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The Physical Damage of Climbing Activity on Sandstone Lichen Cover

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Abstract: Climbing activities affect cliff site species. With cliff sites harbouring unique species communities, the rise in popularity of outdoor climbing activities is a major threat. In this study, we assessed a previously unclimbed boulder before, during and after 500 climbing ascents. We observed an overall reduction in lichen cover by 4.2–9.5%, located around the footholds and combined foot- and handhold but not the handhold. We found the reduction in lichen cover to be strongest at the very start of the climbing treatment and to lessen over time. Therefore, management should focus on directing climbing activities to selected sites, while protecting sites with high conservation value where climbing is prohibited entirely.

Keywords: cliff ecology; climbing impact; conservation; human disturbance; recreation; sport ecology

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1. Introduction

Climbing activities affect cliff site species [1–5]. With bouldering, rock climbing and other climbing activities becoming more popular, and with sport climbing being now accepted as an Olympic discipline, the importance of understanding the ecological impact of climbing activities increases. Estimates for 2010 and 2017 indicate an increase from 300,000 to 9,700,000 climbers in the USA [6] and from 300,000 to over 500,000 climbers in Germany [7,8]. Cliff sites are naturally protected by their inaccessibility against common disturbances, e.g., grazing or human activity [9]. They are known to harbour unique species diversity, including rare and endemic taxa [10–14]. Understanding how environmental damage scales with the number of climbing ascents is one of the central questions for sustainable management of the popular sport in semi-natural settings.

Cliff sites consist of zones, each offering different habitat parameters promoting distinct species communities [10]. The most abundant organisms at cliff sites are lichen [15]. They are a symbiotic connection of fungi and photobiotic organisms, such as cyanobacteria or green algae. The fungus provides protection and fixation to the substrate, while the algae provides nutrition via photosynthesis [16]. Lichen can grow on substrates with little or no nutrition, such as bare rock. Most lichen are sealing off stone surfaces and thus can prevent erosion [17]. Lichen can also exudate chemical weathering agents, which facilitate mineral neoformation, e.g., turning rock surfaces into soil [18]. They serve as food for higher order taxa, such as snails, and can be used as an indicator to monitor shifts in cliff ecosystems [19]. Climbing activity reduces the cover and number of lichen species [9] and especially lowers the frequency of epilithic lichen [19]. However, when accounting for abiotic effects, such as slopes and pockets, species numbers can be increased by climbing [12]. When affected, lichen are oftentimes scraped off the rock, whereas affected vascular plants suffer mostly non-lethal damages [20,21]. Other than lichen, vascular plants are mostly found on soil trapped in crevices or pockets or on plateaus. At climbed sites, they can be damaged by trampling or being used as anchors. Case studies have found that White Cedar trees

(*Thuja occidentalis*) show more signs of physical damage [20] and 35% more flowering ramets of *Solidago sciaphila* break at climbed sites compared to unclimbed sites [21]. In contrast to lichen and vascular plants, studies generally found that bryophytes are not impacted by climbing activity [9,12,19].

In this study, we investigate how the number of climbing ascents scales with the damage caused to lichen cover. It is possible that climbing activities could be restricted to a sustainable limit. However, if sensitive species already suffer from very few climbing ascents, management strategies may have to direct climbing activities to selected sites while protecting cliff sites where climbing is prohibited entirely. The differences between lichen communities at climbed and unclimbed sites has been shown to increase with rising climbing activity [13]. Climbed sites with high visitor numbers show a greater reduction in the abundance and richness of endangered plant species [2]. In contrast, moderate bouldering activity in a remote area was not found to threaten vegetation diversity [1]. However, diversity may be a misleading indicator when evaluating threats to rare species, since a high number of species does not necessarily equal species of high conservation value.

Contrasting findings, regarding the relationship between vegetation and climbing activities, could reflect natural variation in plant communities [22] and cliff site topography but may also be caused by study design [15]. Not controlling for biotic and abiotic differences between climbed and unclimbed sample cliff sites can result in potential selection bias [15] and lead to muddied or contradictory results. Unfortunately, research that controls for additional factors instead of just climbing activity itself is scarce, but considering and minimizing differences between climbed and unclimbed sample cliff sites is necessary to learn about the actual impact of climbing activity.

In this study, a climbing treatment was applied to a previously unclimbed sandstone boulder. It was monitored how the impact on lichen cover developed with the number of climbing ascents on the boulder. The data allows contrasting two management options for climbing activities in semi-natural settings: (1) If climbing activity causes only little damage until a threshold, managing activities within this limit would allow for sustainable climbing. (2) In contrast, if damage by climbing activity is highest at the beginning, with most of the lichen cover lost within few ascents, management should focus climbing activity on few selected sites and prevent any activity on other sites, thus keeping them undisturbed.

