

**BRYOPHYTES AS INDICATORS OF NATURAL VALUES ON MINERAL
WORKINGS AREAS – A CASE STUDY FROM LIMESTONE QUARRY
“GÓRAŹDŹE” (OPOLE PROVINCE, POLAND)**

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ABSTRACT: In 2012 investigations using bryophytes as indicators of natural values were carried out in the limestone quarry “Góraźdże” located in Opole Province in southern Poland. As a result the localities of 64 species and two varieties of bryophytes were found, including 17 species protected in Poland and threatened in Europe, Poland and Opole Province. Three protection worth places were distinguished. Using Shannon-Wiener index it was established that biodiversity in restored parts of excavation is higher than in natural neighbouring forest. Comparison between intensively and extensively restored areas demonstrated, that the last way is more effective from the point of view of the biodiversity.

KEY WORDS: bryophytes, mosses, liverworts, bioindicators, biodiversity, distribution, Góraźdże, Opole Province, Silesia, Poland

Introduction

Bryophyta species are a significant, yet a poorly researched plant group. They play an important role in various ecosystems. As taxonomically differentiated organisms and stenobionts (in terms of various ecological factors), they are used as bioindicators, e.g. of heavy metals contamination, atmosphere contamination with sulphur and nitrogen oxides, ecosystems' naturalness, etc. The investigation carried out in the “Góraźdże” quarry allowed to:

- (a) determine the diversity of quarry bryophytes, with special regard to protected and endangered species, which will contribute to better understanding of such areas biodiversity,
- (b) work out the moss species protection methods within areas where mineral resources are exploited; the methods will help to preserve this piece of natural heritage of Opole Province,

(c) modify some of the restoration process stages, which will create appropriate conditions for endangered and protected species development.

It is necessary to emphasize the fact that the moss species protection policy within areas where mineral resources are exploited has not been realised yet. The supporting company was the pioneer institution taking part in this kind of project.

Description of the project

The project assumed a full inventory of moss flora resources in the area of the limestone quarry “Górażdże”, collecting all the available habitat parameters for particular species and elaboration of recommendations for their effective protection, with a special attention to the so called ‘key species’, i. e. threatened and legally protected in Poland. The main goal of this project is to answer the following questions:

1. What threatened and legally protected bryophytes occur in the limestone quarry?
2. What are the habitat conditions of these species?
3. Do places worth protection exist in the quarry?
4. Which way of restoration is the best from the point of view of conservation of local biodiversity?

Methods

Investigations were carried out from March to September 2012. During the field work for each location of a ‘key species’ the following information was gathered:

- 1) Microhabitat.
- 2) Plant community.
- 3) Reproduction.
- 4) Light intensity.
- 5) Degree of moisture.
- 7) Abundance of population.

The particular locations were determined with the use of geographical coordinates obtained from the GPS receiver. Distribution analysis of the ‘key species’ allowed to designate the most valuable places from the bryological point of view in which permanent plots were established.

The botanical nomenclature follows: Ochyra *et al.* (2003), mosses, and Klama (2006a), liverworts. Protected species in Poland are given after ‘The Order of the Minister of the Environment’ (Anonymus 2012), threatened species in Poland are given after Klama (2006b) and Żarnowiec *et al.* (2004), in Europe Schumacker and Martiny (1995) and in Opole Province Stebel (2006).

To examine changes in biodiversity, seven investigation plots were established. They represent main stages of lime exploitation and land restoration. In order to compare bryofloristic patterns in natural and semi-natural habitats, two plots were located in the “Kamień Śląski” nature reserve and in managed forest between the reserve and the quarry, respectively (Fig. 1).

In particular plots Shannon-Wiener index of general diversity H' were calculated.

