RESEARCH ARTICLE

Rock climbing activity and physical habitat attributes impact avian community diversity in cliff environments

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Abstract

As the sport of outdoor rock climbing rapidly grows, there is increasing pressure to understand how it can affect communities of organisms in cliff habitats. To that end, we surveyed 32 cliff sites in Boulder, Colorado, USA, and assessed the relative roles of human recreation and natural habitat features as drivers of bird diversity and activity. We detected only native avian species during our observations. Whereas avian abundance was not affected by climbing, avian species diversity and community conservation value were higher at low-use climbing formations. Models indicated that climber presence and cliff aspect were important predictors of both avian diversity and avian cliff use within our study area, while long-term climbing use frequency has a smaller, but still negative association with conservation value and cliff use by birds in the area. In contrast, the diversity of species on the cliff itself was not affected by any of our measured factors. To assess additional community dynamics, we surveyed vegetation and arthropods at ten site pairs. Climbing negatively affected lichen communities, but did not significantly affect other vegetation metrics or arthropods. We found no correlations between avian diversity and diversity of either vegetation or arthropods. Avian cliff use rate was positively correlated with arthropod biomass. We conclude that while rock climbing is associated with lower community diversity at cliffs, some common cliff-dwelling birds, arthropods and plants appear to be tolerant of climbing activity. An abiotic factor, cliff aspect strongly affected patterns of both avian diversity and cliff use, suggesting that the negative effects of rock climbing lC

were calculated by measuring the elevation at the base of the cliff at the survey location and subtracting this from the maximum elevation of the formation at the survey location. Verticality was measured in the field using a clinometer. Information on the number of climbing routes was obtained from *Climbing Boulder's Flatirons* [28]. Additional measurements of distances from each study site to streams [29], trails [26] and parking lots [30] were conducted in ArcGIS.

Avian observations

We conducted surveys of birds from May 10 to July 24, 2015 to assess species diversity and behavior. Each survey was one hour long. To account for variations in activity for both birds and climbers, we surveyed each site twice during early morning (n = 64 surveys) and mid-day (n = 64 surveys), and at least once during the evening (n = 54 survey) for a total of 182 surveys. Early morning included sunrise and the following three hours, mid-day was from 1030 to 1330, and evening was three hours prior to sunset. The order in which sites were visited was randomized for the first set of surveys. Sites were revisited in the same order for subsequent surveys.

During the surveys, the researchers sat 20 m away from the base of the cliff to conduct observations of a 30 m wide section of cliff face (Fig 2). The relatively small size of this survey area was due to limitations in visibility in the Flatirons area given the forest matrix surrounding cliffs. The cliff face, as well as the space between the surveyor and the cliff and the air space immediately above this location, were included in the survey area (Fig 2). At one minute intervals the surveyor recorded the bird species present, the maximum number of individuals of all species observed (ªbird abundanceº), and all location(s) of the bird(s), differentiating bird's use of the actual cliff versus the surrounding area. Additional data collected included the presence of climbers at the site.

Vegetation surveys

We conducted vegetation surveys at a subset of our sites: 10 high climbing use and 10 low climbing use cliffs from July 10 to July 22. We quantified vegetative cover by estimating percent cover of vegetation types within 0.25 m^2

Arthropod sampling

At each of the 20 sites where

parking lots, and elevation. Therefore, in each of these instances we included only the variable that we thought was most biologically relevant to avian communities (i.e. climbing use rating, aspect, and distance to parking lots respectively). We conducted a Backwards Stepwise Selection procedure based on Akaike's Information Criterion corrected for small sample size (AIC_c)[33]. We considered models with a ΔAIC_c within 2 of the best fit model to be significant and reported these in our results section. All avian surveys were included in these analyses.