2. Materials and Methods

This study quantifies the resistance of previously undisturbed lichen communities to climbing activity by adapting the established experimental setting used to quantify trampling on ground vegetation. For that purpose, a standardized experimental protocol is commonly used in order to quantify the resistance of a specific plant species or community [23]. The relative vegetation cover is documented before, in between and after the treatments and is continuously plotted against the respective number of ascents. The trend of the resulting curve can be approximated with a regression curve, indicating a relative stabilization of cover reduction over time. This study uses a similar experimental approach, adopting the trampling resistance protocol to a vertical cliff face, while continuously monitoring lichen cover reduction.

This study focusses on sandstone rock, which is a popular rock type among climbers due to its high friction coefficient. Sandstone is very porous and shows high water absorption [24] and is therefore an ideal substrate for many local lichen species. Sandstone lichen appear to be especially vulnerable to climbing [25]. An undisturbed sandstone boulder with characteristics attractive for climbing was selected for this study. Its vertical rock face is about 4 m tall, with numerous pockets and ledges serving as holds. The boulder is located 100 m away from the nearest path in the forest (49°55′03.3″ N, 11°30′26.8″ E, see Figure 1). We found no signs of previous climbing activity, such as chalk marks or ground vegetation trampling, therefore, we consider this specific boulder unclimbed. After the landowner and local authorities granted permission, the study was conducted from 24 June to 7 July 2020. During the study period, the weather was dry with no precipitation.

Temperature and relative humidity ranged from 19–26 °C and 45–75%, respectively. The boulder was covered with lichen and bryophytes, which were not identified to species level. On the route chosen, only lichen occurred, with no bryophytes near the holds.

Figure 1. Location and picture of sandstone boulder used in study. All holds are visible (© openstreetmap.org contributors).

During the study period of eight days, a daily treatment of 50–100 climbing ascents was applied at seven days, resulting in a total of 500 ascents. The same holds for hands and feet were used for all ascents. The treatment was applied by two people weighing 64 kg and 68 kg and wearing regular climbing shoes. Both topped out after each ascent and returned to the bottom on a different way. No chalk or brushes were used to increase friction. At 14 points in time (before the treatment, after 10, 20, 30, 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 ascents), photographs were taken from 4 holds, of which 2 were footholds (FH1, FH2), 1 was a handhold (HH) and 1 was a combined hold for hands and feet (CHF) (Figure 2). The digital camera used was a Sony Cybershot DSC-T99.

To ensure the photos were taken from the same angle and section, a square 20 × 20 cm frame was used, but alas, this could not be achieved in every case. Due to small variations of exposition, angle and resolution, the images are not perfectly identical and possibly caused variation in cover estimation. Using more sophisticated equipment, such as stationary cameras and exposure units, sufficiently similar pictures can be taken to use automated computerized analysis methods. The assessment of the 3D hold topography was not possible due to equipment limitations. The extent of the holds in depth direction could not be accurately measured, so the lichen cover might be underestimated due to perspective distortion.

The presented results only apply for lichen dwelling on Middle European sandstone. Future studies on different rock types and climate zones are needed for assessing possible differences in the impact of climbing activities under respective regional conditions.

For lichen cover estimation, the photographs were cropped to remove the frame. They were also edited to optimize exposition, contrast and colour saturation for lichen identification. Cover was estimated visually using a 10 × 10 layover grid with each cell being 2 × 2 cm, as suggested by Reeding [26]. The relative lichen cover was recorded separately for each grid cell in each of the 52 photos. The mean of all cells represented the relative lichen cover for the respective number of ascents at that hold. The order of the photos was randomized to prevent bias during cover estimation. The relationship between estimated lichen cover and the number of ascents was analysed using segmented regression with unknown breakpoints [27]. Model performance was compared with standard linear regression. Analyses and visualizations were implemented in R version 4.0.3 [28].

