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The transformation of the vascular flora of limestone monadnocks by rock climbing

Anna Bomanowska[1], Agnieszka Rewicz[1], Anna Kryscinska[2]

[1]Department of Geobotany and Plant Ecology, Faculty of Biology and Environmental Protection, University of Lodz, Banacha 12/16, 90-237 Lodz, Poland
[2]Smugowa 33/8, 95-200 Pabianice, Poland
knopikaa@biol.uni.lodz.pl

Abstract: The study examines the impact of rock climbing on the richness and diversity of vascular plants in one of the most popular climbing areas in Poland, named the Mirow Rocks. The study assesses the ecological effects of climbing by comparing how the vascular flora differs on climbing routes with respect to level of climbing difficulty, occurrence of protection points, intensity of climbing as well as rock surface smoothing. The results indicate that it is necessary to control tourism and rock climbing in order to reduce their negative impact on species diversity in the vascular flora on rock surfaces. Preservation of the monadnock habitat may be the most important short term management goal.
[Bomanowska A, Rewicz A, Kryscinska A. **The transformation of the vascular flora of limestone monadnocks by rock climbing.** *Life Sci J* 2019;16(8):78-87]. ISSN: 1097-8135 (Print) / ISSN: 2372-613X (Online). http://www.lifesciencesite.com. 10. doi:10.7537/marslsj160819.10.

Keywords: Disturbance; floristic diversity; limestone rocks; karst landscape; recreation; Poland

1. Introduction

The second half of the XXth century brought a dynamic development of tourism movement and services all over the world. Tourism has become not only one of the largest branches of the global economy, but also a determinant of modernity and an indicator of the standard of living (Milne and Ateljevic, 2001). The dynamic development of various types of outdoor recreation has brought increased human interference in nature (Liddle, 1991, 1997; Cole, 1993; Cole and Landres, 1996; Pickering and Hill, 2007; Ines and Torbidon, 2011).

The most significant environmental transformation has taken place in the mountains, where tourism is not subject to significant seasonal fluctuations, and functions with differing intensities almost all year long (Hanemann, 2000). Ecologists have demonstrated the impact of increased tourist activities, i.e. skiing, hiking and cycling, on floristic diversity and vegetation structure in mountain areas all over the world (Thurstone and Reader, 2001; Cessford, 2002; Tsuyuzaki, 2002; Chiu and Kriwoken, 2003; Wipf et al., 2005; Pickering and Hill, 2007; Pickering et al., 2007; Rusterholz et al., 2011; Oishi, 2013). In recent decades, climbing has become one of the most popular forms of mountaineering (Krajick, 1999; Hanemann, 2000; Schuster et al., 2001; Abramson and Fletcher, 2007), especially in the mountain regions at low elevations where there are no seasonal restrictions. Excessive interest in this type of outdoor activity presents a danger to the existence of rock ecosystems, which are often the only habitats for unique species of flora and fauna. Research carried out in Germany (Wezel, 2007; Vogler and Reisch, 2011), Switzerland (Muller et al., 2004; Rusterholz et al., 2004; Baur et al., 2007), Canada (Kelly and Larson,1997; McMillan and Larson, 2002; Kuntz and Larson, 2006) and the United States (Nuzzo, 1995; Camp and Knight, 1998; Farris, 1998) evaluating the ecological effects of rock climbing have focused on changes in the structure and composition of cliff-face vegetation. Climbing has been shown to significantly reduce plant cover as well as species richness and diversity (Camp and Knight, 1998; McMillan and Larson, 2002; Muller et al., 2004; Rusterholz et al., 2004; Kuntz and Larson, 2006). Rock climbing leads to an increase in ruderal and alien species, and to a decrease in rare and endangered species (McMillan and Larson, 2002; Rusterholz et al., 2004). Other disturbances include skewed size and age distributions of individual species (Nuzzo, 1995; Kelly and Larson, 1997; Wezel, 2007; Vogler and Reisch, 2011). A few studies have identified significant changes in lichen biota to be associated with climbing (Farris, 1998; Baur et al., 2007).