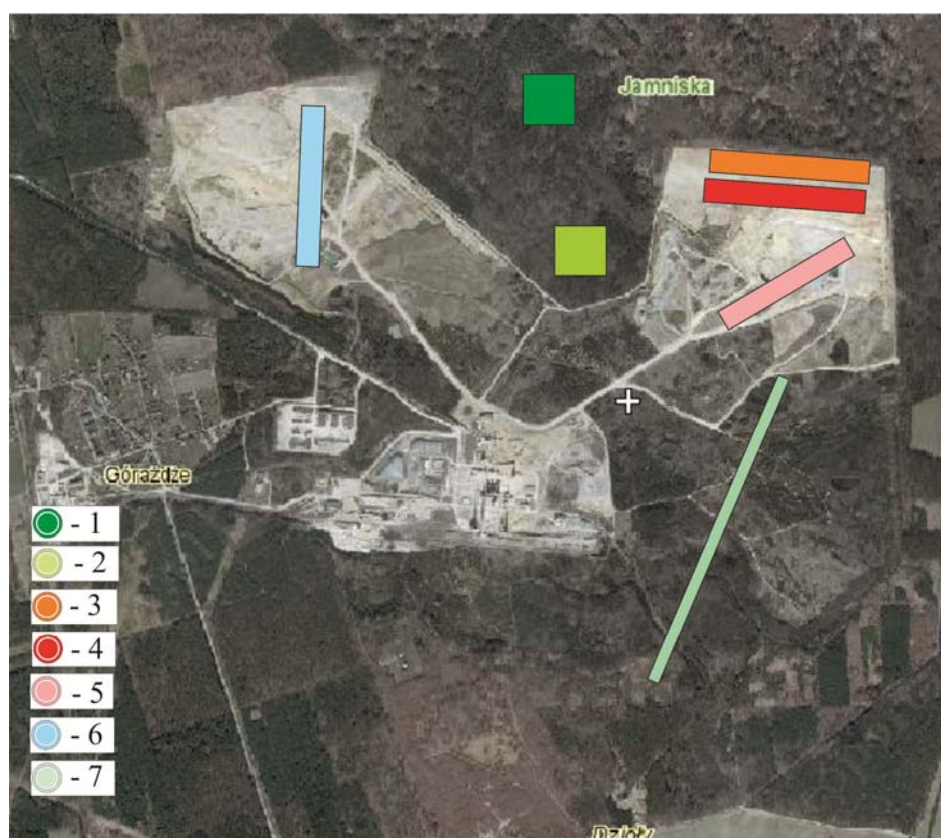


Fig. 1. Distribution of investigation plots: 1 – “Kamień Śląski” nature reserve, 2 – managed forest, 3 – area prepared to exploitation, 4 – area of exploitation, 5 – intensive land restoration, 6 – extensive land restoration, 7 – restored area.

Results

General remarks

The bryoflora comprises 62 species and 2 varieties, including 17 species protected in Poland and threatened in Europe, Poland and Opole Province. (Table 1). As in most local floras, the analysis of frequency showed that the largest groups were the very rare (46.9%) species. Sporophytes were observed in 18 species (28.1% of the bryoflora) and gemmae in 1 (1.6%).

Interesting components of the bryoflora

Among the bryophytes found in the limestone quarry “Górażdże”, the following species deserve special attention:

Marchantia aquatica – rare liverwort of damp habitats. At present the only locality in the whole Opole Province (Fig. 2).



Fig. 2. Thallus of *Marchantia aquatica* in the “Górażdże” limestone quarry (photo A. Stebel, 2012).

Leiocolea badensis – small liverwort connected with open, wet lime soil. In Opole Province known from a few localities, all located in abandoned limestone quarries. Species threatened in Poland.

Orthotrichum patens – rare epiphytic moss, known from a few localities in Opole Province. Species threatened in Europe and Poland.

Philonotis calcarea – fairly frequent in mountains, very rare in lowlands moss of mire habitats. At present the only locality in the whole Opole Province. Population very abundant. Species protected in Poland (Fig. 3).



Fig. 3. Turf of *Philonotis calcarea* in Górażdże limestone quarry (photo A. Stebel, 19 May 2012).

Philonotis marchica – very rare moss of mire habitats, occurring in scattered localities in Poland. At present the only locality in the whole Opole Province. Population abundant. Species protected and threatened in Poland.

Places worth protection

On the area of limestone quarry “Górażdże” three places are worth protection. They are:

1. N 50° 31' 45.73"; E 18° 02' 28.75"; Bryological values: *Leiocolea badensis* and *Philonotis calcarea*.
2. N 50° 31' 52.90"; E 18° 02' 43.80"; Bryological values: *Marchantia aquatica*.
3. N 50° 31' 19.82"; E 18° 00' 59.26"; Bryological values: *Philonotis marchica*.