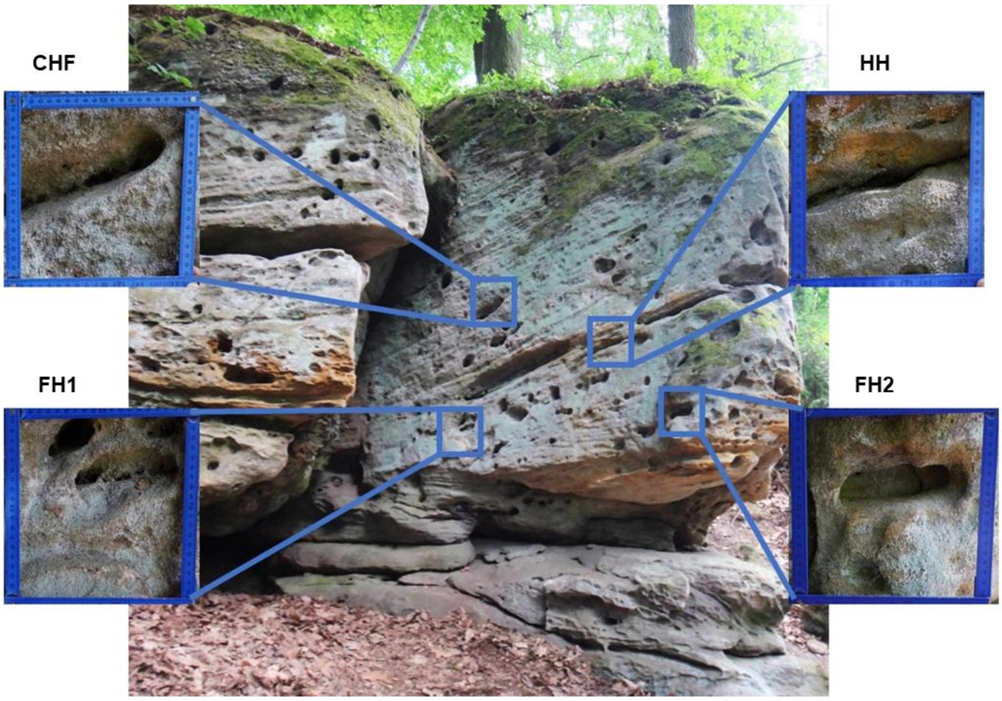

Figure 2. Positions of Footholds 1 and 2 (FH1, FH2), Handhold (HH) and Combined Hand- and Foothold (CHF) on the boulder used in study.

3. Results

Climbing activity reduced lichen cover (Table 1). The effect is very localized and concentrates on the immediate surrounding area of the holds. The loss in lichen cover is accompanied by significant rock abrasion (Figure 3).

Table 1. Development of lichen cover in the 20 × 20 cm squares around the holds before and after climbing treatment at Footholds 1 and 2 (FH1, FH2), Handhold (HH) and Hand- and Foothold (CHF).

	Lichen Cover Unclimbed		Lichen Cover Climbed		Change in Lichen Cover	
	Relative	Total [cm^2]	Relative	Total [cm^2]	Relative	Total [cm^2]
FH1	84.9%	339.5	70.1%	280.3	−14.8%	−59.2
FH2	94.8%	379.1	82.1%	328.3	−12.7%	−50.8
HH	74.3%	297.3	75.4%	301.4	1.0%	4.1
CHF	94.6%	378.4	85.3%	341.1	−9.3%	−37.3

Before the climbing treatment, the relative lichen cover was high (74.3–94.8%). The complete treatment of 500 ascents reduced the lichen cover by 4.2–9.5% to 70.1–85.3% overall. The lichen cover around the Handhold (HH) did not change, while the cover around the Footholds (FH1 and FH2) decreased by 12.7% and 14.8%, respectively, resulting in a total loss of 50.8 cm^2 and 59.2 cm^2. The Combined Hand- and Foothold (CHF) showed a reduction of 9.3% or 37.3 cm^2 in the lichen cover.

Breakpoint estimates for Foothold 1 (FH1), Foothold 2 (FH2) and the Combined Hand- and Foothold (CHF) indicate a much faster decline in lichen cover within the first

50–100 ascents (Table 2, Figure 4). The decrease in lichen cover per ascent lessens by about a factor of 10 after the breakpoint. The models analysing the relationship between lichen cover and the number of climbing ascents are non-significant for the Handhold (HH), suggesting a much lower effect of climbing at the Handhold.