In Poland, the best place to try this extreme outdoor activity is the Krakow-Czestochowa Upland (Krakow-Czestochowa Jura). The Krakow-Czestochowa Jura as a belt of hills with elevations between 300 and 500 m a.s.l., and is the most typical karstland of Poland (Partyka, 1992; Alexandrowicz and Alexandrowicz, 2003). A characteristic landscape element is formed by limestone rocky crags, often with medieval castle ruins positioned on top of them, as well as numerous caves and erosion valleys. Because of the unique shape of the monadnocks and their relatively small size, together with the occurrence of many climbing routes with different difficulty levels. The upland has an extraordinarily rich and varied flora, comprising 1441 permanently naturalized species. The area supports unique and diverse plant communities. The great richness of plant species, the rarity of the habitat type and the historical peculiarity give the limestone monadnocks a high conservation value (Urbisz, 2008; Urbisz et al., 2011).

Until 1989, rock climbing did not constitute any serious threat for the limestone monadnocks as contemporary legal restrictions permitted only sport clubs and Tourist and Sightseeing Society members to practice it (Pawlusinski, 2007). However, climbing activity has increased dramatically during recent decades, which poses a threat to the plant cover of the region. Although the impact of climbing on flora and vegetation in the Polish Jura is visible and still increasing, no botanical studies performed on this area have yet addressed this problem. Existing floral studies, including i.a. Urbisz (2008), Urbisz et al. (2011) and the literature cited therein, focus mainly on the phytogeographic and syntaxonomic problems faced by the plant cover. The main reason for the lack of work concerning the impact of rock climbing on flora and vegetation is the difficulty associated with making an inventory of climbing habitats, which can only be done by a person who is capable of climbing and using specialized equipment. Nevertheless, an examination of this issue seems to be particularly important because of the strong need to protect the rock flora against the effects of such considerable growth in the popularity of climbing tourism. One of the most well-known and respected places for climbing in the area of the Krakow-Czestochowa Jura are the Mirow Rocks.

The preponderance of existing studies on the impact of climbing disturbance compare climbed and unclimbed cliffs without any detailed analysis of the different aspects of the disturbances caused by climbing, such as the difficulty level of the routes or the occurrence of protection points. This study examines the ecological effects of climbing by comparing the vascular flora of climbing routes which differ in terms of difficulty level, occurrence of protection points, intensity of climbing as well as rock surface smoothness. It focusses on the impact of rock climbing activity only within climbing routes. In particular, the vascular flora of examined climbing routes is characterised, with the aim of answering two key questions: i) do climbed and unclimbed monadnocks differ in plant richness, and ii) does the difficulty level, climbing intensity and the type of the safety devices used by climbers affect the richness of rock flora? The overall aim of our study was to provide basic ecological information to be used in further detailed studies and conservation proposals intended to limit the negative impact of climbing on specialized rock flora.

2. Material and Methods

Site description

The study was carried out in the Mirow Rocks, located in the northern part of the Krakow-Czestochowa Jura (50^0 614’105’’ N, 19^0 475’098’’ E) in the Niegowa municipality (Fig. 1). This mountain range covers an area of 0.8 km^2 and extends from west to east in the form of a rocky belt (1.5 km length) formed by rocks, singly or in groups, reaching up to 360 m a.s.l. Within an area of less than one km^2, there are 114 climbing routes (Haciski, 2002).

Figure 1. The study area

The climbing routes in the Mirowskie Rocks are vary considerably with respect to the 6-point difficulty scale used by the Polish Mountaineering Association, which was worked out in the 1970s especially for describing short climbing routes on limestone rocks on lower formations such as the Krakow-Czestochowa Jura (Haciski, 2002). According to this scale, levels I-III represent the easiest route that can be taken without protection or mountaineering experience. Levels IV-VI.1 represent routes of medium difficulty, for beginners and intermediate climbers, and a score of VI.2 represents routes of great difficulty requiring an acquaintance with advanced climbing techniques. Climbing routes in this area are range from easiest (I-III) to very difficult (VI.5; Haciski, 2002). Most routes (72%) are considered easy and the medium difficult and they are very popular among novice climbers. In recent years, numerous climbing routes have been equipped with protection points, so called certified rings, and so have become available to a greater number of climbers. Amateurs prefer the use of top-roping, the easiest and safest way of climbing, which involves the establishment of the rappel stance on the top of the rock with the climber using their own climbing tapes and ropes with natural anchors like rocks or other monadnock elements. On the other hand, experienced climbers often use so-called belays, with a capacity of about one ton, without top-roping to penetrate a large part of the rock, despite the overload.