Response variables included avian community conservation value (CCV), the number of scans in which we observed birds using the cliff (a measure of cliff use frequency), and the following metrics for both the full survey area and for the cliff face: species richness, numbers of individual birds, and Shannon-Wiener Diversity Index (*H'*) [34]. We calculated species richness values for each survey as the total number of species observed, richness was 45, with 37 species observed at high-use climbing sites and 39 species observed at low-use climbing sites (Table 2). Non-native species, such as European starlings (*Sturnus vulgaris*) and house sparrows (*Passer domesticus*), were never observed (Table 2). Species that were observed using the cliffs in our study area included White-throated Swifts, Violet-green Swallows, Common Ravens (*Corvus corax*), Prairie Falcons (*Falco mexicanus*), Peregrine Falcons (*Falco peregrinus*), Canyon Wrens, Townsend's Solitaires (*Myadestes townsendi*), and occasionally White-breasted Nuthatches (*Sitta carolinensis*), and Rock Wrens. The other species observed during surveys were typically seen in the areas near or above the cliff. We observed climbers on the cliffs in 6.6% of the surveys comprising 38 individuals (11% of surveys and 35 individuals for high-use climbing sites and 2.2% of surveys and three individuals for low-use climbing sites). Although we did not observe high rates of climbing use during our study, our numbers are consistent with the categories supplied by the local climbing community, providing support for the validity of those categories.

Avian diversity, species richness, and community conservation value (CCV) were higher within survey areas at low climbing use sites (Fig 3, Fig 4), however this difference was reduced on the cliffs relative to the whole survey area (Fig 3). Bird abundance was similar at high- and low-use climbing sites (Fig 3). Surprisingly, the numbers of individual birds on cliffs and scans that birds were observed using cliffs was higher at high-use climbing formations (Fig 3). Overall, species diversity, species richness, and bird abundance on the cliffs was much lower than the same metrics for the whole survey area (Fig 3).

Combined, results of linear mixed models (LMMs) indicated that climber presence and cliff aspect most strongly influenced the abundance and diversity of birds in local cliff communities, as each of these were included in four of the eight best fit models for our response variables (Table 3, S1 Appendix). Climbing use rating also predicted CCV and the number of scans birds were observed on cliffs. Cliff height was only included in one model where the delta AICc was <2 and distance to parking lots did not appear in any of the selected models (Table 3, S1 Appendix). For our measures of avian diversity and abundance on the cliff itself, three out of four best fit models were the null models that included only the random factor (site identity).

Avian diversity

On average, west-facing cliffs showed a trend of lower avian diversity (*H'*) within the survey area compared to other aspects, while east-facing cliffs generally had the highest avian diversity ($H'_{East} = 1.45 \pm 0.10$, $H'_{South} = 1.30 \pm 0.09$, $H'_{North} = 1.10 \pm 0.05$, $H'_{West} = 1.08 \pm 0.07$). Despite this, the best fit model of avian diversity in the entire survey area identified climber presence as the only significant predictor (Table 3, Table A in S1 Appendix). *H'* was lower when climbers were present compared to when they were absent (*H'* climbers present = 1.02 ± 0.10, *H'* climbers absent = 1.25 ± 0.04). None of our parameters had a significant effect on diversity when restricting analyses to birds on the cliff itself (Table 3, Table B in S1 Appendix).

Species Richness

Cliff aspect was the strongest predictor of avian species richness within the survey area (Table 3). Similar to the pattern observed with our avian diversity results, species richness was highest at east- and south-facing cliffs ($\text{No.Species}_{East} = 5.67 \pm 0.40$, $\text{No.Species}_{South} = 4.54 \pm 0.27$, $\text{No.Species}_{North} = 3.88 \pm 0.31$, $\text{No.Species}_{West} = 3.81 \pm 0.26$). Although the best fit model for species richness in the survey area included only aspect as a predictor (Table 3, Table C in S1 Appendix), there was little difference (ĭAICc < 2) between the cliff aspect

Appendix). Species richness on the cliff was not predicted by any of our modeled variables (Table 3, Table D in S1 Appendix).