Bryophytes as indicators of environmental changes

General characteristics of the investigation plots

The first plot was marked out in the 'Kamień Śląski' nature reserve (N 50° 32' 11.90"; E 18° 01' 57.30") with well-preserved forest bryoflora and many species considered as a 'relics of primeval forests', e.g. *Anomodon attenuatus*, *Homalia trichomanoides*, *Porella platyphylla* and *Serpoleskea subtilis*. Second plot was located in the managed forest (50° 32' 03.5"; E 18° 02' 08.80") in which common forest species predominate, e. g. *Brachythecium rutabulum*, *Hypnum cupressiforme* and *Plagiomnium cuspidatum*. Third plot was in the area prepared for exploitation (50° 32' 15.20"; E 18° 02' 30.40") with very low biodiversity (only three species were observed: *Barbula convoluta*, *Ceratodon purpureus* and *Didymodon fallax*). Fourth plot was located in exploitation area (50° 31' 58.22"; E 18° 02' 35.46"). It was a 'bryological desert' - lack of species. Fifth plot was in the land with intensive restoration (50° 31' 56.00"; E 18° 02' 47.3") where succession started and first bryophytes appeared, e.g. *Aneura pinguis*, *Ceratodon purpureus*, *Cratoneuron filicinum*, *Dicranella varia* and *Didymodon fallax*. Sixth point was in the land with extensive restoration (50° 32' 19.82"; E 18° 00' 59.26") where succession also started with such bryophytes, as *Aneura pinguis*, *Ceratodon purpureus*, *Dicranella varia*, *Didymodon fallax*, *Orthotrichum anomalum* and *Philonotis marchica*. Finally, the seventh point was located in restored area (50° 31' 34.84"; E 18° 02' 47.14") where new plant associations arose with such bryophytes, as *Fissidens taxifolius*, *Hylocomium splendens*, *Leptodictyum riparium*, *Orthotrichum diaphanum*, *Orthotrichum pumilum*, *Oxyrrhynchium hians*, *Plagiomnium affine* and *Pseudoscleropodium purum*.

Changes in biodiversity

Calculated Shannon-Wiener indices show, that biodiversity varies, from relatively high in the Kamień Śląski nature reserve to zero in exploitation area, in restored area it reaches the highest value. Two observations are remarkable:

1. In extensively restored areas biodiversity is higher than in these with intensive restoration (Fig. 4).
2. Biodiversity in restored areas is higher than in the natural areas (in this case in the "Kamień Śląski" nature reserve). Of course, the character of the bryoflora is different and in the nature reserve hemerophobous species predominate, whereas in the restored areas mainly hemerophilous bryophytes occur.