Sampling methods

The impact of rock climbing on the vascular flora of six different Mirow Rocks cliffs was assessed. For floristic investigations, six climbing routes (referred to as A-F, Table 1) were chosen on cliffs with similar exposures and insolations, but different categories of difficulty and climbing intensity. Three routes with top-roping were chosen in which there are no fixed protection points (belays) like hooks and spits (not secured, A-C) and three routes that are equipped with certified rings (fully secured, D-F). In addition, a rock which had not been used by climbers before was chosen as a control (G). As well as the level of difficulty, all the routes certified by the Polish Mountaineering Association have also been described with regard to the slipperiness (smoothing) of the rocks and the intensity of climbing activity.

Table 1. Description of climbing routes investigated in Mirowskie Skały (Krakow-Czestochowa Jura)

Route	Name	Exposure	Climbing protection	Difficulty level	Smooth of rock	Climbing intensity
A	Filarek baranka	NW	N	V+	2	2
B	Droga zejściowa	S	N	III	4	2
C	Lewa rysa	E	N	V+	3	4
D	Ludzie silnej woli	E	U	VI 2/2+	3	2
E	Bez nazwy	E	U	VI	3	4
F	Ringi kursowe	E	U	IV	4	5
G	„Control”	E	unclimbed	VI+	1	1

Rock smoothness reflects the intensity of exploitation of a given route and was evaluated on the basis of limestone surface polishing by climbing shoes and rope. A scale from 1 to 4 based on visual evaluation is used for this purpose, where 1 signifies that slipping is non-existent, 2 – low, 3 – strong, 4 – very strong. The division is based on the number of people climbing a given route: 1 – lack of climbing activity (0 climbers), 2 – rarely frequented (1- 4 climbers/day), 3 – often (4- 10 climbers/day), 4 – very often (10-15/day), 5 – commonly used (<15 climbers/ day). Samples were taken in 2007 to coincide with the flowering season of the vascular plants.

The floral inventory was assembled by rappelling for each of the designated routes (Fig. 2, Table 1) by the climbing method (the climbing zip line). On the routes equipped with belays (rings or spits) and the rappel stance, the inventory started from the above mentioned rappel stance installed at the top and ended at the foot of the rock. In the case of routes that did not have fixed belay points, a new rappel stance was installed in accordance with the methods of rock climbing. Omitting the top was necessary for the maintenance of established research methods, which require only plant species growing within the climbing route to be listed.

Sampling methods

Each of the tested climbing routes (A-G) was treated as a single sampling plot. Due to the method of collecting the floral samples included in the analysis, the data on species occurrence was encoded in a binary fashion (0-1, absent-present) without taking into account any degree of quantitative occurrence.

The nomenclature of vascular plants and species status in Poland is based on (Mirek et al., 2002). For particular species, (*sensu* Raunkiaer) classification is based on Zarzycki et al. (2002). The analysis included groups of species identified as being specific to the limestone monadnock habitat: thermophilic species (xerotherms *sensu* Urbisz, 2008) and specialized rock species (litophytes *sensu* Urbisz et al., 2011). Moreover, the presence of regionally endangered species and legally protected species, chosen according to Hereźniak (2002) and current Regulation of the Polish Minister of Environment on 05 January 2012, was taken into account.