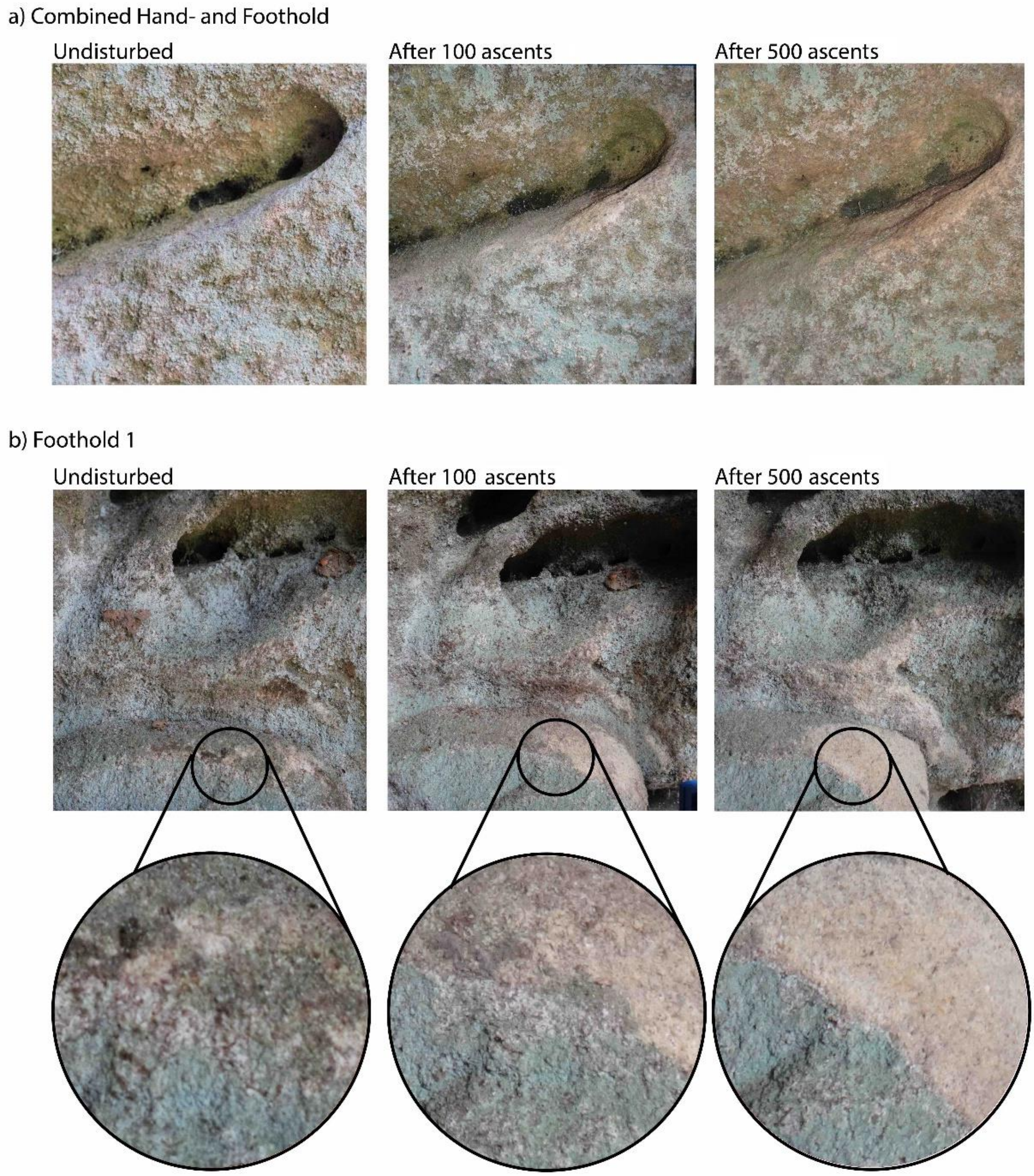

Figure 3. Images of (**a**) Combined Hand- and Foothold (CHF) and (**b**) Foothold 1 (FH1) after 0, 100 and 500 ascents. For FH1, exemplary details show abrasion over the course of the study.

Table 2. Model characteristics of the segmented linear regression and comparison to linear regression as well as a null model with zero slope. Breakpoint and slope estimates are provided with standard error (±).

	FH1	FH2	HH	CHF
Breakpoint estimate	50.0 ± 11.7	58.1 ± 11.6	-	100.0 ± 38.5
Slope before breakpoint	−0.195 ± 0.055	−0.116 ± 0.024	-	−0.061 ± 0.027
Slope after breakpoint	−0.012 ± 0.003	−0.014 ± 0.002	-	−0.003 ± 0.003
AIC null model	87.4	83.9	54.2	72.9
AIC linear model	71.8	59.8	56.1	60.0
AIC segmented model	50.6	43.3	54.5	45.9
p-value segmented model	0.005	<0.001	Non-significant	0.046
R^2 linear model	0.72	0.85	-	0.66
R^2 segmented model	0.95	0.96	-	0.91