Abundance

Bird abundance in the entire survey area was best predicted by a model that included both climber presence and cliff aspect (Table 3, Table E in S1 Appendix). There were three models for bird abundance in the full survey area with ĭAICc < 2 that included cliff aspect, climber presence, and climbing use. Although more individual birds were typically observed at high climbing use sites (Fig 3), we observed fewer birds during surveys when climbers were present (5.85 ± 3.11 birds per survey) compared to when climbers were absent (8.24 ± 4.94 birds per survey). As with our diversity measures, east facing cliffs supported the greatest number of birds ($No.Individuals_{East}$ = 10.17 ± 0.89, $No.Individuals_{North}$ = 7.94 ± 0.76, $No.Individuals_{South}$ = 7.69 ± 0.58, $No.Individuals_{West}$ = 6.93 ± 0.62).Bird abundance on the cliff was not predicted by any of our modeled variables (Table 3, Table F in S1 Appendix)

Community Conservation Value (CCV)

The best fit model for CCV, which was calculated for the full survey area, included climbing use, cliff aspect, and climber presence., with low climbing use and east-facing cliffs having

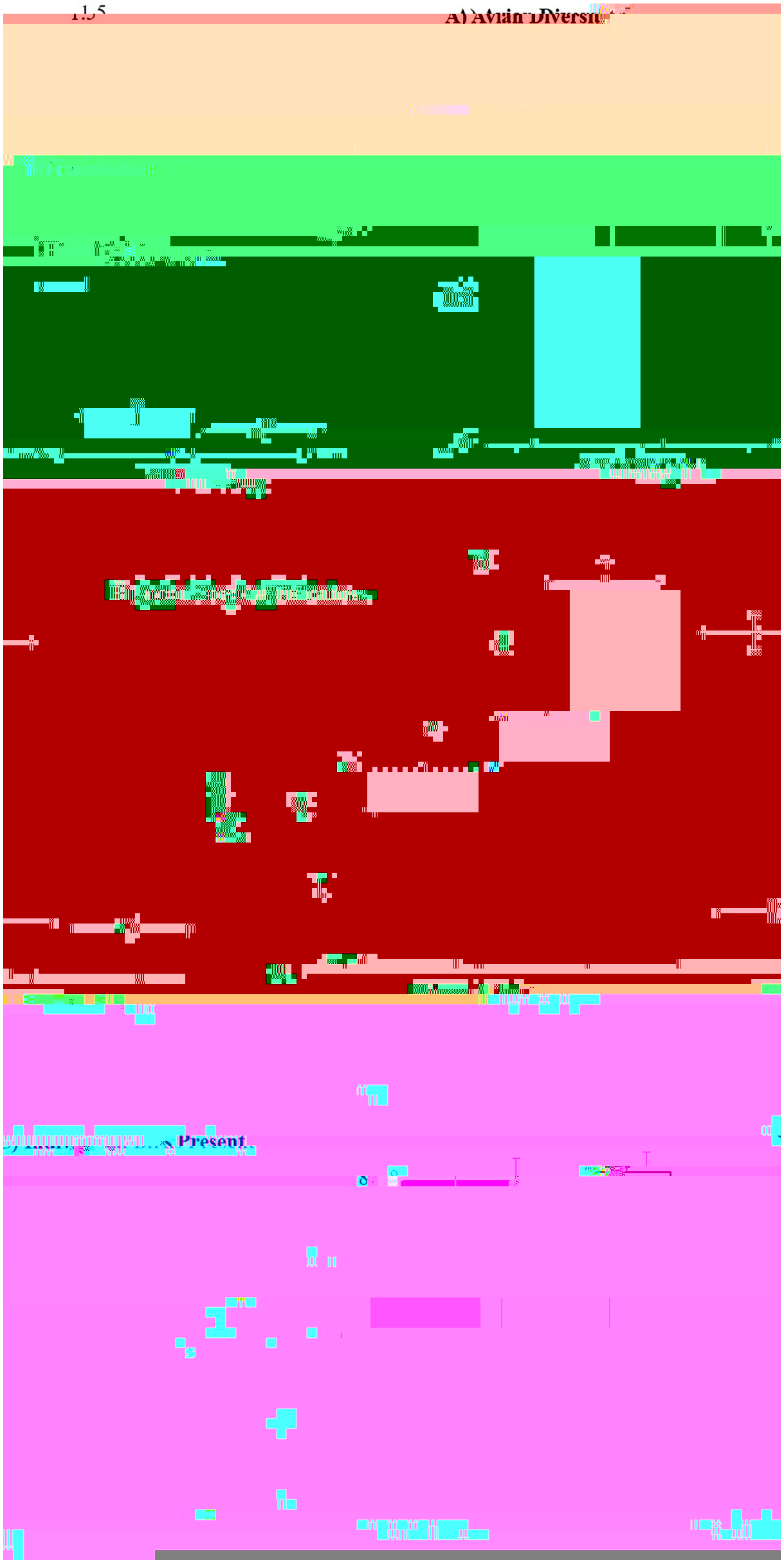

Fig 3. Comparison of (A) avian diversity (B) avian species richness (C) number of individual birds present between high and low use climbing areas. Numbers are based on overall survey averages for high and low-use climbing site surveys (n = 91each for the high and low categories) ± SEM. Individuals were summed across species.