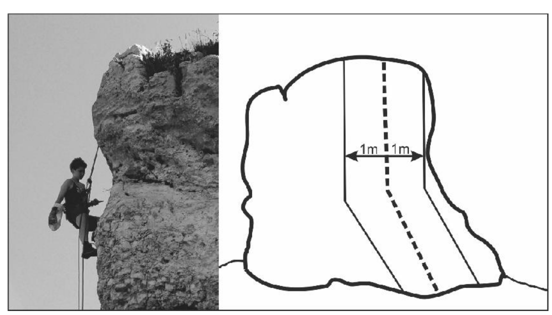

Figure 2. The inventory method

To characterize habitat requirements, the ecological indicator values of Zarzycki et al. (2002) were used. Those ecological indices are similar to those of Ellenberg et al. (1992), but were developed exclusively for Polish vascular flora, and are thus more accurate for our study. Six ecological factors were used based on Zarzycki et al. (2002): L – light value (1 = full shade, to 5= full sun), T – temperature value (1 = cold conditions, mainly found in alpine and subnival zones, to 5 = warmest habitats), W – soil moisture value (1 = very dry soils, to 6 = aquatic habitats), Tr – soil trophic value (1 = extremely poor, to 5 = extremely fertile), D – soil granulometric value (1 = rocks and rock crevices, to 5 = heavy clay and loam), H – organic matter content value (1 = soil poor in humus, to 3 = soil rich in organic matter). The average indicator values were calculated on the basis of the abundance of individual plant species for each sampling plot (climbing route).

For each species recorded in this study, its relative frequency of occurrence (Brower and Zar, 1984) and rarity coefficient were calculated (Géhu, 1979).

Frequency (*Fi*) was calculated according to the formula:

$Fi = (j_i / k) \times 100$ %, where: j – the number of road, in which species ‘i’ was recorded, and k – the total number of road.

The rarity coefficient of a species (*Wr*) was calculated according to the formula:

$Wr = (N-n) / N$. Where: *N* – total number of road, *n* – number of road in which the species occurs.

An rarity coefficient of 0 indicates a stable species, that is one which occurs in all of the plots, and values close to 1 indicate occasional species. Absolute values of *Wr* were transformed into relative values through division into one of five classes of rarity based on the proportional ranges: I (*Wr* 0.8-0.99), II (0.6-0.79), III (0.4-0.59), IV (0.2-0.39), V (< 0.2).

Floral richness and diversity of the climbing routes was estimated on the basis of the absolute number of species in each study route and the floristic value (*Wf*; Géhu, 1979). The floristic value was calculated for each sampling plot according to the formula:

$Wf = \sum Wr$. where: *Wr* is the rarity coefficient of a species.

The similarity of plant species diversity between the study climbing routes was evaluated using the Jaccard similarity coefficient (C_J).

For a statistical analysis of the data, MVSP ver. 3.2 software was employed. Descriptive statistics were used to compute summary values such as mean values and standard deviations.

3. Results

Overall, on all of the seven examined climbing routes, 63 species of vascular plants were recorded, which constitutes 23.2 % of all of the species growing in the Mirow Rocks area. (Kryścińska unpublished), the great majority of which (61; 97%) are native species. Only two alien species were found: *Convolvulus arvensis* (route G) and *Fallopia convolvulus* (route C). The general number of species included also 17 litophytes and xerotherms (27.0%). Additionally, 7 species (11.1%) which are either vital for the region, protected or endangered have been recorded: *Cystopteris fragi*lis (R), *Frangula alnus* (protected, R), *Gymnocarpium robertianum* (R), *Jovibarba sobolifera* (protected, V), *Libanotis pyrenaica* (R), *Polypodium vulgare* (protected, R), *Ribes alpinum* (R). With regard to life-form, hemicryptophytes flora prevailed (40, 63.5 %) over other life-forms seen on the climbing routes: chamaephytes (8, 12.7%), nanophanerophytes (8, 12.7%) and geophytes (5, 7.9%). Only two species of therophytes were recorded – *Chaenorrhinum minus* and *Fallopia convolvulus* (Table 2).

Table 2. Effect of rock climbing on the various properties of the flora of studied climbing routes

	Non protected routes N=3	Protected routes N=3	Unclimbed (control) N=1
Number of all species	23 ± 11.26943	9.7 ± 7.094599	43
Number of litophytes	6.33 ± 0.57735	3.66 ± 4.041452	12
Number of xerotherms	7.33 ± 2.081666	0.33 ± 2.08166	14
Number of valuable species	2.66 ± 2.081666	1.0 ± 0.57735	6
Floristic value (WF)	12.9 ± 7.883635	4.6 ± 3.719816	26.5
Ecological indicator values			
Light (L)	4.3 ± 0.296884	4.2 ± 0.296827	4.2
Temperature (T)	3.8 ± 1.033383	3.7 ± 1.033340	3.7
Soil moisture (W)	2.2 ± 0.682630	2.2 ±0.682629	2.2
Trophy (Tr)	2.9 ± 0.062128	2.9 ±0.062568	2.9
Soil gran. (D)	3.0 ±0.101057	2.7 ±0.099903	2.8
Organic matter content (H)	1.9 ±0.091854	2.0 ±0.091948	1.9