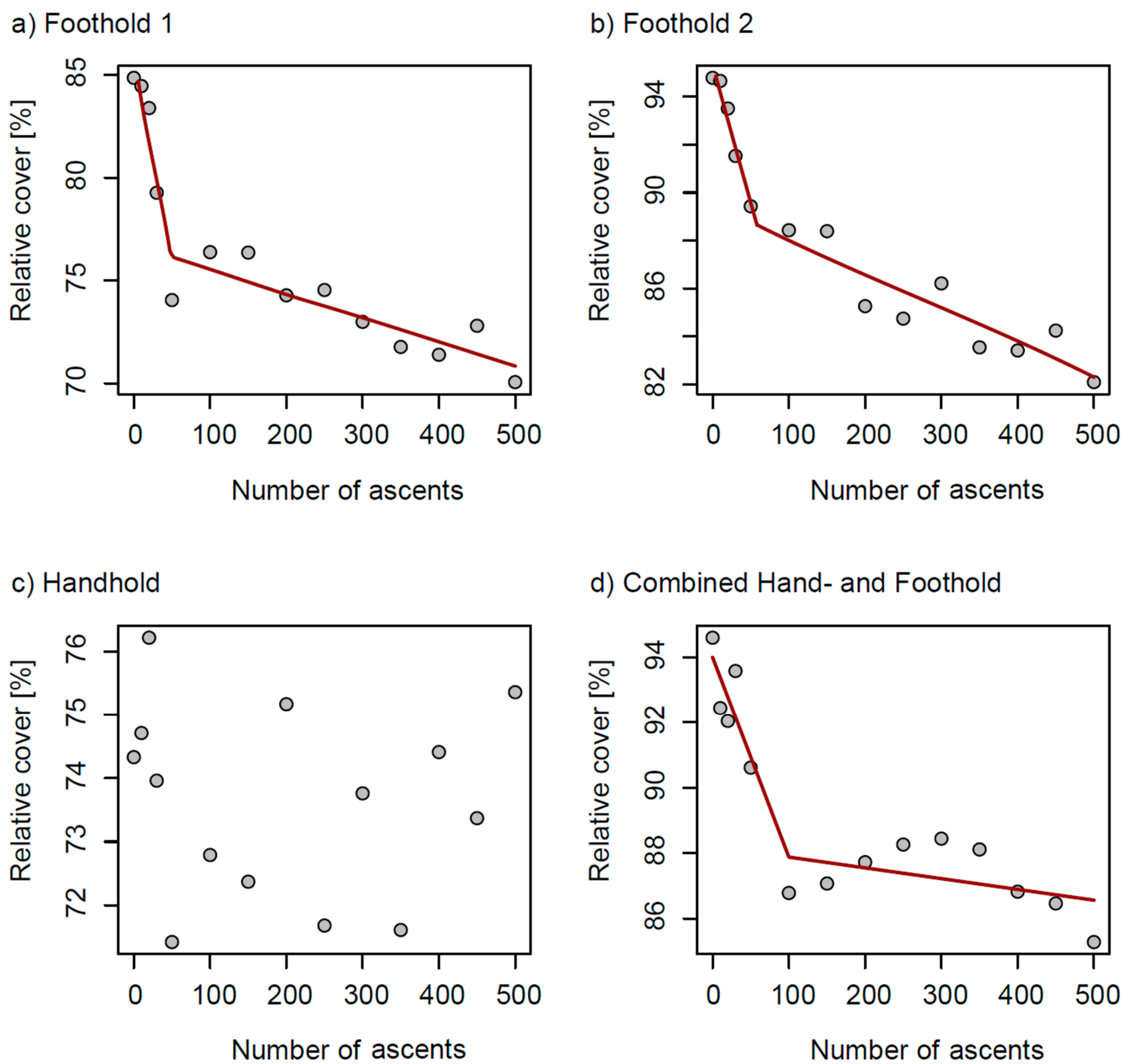

Figure 4. Relative lichen cover and number of ascents at Foothold 1 (**a**), Foothold 2 (**b**) and Combined Hand- and Foothold (**d**) with segmented breakpoint regression. The Handhold (**c**) showed no significant relationship between relative lichen cover and the number of ascents.

4. Discussion

This is the first study to assess the alteration in lichen cover on a previously unclimbed sandstone boulder during a climbing treatment. Since we observed the same boulder before, during and after climbing treatment, we circumvented potential observation bias that can occur when comparing different sites [15,29]. Although based on the observations of a single boulder with only four holds, the results allow a clear conclusion: The reduction in lichen cover is dependent on the number of climbing ascents. This effect is strongest in the very beginning of the climbing treatment (first 100 climbing ascents) and lessens over time without stopping entirely, even after 500 ascents. Hence, to protect lichen, management should focus on strictly separating and controlling climbed and unclimbed sites.