ªSurvey Areaº refers to birds observed within the total survey area, ªCliffº indicates birds that were observed on the rock formation itself.

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transects and both cliff and ground plots (Table 4). However, low climbing use plots had more foliose lichen cover and more trees, though the difference in tree cover was not significant at an ʼn-level adjusted for multiple comparisons (Table 4).

Presence of arthropod orders was similar between high- and low-use sites (Table 5). Mean *H'* for low-use sites was 1.20 (±0.10) and 1.08 (±0.09) for high-use sites (Mann-Whitney U:, U = -0.79, p = 0.43). Average arthropod biomass did not differ between low-use sites (13.58 ± 3.17g) and high-use sites (11.85 ±2.94g; Mann-Whitney U:, U = -0.34, p = 0.74).

Correlation analyses indicated that neither arthropod diversity (R^2 = 0.004, F_{19} = 0.080, p = 0.78) nor vegetation diversity (R^2 = 0.04, F_{19} = 0.69, p = 0.42) were significant predictors of avian diversity. However, arthropod abundance did predict the number of scans in which birds were observed on cliffs. Avian cliff use was correlated with arthropod biomass (R^2 = 0.25, F_{19} = 5.93, p = 0.026), but not percent vegetative cover (R^2 = 0.087, F_{59} = 1.70, p = 0.21).

Discussion

Our research suggests that in a cliff and ponderosa pine forest matrix with relatively high recreation rates, rock climbing has negative impacts on cliff bird community diversity and conservation value, and mixed effects on individuals. Encouragingly, although climber presence and high rock climbing use affected a site's avian species diversity and community conservation value, one of the best predictors of local avian diversity and cliff use was a natural physical characteristic: cliff aspect. East-facing cliffs had the highest avian species diversity while west-facing cliffs had the lowest. Additionally, bird abundance was not related to increases in climbing use, indicating that certain cliff-associated species are relatively tolerant of human activity. Finally, we detected only native avian species, including some considered of conservation concern in Colorado [36], suggesting that our study sites consisted of high-quality habitat.

We observed 45 native bird species using cliff habitats within our study area, including 13 cliff-nesting species previously documented in the area [15]. Presence of local cliff-nesting

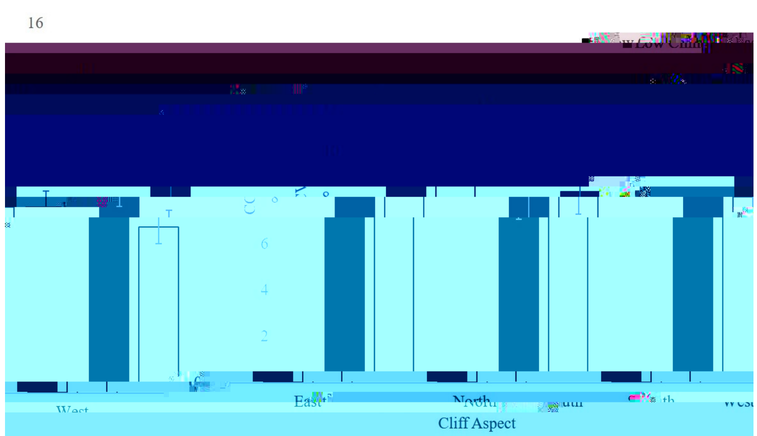

Fig 4. Community conservation value (CCV) by cliff aspect and climbing use rating. Numbers are based on overall survey averages for high and low-use climbing site surveys (n = 91 each for the high and low categories) ± SEM. Individuals were summed across species.