The analysis of plant species frequency measured in all studied routes revealed a group of species that occur in most of the investigated areas. The most frequently occurring plant was the highly specialized rock species *Asplenium ruta-muraria,* registered in all study plots (*Fi* =100%; *Wr* < 0.2), and *Potentilla neumanniana* recorded in two routes (*Fi* = 86%; *Wr* < 0.2). Moreover, xerotherms were also found to be common: *Acinos arvensis*, *Jovibarba sobolifera* and *Thymus pulegioides* (5 routes; *Fi* = 71%; *Wr* = 0.28). *Asplenium trichomanes, Festuca rubra* and *Poa pratensis* (4 routes; *Fi* = 57%; *Wr* = 0.43) were recorded on four routes. The majority of constituted species (24) grow only on one route (*Fi* = 14%; *Wr* = 0.86) three of which are *Polypodium vulgare*, *Rosa canina* and *Verbascum lychnitis.*

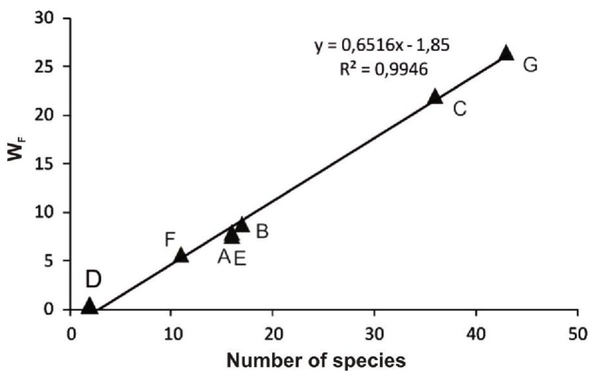

Figure 3. Linear correlation between number of species and floristic value (*Wf*). A, B, C… G – signature of climbing route

The richest and the most varied vascular flora occurred on the control route (G) which was marked up on a rock never used for climbing activity (Table 2, Fig. 3). It was found to have the most species in general (43), as well as litophytes (12), xerotherms (14) and others important for the region (6). This route was also characterised by the highest floristic value (*Wf*=26.5). Only on that unclimbed route were found *Arabis glabra, A.hirsuta*, *Ribes alpinum, Rubus idaeus, Senecio jacobaea, Seseli annuum, Silene vulgaris* and *Verbascum lychnitis*. All of the examined climbing routes were floristically poorer than the control route, in that they possessed smaller numbers of species and lower floristic values *Wf* (G; Table 2, Fig. 4).

Among the examined climbing routes, excluding the control route, the greatest species richness (36 species; *Wf* = 22) was characterized by the C route (difficulty level V+), which ran up highly slippery rock (4) with a high intensity of climbing activity (4). By contrast, for route A (difficulty level V+), was characterised by a low rock slipping value (2) and was rarely frequented (2), fewer species were recorded (16) and the floristic value *Wf* for that route amounted to 7.94. On the insecure routes (A-C), between 16 and 36 species were recorded (mean 23), and the mean indicator value *Wf* for those routes amounted to 12.9. The secured climbing routes (D-F), however, were poorer in terms of flora, between 2 and 16 species were recorded there (mean 9.7), and the medium values of *Wf* indicator amounted merely to 4.6. The smallest number of species from all of the examined plots were recorded on secured route D: only 2: – *Asplenium ruta-muraria* and *Poa pratensis*.