Lichen can grow on bare rock surface, where they generally are the most abundant and species-rich group [15]. They are key organisms in shaping the species community at cliff sites and therefore a fit model to monitor shifts in cliff ecosystems [19]. In accordance with the findings on ground vegetation trampling [30], the lichen cover reduction on rock shows continuous decline. The initial impact during the first 50–100 ascents is very high. Considering that the impact is very localized to the immediate surrounding area of the holds, it is possible to explain the impact mechanism on lichen: During the first 50–100 ascents, the lichen at the immediate surrounding area of the holds are removed. On the following ascents, further cover is only removed when a foot deviates from the ideal hold position (Figures 3 and 4). As a result, the cover reduction stabilizes over time. When climbing, the tip of the climbing shoe sole is the preferably used support area of the shoe. The observed total cover loss of 50–59 cm^2 at the footholds is roughly 1.5 times the size of the climbing shoe tip (climbing shoe tip area of shoe used in study was 37 cm^2). A more precise foot placement will therefore lead to a smaller reduction in lichen cover over time. The area loss at the combined hand and foothold (CHF) is smaller with only 37.3 cm^2, which can be explained by the smaller size of the support area at that hold, compared to the larger holds of Foothold 1 and 2 (FH1, FH2). The topography of the holds also contributes to the magnitude of lichen cover loss. This is in accordance with previous studies that found a smaller impact on cliff site vegetation at more difficult routes with smaller holds [12]. In this study, only two people climbed the boulder, always using the exact same holds. Other climbers may use different holds, resulting in higher cover reduction. The use of brushes and chalk would probably enhance the rock abrasion as well. Preliminary work has found chalk to influence algae positively and moss and lichens negatively on cliffs [31,32].

Notably, the effect of 500 ascents was not observed at handholds but only at footholds or combined foot and handholds. Our results implicate different impact mechanisms of feet and hands in climbing activities. A possible explanation is the higher reaction force applied by feet when holding on to a vertical wall [33]. In the quadrupedal position, when the body is supported by both hands and feet, a 33% higher force is applied to the footholds, compared to the handholds. Even higher forces occur when lifting one foot of the wall. Additionally, climbing shoe soles are less elastic (Young's modulus = approx. 7.33 MPa [34]) than the skin of fingers (Young's modulus = approx. 0.03 MPa [35]). This leads to a higher load on the top layer of the uneven rock surface, while skin is deforming and adapting to the micro topography of the surface, distributing the load to a larger area and more evenly. Moreover, the rubber could lead to more abrasion. In climbing, the slipping of feet seems to occur more frequently than the slipping of hands, which might be explained by more precise positioning of the latter.

With the onset of climbing activity, lichens are not only damaged directly by contact with finger skin or shoe sole but indirectly by the removal of sandstone substrate due to abrasion. Sandstone, as a rock type, has the lowest abrasion resistance [24] and lichen on that substrate are therefore the most vulnerable to being removed together with the top rock layer [25]. Since, in this study, most rock abrasion and loss of lichen cover happened at footholds, we suspect that the loss of lichen cover was mostly caused indirectly by rock abrasion. In contrast, at handholds, less lichen cover was lost and less rock abraded. Since lichen, except for crustose lichen, are known to seal off the rock surface and prevent erosion [17], rock may be doubly threatened to abrade when lichen cover decreases. Although this study found the loss of lichen cover to be small and very localized, rock abrasion is a serious matter which affects boulders and whole cliff sites. Future studies should focus on the ability to regrow previously removed lichen in order to determine whether the effect is temporal or permanent. Since climbing activities are mostly seasonal sports, climbed as well as unclimbed cliff sites can be studied to research lichen rehabilitation.

When searching for a suitable route, climbers tend to choose cliff sites covered with less lichen and vegetation to avoid slipping [9,12,36]. In addition, most times the rock surface is "cleaned" by removing all lichen, bryophytes and most vascular plants when a new climbing route is established. This is performed to make the new routes more attractive and safer by, e.g., reducing the risk of slipping. A "cleaned" surface helps to place hands and feet more precisely on the rock surface, creates a more direct contact between rock and hands/feet and allows a better 'grip', as climbers claim. This is yet another reason to declare specific cliff sites as climbed or unclimbed, contrary to regulating visitor numbers.

Cliff sites offer unique habitats, oftentimes populated by endemic species. The conservation and protection of cliff sites requires scientific knowledge about the impact induced by climbing activity in order to take evidence-based conservation measures. As climbing activities become more and more popular, the need for tangible conservation measures rises. This study contributes to the understanding of the impact mechanism of climbing on rock dwelling lichen on sandstone, with abrasion potentially being the most impactful physical damage for lichen at cliff sites.

