichen colony measured, there were 14 total observations in the northwest group, 10 in the northeast group, 11 in the southeast group, and 6 in the southwest group. The mean sample ratios in each group were 20.96% in northwest (21.13% standard deviation), 14.62% in northeast (27.18% standard deviation), 33.48% in southeast (32.42% standard deviation), and 21.39% in southwest (25.92% standard deviation). The ANOVA test returned an f-ratio value of 1.37109 and a p-value of .266701, a non-significant result at the 95% confidence interval. There appears to be no significant difference in lichen growth based on either the orientation of the face on which the lichen grows or whether or not that particular face is used as a rock climbing route.

Research Limitations:

During our field research, we encountered the following limitations to our designed research methodology:

- The seemingly random, shapeless manner in which the colonies spread across the rock face makes it difficult to identify with certainty where one colony ends and another begins. Therefore, it is possible there is a more accurate method for measuring the degree of colonization of a rock face by lichen. For example, more advanced electronic devices might be able to scan the entire surface of the rock face and compute a percentage of colonization.



- Some of the faces and colonies selected were extremely tall and impossible to measure safely without climbing equipment. These samples are noted by asterisks in the sample number column in the chart above. In these cases, we measured as best as could be reached from a position of safety. Both the lichen colony and the face equally exceeded the reach of our measurement abilities for these instances; therefore, we feel the ratio calculated from these measurements is not inaccurate. However, a full evaluation of lichen colonies would require climbing and rappelling equipment.
- There are two potential elements of bias in our research. First, one member of our team is a rock climber. Though he does not believe this influenced his data collection, it is possible that some subconscious bias exists out of a desire to protect climbing access. Second, when collecting samples, we looked for samples to measure, rather than looking for an absence of lichen to measure. This methodology could have led to overlooking relevant gaps in lichen growth.

Conclusion:

With recreational climbing and park tourism both growing rapidly in popularity over recent years, it is important to determine the degree to which these activities might be impacting park ecosystems so that park officials can create use plans which balance the human need for outdoor recreation and the goal of preserving natural environments. Ultimately, we failed to reject the null hypothesis concerning recreational rock climbing and its impact on lichen development at ERSNA. This suggests that climbing activity is not having an adverse impact on lichen growth, and therefore should not be considered for limitation by Texas Parks and Wildlife on the basis of protecting lichen development. However, we recommend additional research be conducted to obtain a more complete record of data from other climbing areas at Enchanted Rock and to address the limitations noted above. Further, due to the importance of lichen colonies to the ecosystem and their prevalence in climbing areas in the park, we recommend that park staff create educational materials to make climbers aware of these colonies and the importance of not disturbing them.

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