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Intensity-dependent impact of sport climbing on vascular plants and land snails on limestone cliffs

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ABSTRACT

Limestone cliffs in the Jura Mountains harbour species-rich plant and animal communities including rare species. Sport climbing has recently increased in popularity in this habitat and several studies have reported damage to cliff biodiversity. However, so far how damage levels vary with climbing intensity has not been investigated. We evaluated the effects of climbing intensity on the diversity of vascular plants and land snails in 35 limestone cliff sectors in the Northern Swiss Jura Mountains. Mixed-effects models were used to examine whether species richness of plants and land snails differ between cliff sectors with low and high climbing intensity and unclimbed cliff sectors (controls) taking into account potential influences of cliff characteristics (aspect, cliff height, rock microtopography). At the cliff base, the best fit model revealed that plant species richness was affected by climbing intensity and cliff aspect. Plant species richness was reduced by 12.2% and 13.1%, respectively, in cliff sectors with low and high climbing intensity compared to unclimbed cliff sectors. On the cliff face, plant species richness was only influenced by climbing intensity (species richness reduction by 24.3% and 28.1%). Combining data from cliff base, face and plateau, the best fit model revealed that land snail species richness was only affected by climbing intensity (species richness reduction by 2.0% and 13.7%). In both organism groups, species composition was increasingly altered by increasing climbing intensity. Our study provides evidence that even low climbing intensity reduces cliff biodiversity and that damage becomes more pronounced with increasing climbing intensity.

1. Introduction

Outdoor recreational activities including sport climbing, bouldering (a form of rock climbing on boulders), hiking, and mountain biking have increased enormously in popularity over recent decades (Kuntz and Larson, 2006; Holzschuh, 2016; Tessler and Clark, 2016). Some of these activities are performed in historically inaccessible habitats and thereby increasingly disturb the biota. However, studies assessing the impact of various outdoor activities on the local biodiversity are still rare and their results are inconclusive, partly due to lack of proper controls (Holzschuh, 2016).

Limestone cliffs are globally a rare habitat supporting highly specialized and distinct biotas including lichens, bryophytes, vascular plants, insects and gastropods (Larson et al., 2000; Schilthuizen et al., 2003). The high species richness, large number of rare species and rarity of the habitat type give limestone cliffs a high conservation value (Wassmer, 1998; Baur, 2003; Ursenbacher et al., 2010). The Fauna-Flora-Habitat guidelines of the European Union consider limestone cliffs as habitats of “European importance” (Council Directive 92/43/EEC, 1992). In contrast to large rocky areas of the Alps and other high-elevation mountains, the cliffs of the Jura Mountains in Switzerland are small and isolated, and mostly surrounded by beech forests or xerothermic oak forests (Fig. S1), which have been partly cleared and subsequently used as pasture for some centuries (Moor, 1972). In this landscape at low elevation, the rocky habitats represent islands of special environmental conditions. A variety of organisms living on these cliffs are inter- or post-glacial relics with a recent Mediterranean or Arctic–Alpine distribution (Walter and Straka, 1970).

Rock climbing is very popular in the Jura Mountains in the region of Basel, Switzerland, where this sport can be performed during the entire year (Hanemann, 2000). More than 2000 sport-climbing routes with fixed protection bolts have been installed on 48 rock cliffs of this region (Andrey et al., 1997). Approximately 70% of these sport-climbing routes were opened between 1985 and 1999 (Andrey et al., 1997). The enormous number of climbers has led to conflicts between the goals of nature conservation and recreation activities (Wassmer, 1998; Baur,

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2003).

Damage to vascular plants and lichens due to rock climbing has been recorded on limestone cliffs of the Swiss Jura Mountains (Müller et al., 2004; Rusterholz et al., 2004; Baur et al., 2007), and on other types of rocky cliffs in Germany (Herter, 1993, 1996) and North America (Nuzzo, 1995, 1996; Kelly and Larson, 1997; Camp and Knight, 1998; Farris, 1998; McMillan and Larson, 2002; Clark and Hessl, 2015). Damage includes a reduction of vegetation cover, alterations in the composition of the plant community and local extinction of species sensitive to disturbance and of specialists adapted to these extreme habitats. Clearing of soil from crevices and erosion of the cliff edge and face have also been recorded (McMillan and Larson, 2002; Kuntz and Larson, 2006). Furthermore, human trampling has reduced the above-ground vegetation cover at the base of cliffs and caused significant shifts in plant species composition (Rusterholz et al., 2011).

Climbing-related effects on invertebrate communities have received less attention. McMillan et al. (2003) found that species richness and density of land snails were lower along climbing routes than in unclimbed areas of the Niagara escarpment, and that snail community composition differed between climbed and unclimbed sites. In the Swiss Jura mountains, Baur et al. (2017) found that species richness of live rock-dwelling snails was 61% less in sampling plots along climbing routes than in nearby control plots on unclimbed rock faces, and abundance was 71% less. The complexity of the rock surface had little influence on snail species richness and abundance.