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Data Availability Statement: Publicly available datasets were analysed in this study. This data can be found here: https://nolowimpactpossible.wordpress.com/ (accessed on 5 December 2021).

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References

1. Tessler, M.; Clark, T.A. The Impact of Bouldering on Rock-Associated Vegetation. *Biol. Conserv.* **2016**, *204*, 426–433. [CrossRef]
2. Lorite, J.; Serrano, F.; Lorenzo, A.; Cañadas, E.M.; Ballesteros, M.; Peñas, J. Rock Climbing Alters Plant Species Composition, Cover, and Richness in Mediterranean Limestone Cliffs. *PLoS ONE* **2017**, *12*, e0182414. [CrossRef] [PubMed]
3. March-Salas, M.; Moreno-Moya, M.; Palomar, G.; Tejero-Ibarra, P.; Haeuser, E.; Pertierra, L.R. An Innovative Vegetation Survey Design in Mediterranean Cliffs Shows Evidence of Higher Tolerance of Specialized Rock Plants to Rock Climbing Activity. *Appl. Veg. Sci.* **2018**, *21*, 289–297. [CrossRef]
4. Schmera, D.; Rusterholz, H.-P.; Baur, A.; Baur, B. Intensity-Dependent Impact of Sport Climbing on Vascular Plants and Land Snails on Limestone Cliffs. *Biol. Conserv.* **2018**, *224*, 63–70. [CrossRef]
5. Strumia, S.; Buonanno, M.; Aronne, G.; Santo, A.; Santangelo, A. Monitoring of Plant Species and Communities on Coastal Cliffs: Is the Use of Unmanned Aerial Vehicles Suitable? *Diversity* **2020**, *12*, 149. [CrossRef]
6. The Outdoor Foundation. *Outdoor Participation Report*; The Outdoor Foundation: Washington, DC, USA, 2018.
7. Deutscher Alpenverein e.V. (DAV). Klettern in Deutschland—Zahlen, Daten & Fakten. Available online: https://www.alpenverein.de/der-dav/presse/hintergrund-info/klettern-in-deutschland-zahlen-daten-fakten_aid_31813.html (accessed on 21 August 2020).