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species was comparable between high- and low-use climbing sites. We identified 19 orders of arthropods living on and within cliff surfaces, and we documented variation in lichen among sites that experience different

Table 5. Comparison of arthropod order counts and presence at high- versus low-use climbing sites. Numbers indicate at how many sites each order was observed. n = 10 sites of each type with 44 traps at high-use climbing sites and 47 traps at low-use climbing sites.

Order	High-Use	Low-Use
Isopoda	2	0
Polyxenida	9	6
Opilones	7	6
Acari	10	10
Araneae	8	8
Thysanura	16	

rock climbing sites compared to high-use rock climbing sites and were also higher during surveys when climbers were absent. Greater CCV scores at low-use climbing and climber-absent cliffs suggest that high levels of rock climbing activity reduce the presence of avian species of conservation concern in the area [19]. The difference in CCV scores is important because human activities, including both development and recreational activity in an area, have been found to decrease densities of sensitive and/or specialist native species [37] even if species richness and diversity are similar.

Our model-fitting approach for the entire survey area revealed that avian diversity, abundance, and CCV were best predicted by combinations of cliff aspect, climber presence, and climbing use rating. Species richness was moderately affected by climbing use, however the best fit model only included cliff aspect. None of our cliff-only models found a negative impact of climbing on diversity, species richness, or abundance. This could reflect the much smaller sample size of birds using the cliff or perhaps species that use cliffs regularly are less affected by climber activity. Our results indicate i) that climber intrusion has a measurable negative effect on avian communities in the area but not necessarily on birds using the cliff and ii) that this effect is comparable to the influence of a natural attribute of the habitat.

Low-use rock climbing sites tended to have more trees compared to high-use sites, which could influence species composition by increasing habitat heterogeneity. East-facing cliffs had the highest diversity and CCV indices of birds and were unique in several ways. East-facing cliffs had the lowest angles (range: 47±63Ê), thus they receive more sunlight and have more vegetation growing on the cliff face (N.C. pers. obs.). South-facing cliffs, which also receive more sunlight compared to north and west-facing cliffs, had the second highest avian diversity. We hypothesize that thermal benefits as well as differences in vegetation composition influence spatial bird diversity, as has been documented in other studies [38±40].

We found that patterns of bird abundance did not align with patterns of diversity. In agreement with previous research [14], we found no difference in bird abundance at high- and low-use climbing sites. In other studies, high bird abundance was maintained at climbing sites via shifts to generalist and non-native species within a community [14, 41, 42]. While we found differences in avian CCV between high- and low-use climbing sites, the absence of non-native, generalist species, such as European Starlings, Brown-headed Cowbirds (*Molothrus ater*), and House Sparrows, in our study is encouraging. Furthermore, high-use climbing sites supported as many individuals of native cliff adapted species as did low-use climbing sites, suggesting that disturbance at high-use climbing sites in our study area was low compared to other areas [14], or was mitigated by physical attributes of the cliffs. Our finding that distance to parking lots had no effect on any of our avian cliff community metricsfurther supports this conclusion. It is possible that proximity to major human access points did not predict cliff community attributes because all parking lots were far enough away from our climbing formations to preclude such an effect.

Avian cliff use

Interestingly, our hypothesis that birds would use the cliff face more often at low-use climbing formations was not supported. High-use sites had a higher average number of scans in which birds were observed on the cliff. This contrasts with existing research which found that birds at popular climbing cliffs were more likely to be located farther from the cliff face while birds at unclimbed cliffs were more likely to be either closer to the cliff or perched on the cliff face [14]. Our results may not align with previous work because of differences in location, recreation intensity, avian community, habituation of species, or landscape effects [6, 43, 44]. Additionally, tolerance to human intrusion varies among avian species [45]. While some birds tolerate or even thrive in areas of high anthropogenic activity, others are more sensitive and will flush quickly upon disturbance and eventually abandon an area that is overly stressful [42]. We hypothesize there may be a greater number or at least a greater percentage of anthropogenic-tolerant avian species in Boulder OSMP compared to JTNP.