Not all parts of a cliff might be affected in the same way by sport climbing. At the cliff base (or talus), trampling by climbers and people securing the climbers destroys the ground vegetation, reduces the litter layer and the abundance of invertebrates living in it, and compacts the soil (Rusterholz et al., 2011; Fig. S2). On the cliff face, climbers may remove soil, damage vegetation and crush snails when establishing a new route and during ascents (Nuzzo, 1995; Farris, 1998; Adams and Zaniewski, 2012; Fig. S3). The magnitude of these disturbances may depend partly on the microtopography of the cliff face, because soil volume and vegetation abundance increase with the number and size of microtopographic features, such as crevices, cracks, pockets and ledges (Holzschuh, 2016). The cliff plateau is normally not accessed by climbers, because sport climbing routes typically end at the top of the face (Andrey et al., 1997; Fig. S4).

In a recent review of the impact of rock climbing, Holzschuh (2016) criticised the lack of proper controls in some studies and argued that potential differences in slope, aspect, insolation and microtopography between climbed and unclimbed areas were not always considered. Holzschuh (2016) also noted that no study had investigated how climbing effects vary with climbing intensity. Such studies would facilitate improved management of rock climbing areas that are rich in biodiversity and harbour rare and threatened species.

In our study, in the Northern Swiss Jura Mountains, we used a multi-taxon approach (vascular plants and land snails) to examine whether limestone cliffs with low or high climbing intensity differed in species richness, species composition and abundance, and whether they differed from unclimbed cliffs, considering confounding effects of aspect and microtopography of the cliffs. We recorded species richness and species composition of vascular plants and shelled gastropods (land snails) at the base, on the face and on the plateau of 35 cliff sectors. We also examined whether unclimbed cliff sectors and cliff sectors with low and high climbing intensity differ in abiotic factors (complexity of the rock surface, aspect of cliff face, etc.) and in visitor-related aspects (distance to nearest parking area, distance to the city).

In particular, we tested the following hypotheses:

1) The impact of sport climbing on both plant and snail species richness becomes more pronounced with increasing climbing intensity.
2) Plants growing on the plateau are less impacted than those at the cliff base and on the face.
3) Different plant and land snail species are unequally affected by climbing activities. Species-specific responses of plants and snails can be explained by particular life-history traits (or combination of traits).

2. Material and methods

2.1. Study sites

The study was carried out at eight isolated limestone cliffs in the Northern Swiss Jura Mountains, 10–20 km S–SE of Basel (47° 35′N, 7° 35′E; Fig. S5). The cliffs are at elevations of 470–700 m above sea level and 1–25 km apart from each other (Table S1; Fig. S5). They mainly consist of Jurassic coral chalks (Bitterli-Brunner, 1987). The cliff bases are covered by stands of deciduous forests belonging to Fagetum and Tilietum associations (Burnand and Hasspacher, 1999). In this region, the annual temperature averages 9.6 °C and annual precipitation is 1021 mm (MeteoSwiss, 2012).

In the Jura Mountains, most of the cliffs are naturally subdivided by canyons, rock falls or steep forested slopes into several sectors. We investigated the plant and snail diversity in 35 cliff sectors belonging to the eight cliffs (Table S1).

For each cliff sector the following ecological variables were recorded: aspect of the cliff face (in degrees from north using a compass), elevation at the base (in metres above sea level, measured by a GPS receiver and checked against 1: 25000 topographical maps), geographical coordinates (measured with the GPS receiver), average height of the cliff (in m; data extracted from Andrey et al., 1997), and the length of the cliff sector (measured in m at the cliff base).

To assess the complexity of the rock surface (hereafter microtopography) in a cliff sector, we determined the number of fissures (any narrow linear crevices or cracks extending into the rock surface), the number of ledges (any features extending out horizontally from the rock surface), and pockets (solution pockets consisting of roughly circular cavities extending into the rock surface) in 15 plots each measuring 50 cm × 50 cm. Three plots were arranged in a vertical line at heights of 1 m, 1.75 m and 2.5 m, and the five vertical lines were evenly distributed over the length of the cliff sector. We used a semi-quantitative scale of cumulative scores to express rock surface complexity in each plot. The scores considered fissures: (0) no fissures present, (1) total fissure length ≤ 30 cm, (2) total fissure length > 30 cm; ledges: (0) no ledges present, (1) total ledge length ≤ 30 cm, (2) total ledge length > 30 cm, and pockets: (0) no pockets present, (1) total pocket diameter ≤ 10 cm, (2) total pocket diameter > 10 cm. Thus, each plot received a score ranging from 0 (no structure in the rock surface) to 6 (highly structured rock surface). To characterize the microtopography of a cliff sector, we added the scores of the three plots in a vertical line resulting in total scores ranging from 0 to 18 and presented the mean score of the five vertical lines per cliff sector. Our measure of the rock face microtopography relates only to the lower part of the cliff (height 0.5–2.5 m). In contrast, the difficulty grade for climbing (see below) relates to the entire climbing route (length 12–30 m).

Information on the number of climbing routes (indicated by the presence of fixed protection bolts) and their difficulty grade for climbing (French scale) was obtained from Andrey et al. (1997). Information on climbing intensity (three categories) in the different cliff sectors was obtained from climbers (Knecht, 1999): (0) no climbing, (1) low or moderate sport climbing activity (hereafter low climbing activity), and (2) intense sport climbing activity (hereafter high climbing activity). Unclimbed cliffs were mainly situated in nature reserves, in which climbing is not allowed. The categories low and high climbing intensity consider the number of climbing attempts per year on the various routes in each sector (Knecht, 1999). High climbing activity means that a cliff sector is visited almost daily for climbing.

We measured the walking distance from the nearest parking area to each cliff sector using 1: 5000 topographical maps. As a proxy for cliff