8. Deutscher Alpenverein e.V. (DAV). Sportklettern Boomt! DAV. Available online: https://www.alpenverein.de/wettkampf/klettern/wettkampf-abc/sportklettern-und-wettkaempfe-beim-dav_aid_10318.html (accessed on 5 December 2021).
9. Clark, P.; Hessl, A. The Effects of Rock Climbing on Cliff-Face Vegetation. *Appl. Veg. Sci.* **2015**, *18*, 705–715. [CrossRef]
10. Larson, D.W.; Matthes, U.; Kelly, P.E. *Cliff Ecology: Pattern and Process in Cliff Ecosystems*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2000.
11. McMillan, M.A.; Larson, D.W. Effects of Rock Climbing on the Vegetation of the Niagara Escarpment in Southern Ontario, Canada. *Conserv. Biol.* **2002**, *16*, 389–398. [CrossRef]
12. Kuntz, K.L.; Larson, D.W. Influences of Microhabitat Constraints and Rock-Climbing Disturbance on Cliff-Face Vegetation Communities. *Conserv. Biol.* **2006**, *20*, 821–832. [CrossRef]
13. Boggess, L.M.; Walker, G.L.; Madritch, M.D. Cliff Flora of the Big South Fork National River and Recreation Area. *Nat. Areas J.* **2017**, *37*, 200. [CrossRef]
14. de Castro-Arrazola, I.; March-Salas, M.; Lorite, J. Assessment of the Potential Risk of Rock-Climbing for Cliff Plant Species and Natural Protected Areas of Spain. *Front. Ecol. Evol.* **2021**, *9*, 611362. [CrossRef]
15. Holzschuh, A. Does Rock Climbing Threaten Cliff Biodiversity?—A Critical Review. *Biol. Conserv.* **2016**, *204*, 153–162. [CrossRef]
16. Honegger, R. The Lichen Symbiosis—What Is so Spectacular about It? *Lichenol.* **1998**, *30*, 193–212. [CrossRef]
17. Steinbauer, M.J.; Gohlke, A.; Mahler, C.; Schmiedinger, A.; Beierkuhnlein, C. Quantification of Wall Surface Heterogeneity and Its Influence on Species Diversity at Medieval Castles—Implications for the Environmentally Friendly Preservation of Cultural Heritage. *J. Cult. Herit.* **2013**, *14*, 219–228. [CrossRef]
18. Chen, J.; Blume, H.-P.; Beyer, L. Weathering of Rocks Induced by Lichen Colonization—A Review. *CATENA* **2000**, *39*, 121–146. [CrossRef]
19. Baur, B.; Fröberg, L.; Müller, S.W. Effect of Rock Climbing on the Calcicolous Lichen Community of Limestone Cliffs in the Northern Swiss Jura Mountains. *Nova Hedwig.* **2007**, *85*, 429–444. [CrossRef]
20. Kelly, P.E.; Larson, D.W. Effects of Rock Climbing on Populations of Presettlement Eastern White Cedar (*Thuja occidentalis*) on Cliffs of the Niagara Escarpment, Canada. *Conserv. Biol.* **1997**, *11*, 1125–1132. [CrossRef]
21. Nuzzo, V.A. Structure of Cliff Vegetation on Exposed Cliffs and the Effect of Rock Climbing. *Can. J. Bot.* **1996**, *74*, 607–617. [CrossRef]
22. Harrison, G.R. *The Impact of Rock-Climbing Disturbance on Cliff Communities of the Linville Gorge Wilderness Area*; Appalachian State University: Boone, NC, USA, 2020.
23. Cole, D.N.; Bayfield, N.G. Recreational Trampling of Vegetation: Standard Experimental Procedures. *Biol. Conserv.* **1993**, *63*, 209–215. [CrossRef]
24. Kılıç, A.; Atiş, C.D.; Teymen, A.; Karahan, O.; Özcan, F.; Bilim, C.; Özdemira, M. The Influence of Aggregate Type on the Strength and Abrasion Resistance of High Strength Concrete. *Cem. Concr. Compos.* **2008**, *30*, 290–296. [CrossRef]
25. Adams, M.D.; Zaniewski, K. Effects of Recreational Rock Climbing and Environmental Variation on a Sandstone Cliff-Face Lichen Community. *Botany* **2012**, *90*, 253–259. [CrossRef]
26. Reding, J. *Rock Climbing or Lichen Climbing? How Rock Climbing Impacts Bryophyte and Lichen Communities Within the Red River Gorge*; The Ohio State University: Columbus, OH, USA, 2019; Available online: https://etd.ohiolink.edu/apexprod/rws_etd/send_file/send?accession=osu1562584961670604&disposition=inline (accessed on 5 December 2021).
27. Muggeo, V.M.R. Interval Estimation for the Breakpoint in Segmented Regression: A Smoothed Score-Based Approach. *Aust. New Zealand J. Stat.* **2017**, *59*, 311–322. [CrossRef]
28. R Core Team. R: A Language and Environment for Statistical Computing. 2021. Available online: https://www.R-project.org/ (accessed on 5 December 2021).
29. Boggess, L.M.; Georgia, R.H.; Bishop, G. Impacts of Rock Climbing on Cliff Vegetation: A Methods Review and Best Practices. *Appl. Veg. Sci.* **2021**, *24*, e12583. [CrossRef]
30. Hill, R.; Pickering, C. Differences in Resistance of Three Subtropical Vegetation Types to Experimental Trampling. *J. Environ. Manag.* **2009**, *90*, 1305–1312. [CrossRef] [PubMed]
31. Pereira, J. *The Influence of Rock Climbing Chalk on Cliff Plant Communities*; Antioch New England Graduate School: Keene, NH, USA, 2005.
32. Hepenstrick, D.; Bergamini, A.; Holderegger, R. The Distribution of Climbing Chalk on Climbed Boulders and Its Impact on Rock-dwelling Fern and Moss Species. *Ecol. Evol.* **2020**, *10*, 11362–11371. [CrossRef] [PubMed]
33. Noé, F.; Quaine, F.; Martin, L. Influence of Steep Gradient Supporting Walls in Rock Climbing: Biomechanical Analysis. *Gait Posture* **2001**, *13*, 86–94. [CrossRef]
34. Hale, J.; O'Connell, A.; Lewis, R.; Carré, M.J.; Rongong, J.A. An Evaluation of Shoe Tread Parameters Using FEM. *Tribol. Int.* **2021**, *153*, 106570. [CrossRef]
35. Yang, Y.; Wang, L.; Yan, F.; Xiang, X.; Tang, Y.; Zhang, L.; Liu, J.; Qiu, L. Determination of Normal Skin Elasticity by Using Real-Time Shear Wave Elastography: Normal Skin Elasticity on Real-Time Shear Wave Elastography. *J. Ultrasound Med.* **2018**, *37*, 2507–2516. [CrossRef]
36. Farris, M.A. The Effects of Rock Climbing on the Vegetation of Three Minnesota Cliff Systems. *Can. J. Bot.* **1998**, *76*, 1981–1990. [CrossRef]