Alternatively, physical characteristics of the cliffs themselves could cause differential cliff use by birds between high- and low-use climbing sites. In support of this, we found that aspect was also one of the best predictors of avian cliff use, with birds most frequently observed on north and south-facing cliffs. Avian diversity was higher at east-facing cliffs, a result that was driven by a variety of species and may be related to increased habitat heterogeneity at east-facing cliff sites. Activity patterns, in contrast, may be influenced by just a few species. Indeed, much of the cliff activity came from White-throated Swifts and Violet-green Swallows. Large numbers of these two species perching and nesting on north and south facing cliffs led to higher activity levels despite greater species diversity at east-facing cliffs. It is possible that rock climbers and the swift and swallow species in our area prefer similar cliff features, or that swifts and swallows are more tolerant of humans because they have a larger conspecific group size [44], or that a predator refuge effect is occurring. Other researchers have hypothesized that some species may associate with or tolerate human presence in order to escape from their predators, which are more wary of humans [46, 47]. This may explain why birds used the cliffs significantly more often at high climbing use sites. If humans had no effect on bird cliff use and cliff quality was equal, then we would expect cliff use among climbing use categories to be equal as well. Our results suggest that for some bird species, there may be a benefit of associating with climbers. Notably, raptors, which are sensitive to anthropogenic disturbance [11, 48], were not observed more often at high-use climbing sites. Rock climbing presents a serious threat to these birds because climbers have the ability to access areas in close proximity to nests [49].

Vegetation and arthropods

Overall, our hypothesis that high-use climbing sites would have reduced vegetative cover and diversity was not supported. We did, find that there were more trees at low-use climbing sites, but this trend was non-significant when corrected for multiple comparisons. Lichens, however, do appear to reflect climbing pressure; low-use sites had significantly more foliose lichen cover compared to high-use sites. Our results support other studies which have documented negative impacts of rock climbing on delicate foliose lichens accompanied by a simultaneous increase in crustose lichen cover at climbing sites [50±52]. As such, it provides evidence that our high-use climbing sites did in fact have greater climbing activity than low-use climbing sites, and thus may be subject to disturbances documented in other studies.

We found no difference in either the diversity or biomass of arthropods between low- and high-use climbing sites. However, it is likely that our methods did not capture the full range of arthropod diversity present near cliffs. Because we know of no other studies which have described effects of rock climbing on arthropod diversity, more extensive research examining arthropods inhabiting cliffs is warranted.

We did not find a relationship among bird, plant, and arthropod diversity across sites, suggesting that avian diversity does not depend on the diversity of plants or arthropods located on cliffs within these habitats. In contrast, the abundances of different taxa were related; we found that avian cliff use was positively correlated with arthropod biomass. It's possible that increased invertebrate prey at cliff sites may encourage birds to spend more time at those locations, although it should be noted that two of the commonly observed cliff specialist bird species were aerial insectivores (cliff swallows and white-throated swifts). Because our vegetation and arthropod surveys were done at a limited set of sites, and our collection and identification methods were conservative, we consider these results to be preliminary, and we encourage future study that more completely relates these community factors.

Conclusion

Given our findings, we recommend that land managers combine analyses of human activity with information on habitat variation and species presence to determine which areas may be most affected by recreation. Our model suggests bird communities on north-facing cliffs were less diverse than bird communities on east-facing cliffs, but both of these were minimally affected by rock climbing, while communities on south- and west-facing cliffs were more impacted by human recreation (Fig 4). New climbing routes established on north-facing cliffs may cause less of a disturbance to a relatively lower number of bird species than new climbing routes on other cliff aspects. Furthermore, at least within our system, maintaining areas of high avian cliff use would serve to protect high arthropod and foliose lichen biomass.

The results of our study provide insights into cliff communities and how the organisms associated with them respond to rock climbing. Ecosystem responses may also be influenced by local conditions including dominant vegetation type, climate, landscape topography, and climbing intensity. Therefore, we recommend that more comprehensive studies of climbing impacts, including effects on nesting success, are initiated in different locations, and that they consider the combined influences of natural and anthropogenic factors.

Supporting information

S1 Appendix. Table A. Results of LMM for avian diversity (*H'*) for entire survey area.
Table B. Results of LMM for avian diversity (*H'*) on the cliff.
Table C. Results of LMM for avian species richness for entire survey area.
Table D. Results of LMM for avian species richness on the cliff.

Table E.

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