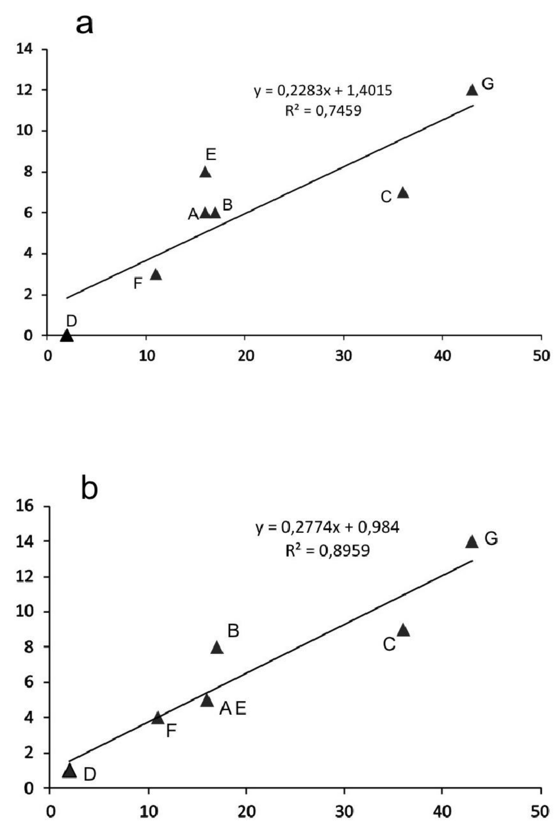

Figure 4. Linear correlation between number of species and number of litophytes (a) and between number of species and number of xerotherms (b). A, B, C…G – signature of climbing route

On the floristically richer insecure routes, species typical of the limestone monadnocks habitat occurred: between 6 and 7 litophytes were recorded (mean 6.33) and between 5 and 9 xerotherms (mean 7.3). Similarly, specialized rock species and xerotherms were found less frequently on secured routes: 3.7 and 0.3, respectively (Table 2). The similarity of plant species diversity coefficient (C_J)

values established in the study routes was rather low (Fig. 5). The highest coefficient values, with regard to all species and xerotherms, were revealed in terms of routes: A (V+, insecure), E (VI, insecure) and B (III, insecure), as well as routes C (V+, insecure) and G (control route), which constituted two distinct groups. The lowest similarity was between the routes D (VI.2/2, secured) and F (IV+, secured). In case of lithophytes, the highest coefficient values were revealed between routes B, C and G, yet in a similar manner, routes D and F differed from the others (Fig. 5).

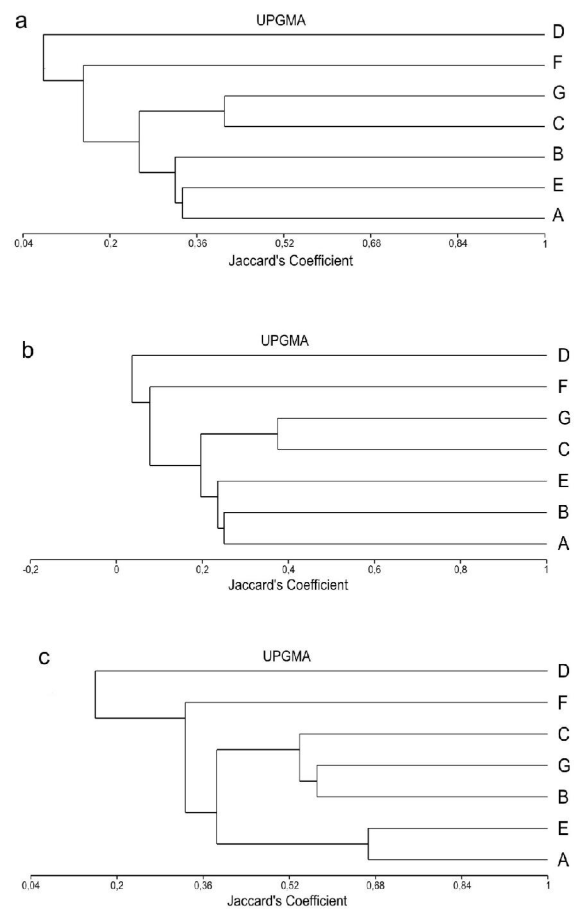

Figure 5. Floristic similarity of rock climbing routes of Mirowskie Skaly: a – all species, b – xerotherms, c- litophytes. A, B, C…G – signature of climbing route

However, the compared climbed routes did not differ in any of the indicator values, confirming that both areas provide similar conditions (Table 2). In addition, the values of selected ecological indicators for climbing routes did not differ from those of the control route. Based on the analysis of mean values of ecological indices, all sapling plots (routes) may be characterized as dry (W=2.2), moderately poor (Tr=2.9), moderately poor in humus (H=1.9), with a moderately cool/moderately warm favourable thermal regime (T=3.8), with the dominance of plants occurring chiefly in full light (L=4.3), which are well adapted to the rocky and sandy soils (D =3.0).

The correlation between the floristic richness and the fracturing of the rock surface was not very strong and statistically not significant in all cases, as were the correlations between floristic richness and the level of route difficulty, as well as those found between floristic richness and intensity of climbing.

4. Discussions

The study showed that vascular flora of limestone monadnocks in the area of Mirow Rocks are strongly affected by rock climbing. Thus, our work supports other studies on changes in plant richness and species diversity due to climbing activity (Nuzzo, 1995; Kelly and Larson, 1997; Camp and Knight, 1998; Farris, 1998; McMillan and Larson, 2002; Muller et al., 2004; Rusterholz et al., 2004; Kuntz and Larson, 2006; Baur et al., 2007; Wezel, 2007; Vogler and Reisch, 2011). Our study showed rock climbing to have a negative impact on species richness on the climbing routes. Most of species found on the limestone rocks in Polish Jura Chain are typically perennial rosette plants with short-range dispersal and high reproductive effort (Urbisz, 2008, Urbisz et al., 2011). On the rocks which are devoid of any human interference, the hands and feet of climbers do not destroy the thin layer of soil and humus which assist in plant colonization and survival of greater species numbers. It has also been observed that on the rock not used by climbers, plant were higher, more specimens were present and they were found in all of the available microhabitats on the whole rock surface. There is no denying that climbing causes disturbances which result in transformations within the rock plant community. Frequently used climbing routes may divide populations of specialized rock plants, and due to the limited dispersal of their seeds, the plants might not be able to cross these gaps, with the consequence that these species will be replaced by other, mainly eurytopic, common species. On the rocks used for climbing, the plants only occurred in crevices and cracks, and usually as single specimens, they did not form any clumps and were smaller. These plants were mainly perennial herbaceous specimens, hemicryptophytes, tolerant of human disturbance, for example *Achillea millefolium, Plantago media,* and *Poa compressa*, which can successfully survive and reproduce, irrespective of the presence of climbers. According to Muller et al. (2004) the occurrence of trampling tolerant species in the area of climbing routes, indicated by a high degree of disturbance at these sites, may prevent any successful colonization of true rock plant species.

Our results suggest that the impact of climbing on the vascular flora of monadnocks varies according to different levels of climbing use. Similar findings have been reported for cliffs at Joshua Tree National Park in California (Camp and Knight, 1998) and the dolomitic limestone outcrops of the Niagara Escarpment in Southern Ontario (Kuntz and Larson, 2006). The most prominent negative impact of climbing on vascular plants has been observed on secured rocks at low difficulty level. The routes fitted with fixed belay stances, on the whole, presented a poorer flora, both globally as well as litophytes and xerotherms, when compared to the insecure routes. This could partly be explained by the fact that during the installation of a climbing route, part of the vegetation is removed to create additional hand and foot holds (Kelly and Larson, 1997; Camp and Knight, 1998; Rusterholz et al., 2004). Moreover, fitting stable anchors and rappel stances makes climbing significantly easier, which results in a greater number of ascents in the case of secured rocks. The number of plant species decreased with increasing climbing use. This was particularly noticeable on the example of a route called “Ringi kursowe” (F). This is a secured route fitted with stable anchors, such as rings and spits, as well as a rappel stance, which gives novice climbers without specialist equipment a chance to climb. For that reason, the route is used by climbing instructors for teaching climbing, and is almost always chosen for the beginner climbers. The large number of climbers clean the rock of any dust, soil particles, and stone debris. In this way, the microhabitat for highly specialized plant species is destroyed. As a consequence of such intensive usage, the level of rock slipping is very high and influences the rock plants in a negative manner. On this route, only a handful of specimens have been recorded, *Hypochoeris radicata, Chaenorhinum minus* and *Achillea millefolium* among others, all of which are represented by single specimens clustered mainly in crevices and cracks: places where a “climber shoe” does not reach. A similar phenomena of dwindling numbers of species and individuals on rocks where heavy climbing takes place has been observed by Camp and Knight (1998) and Müller et al. (2004). Likewise, Rusterholz et al. (2004) report that the frequent use of the same climbing route may damage the remaining plants growing in crevices and cracks. Our results concur with those of Farris (1998) and Kuntz and Larson (2006) who found that floral differences were not only related to climbing disturbance, but they also reflected microsite differences between monadnocks selected by climbers. The fracturing of the rock surface determined plant richness and diversity on the climbing routes. Fractured rocks contain more soil and exhibit a higher microclimatic diversity than smooth cliffs and therefore harbor greater plant species richness (Müler et al., 2004). A smooth rock surface impedes not only plant colonization and growth, but also makes climbing more difficult. On less porous rocks, whose surface is almost smooth and frequently resembles an ice sheet, routes with the highest level of difficulty have been marked up. As a consequence, rocks with a very high difficulty level such as the route “Ludzie silnej woli” (D, high difficulty level VI.2/2+) are almost totally bereft of plants. Even though only few advanced climbers make use of it, it is still characterised by exceptionally poor flora. Merely two plant species represented by single specimens have been recorded there. Such a low number of specimens is the result of difficult habitat conditions which stem from rock build and structure, and its exploitation for climbing. The survival of only two species depends to a great extent on whether they may be removed mechanically, and to a lesser extent, on natural factors such as rivalry for one crevice.

Our results contradict those of McMillan and Larson (2002), Rusterholz et al. (2004) and Kuntz and Larson (2006), who found that climbed rocks support a greater share of alien species. In our study, only two alien species were found. What is more, our results indicate that despite strong human pressure and considerable floral modification, climbing rocks are still the mainstay of valuable elements of the flora. Some plants identified on the climbing routes examined in this study have, according to the Regulation of the Polish Minister of the Environment 2012, almost protected status in Poland: *Frangula alnus* (routes: C, G), *Jovibarba sobolifera* (A-C, E, G), *Polypodium vulgare* (C). Some are regionally rare (according to the Hereźniak, 2002): among others *Cystopteris fragilis* (routes: C, F, G), *Gymnocarpium robertianum* (C, G), *Libanotis pyrenaica* (B, G), *Ribes alpinum* (G). Among the most valuable flora are specialised rock and grassland species which are linked to the particular limestone monadnock habitats. Hence, it might be supposed that to a certain degree, rock climbing influences the flora of explored habitats in a positive manner by restricting the process of secondary succession, and gives xerothermic grasslands the character of an antropoclimax community (Urbisz, 2008). Many years of self-observation of the Mirów Rocks indicate that on the monadnocks which are not used for climbing, xerothermic grassland flora and, to a lesser degree, rock flora undergo transformation: photophilic species make place for, are blocked out or darkened by developing brushwood.

Some authors (Farris, 1998; Kuntz and Larson, 2006) stress the strong influence of environmental factors on rock habitats. As environmental factors are the primary determinants of the rock flora, differences in species number, and species composition could also be a result of differences in abiotic conditions. In the present study, however, investigated rocks did not differ with regard to these factors. It was found that the mean indicator values given by Zarzycki (2002) did not differ between the studied climbing routes, indicating that all plants were exposed to similar environmental conditions, no matter which route they were on. Alternatively, these environmental variables may not be the key factors for the existence of monadnock plants. These results are consistent with trends observed by Rusterholz et al. (2004).

The conducted study shows that the differences identified between the investigated climbing routes are likely based on a combination of rock morphology and climbing pressure, as partially confirmed by Farris (1998).

5. Conclusions

1. The rocks which are often frequented for climbing are characterised by poorer vascular flora than that seen on unexploited rocks. The differences are linked to the number of taxa on a given climbing route as well as floristic composition of the examined routes.

2. Secured routes fitted with fixed anchors (rings, spites) and rappel stances are characterised by much poorer flora in comparison to insecure routes.

3. The routes awarded high difficulty levels are characterized by lower numbers of species when compared to routes given lower difficulty ratings, as a result of rock structure.

4. Rock climbing has got the biggest impact on secured rocks at a lower difficulty level.

Corresponding Author:
Dr. Anna Bomanowska
Department of Geobotany and Plant Ecology
Faculty of Biology and Environmental Protection
University of Lodz
Banacha 12/16, 90-237 Lodz, Poland
E-mail: knopikaa@biol.uni.lodz.pl

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8/16/2019