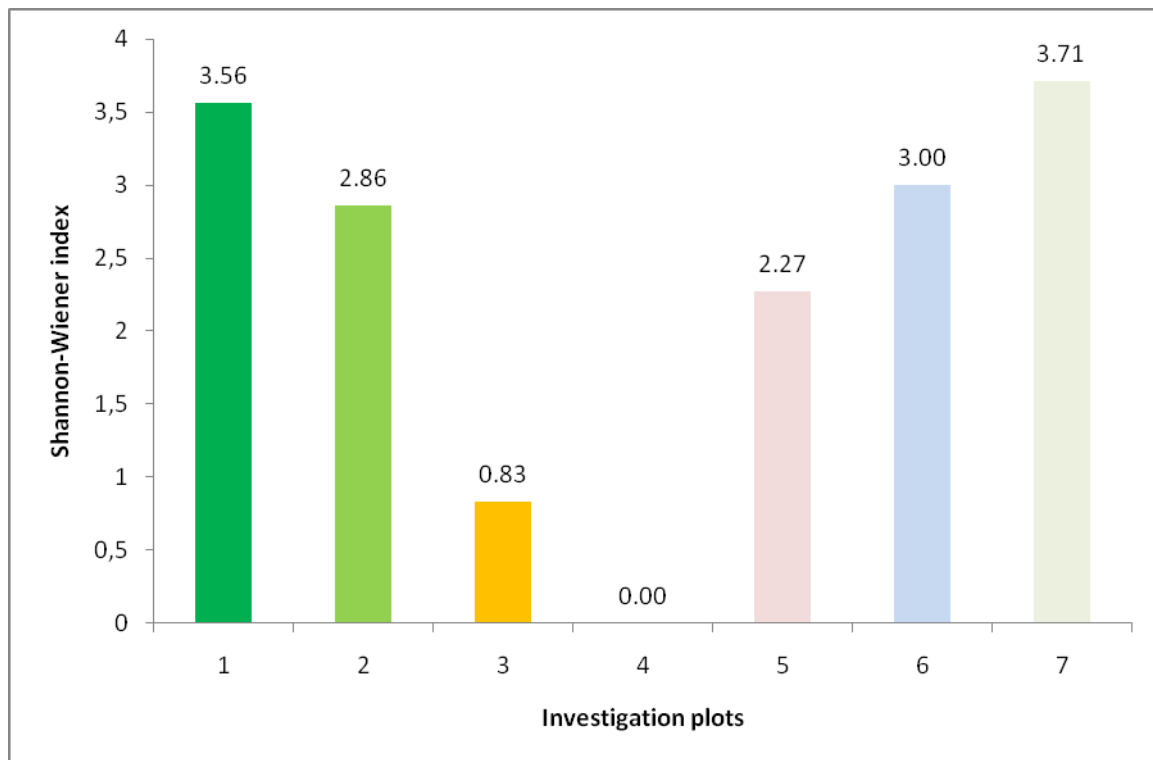


Fig. 4. Changes in biodiversity. 1 – Kamień Śląski nature reserve, 2 – managed forest, 3 – area prepared to exploitation, 4 – area of exploitation, 5 – intensive restored area, 6 – extensive restored area, 7 – restored area.

Conclusions

1. Area of limestone quarry “Górażdże” is characterized by fairly high biodiversity and its flora comprises 62 species and 2 varieties of bryophytes.
2. The special attention deserve species protected by law in Poland, threatened in Opole Province, Poland and Europe, in total 17 species, e.g. *Leiocolea badensis*, *Marchantia aquatica*, *Orthotrichum patens*, *Philonotis calcarea* and *Philonotis marchica*.
3. Investigation based on moss diversity showed that extensive land restoration is the most appropriate from the point of view of biodiversity.
4. Biodiversity in the restored area is high. A lot of habitats (terrestrial, epiphytic, epixylic, epilithic and aquatic) create possibility to gather here threatened bryophytes from other part of

Opole Province. In this way this area will become an important place for conservation of biodiversity of bryophytes in Opole Silesia.

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Table 1. Preliminary list of bryophytes of the Górażdże limestone quarry.

SPECIES NAME	I	II	III	IV	V
Liverworts Marchantiophyta					
<i>Aneura pinguis</i> (L.) Dumort.	-	-	+	+	+
*♦ <i>Leiocolea badensis</i> (Gottsche) Jörg.	-	-	-	+	+
<i>Lophocolea heterophylla</i> (Schrader) Dumort.	-	-	-	-	+
<i>Marchantia aquatica</i> (Nees) Burgeff	-	-	+	-	-
<i>Pellia endiviifolia</i> (Dicks.) Dumort.	-	-	+	+	+

Mosses Bryophyta					
! <i>Abietinella abietina</i> (Hedw.) M. Fleisch.	-	-	+	-	+
<i>Amblystegium serpens</i> (Hedw.) Schimp.	-	-	-	-	+
<i>Atrichum undulatum</i> (Hedw.) P.Beauv.	-	-	-	-	+
<i>Barbula convoluta</i> Hedw.	+	-	-	-	+
<i>Barbula unguiculata</i> Hedw.	-	-	-	+	+
<i>Brachytheciastrum velutinum</i> (Hedw.) Ignatov & Huttunen	-	-	-	-	+
<i>Brachythecium albicans</i> (Hedw.) Schmp.	-	-	+	+	+
<i>Brachythecium glareosum</i> (Spruce) Schimp.	-	-	+	-	+
<i>Brachythecium rutabulum</i> (Hedw.) Schimp.	-	-	+	+	+
<i>Brachythecium salebrosum</i> (F.Weber & D.Mohr) Schimp.	-	-	-	-	+
<i>Bryum caespiticium</i> Hedw.	-	-	-	+	-
♦ <i>Bryum pallescens</i> Schwägr.	-	-	-	-	+
<i>Bryum pseudotriquetrum</i> (Hedw.) P.Gaertn., B.Mey. & Scherb.	-	-	-	+	+
! <i>Calliergonella cuspidata</i> (Hedw.) Loeske	-	-	+	+	+
<i>Campyliadelphus chrysophyllus</i> (Brid.) R.S.Chopra	-	-	-	-	+
♦ <i>Campylidium calcareum</i> (Crundwell & Nyholm) Ochyra	-	-	-	-	+
♦ <i>Campylium polygamum</i> (Schimp.) Lange & C.E.O.Jensen	-	-	-	+	+
♦ <i>Campylium protensum</i> (Brid.) Kindb.	-	-	-	+	-
<i>Ceratodon purpureus</i> (Hedw.) Brid.	+	-	+	+	+
! <i>Climacium dendroides</i> (Hedw.) F.Weber & D.Mohr	-	-	-	-	+
<i>Cratoneuron filicinum</i> (Hedw.) Spruce	-	-	+	+	+
<i>Dicranella varia</i> (Hedw.) Schimp.	-	-	+	+	-
<i>Didymodon fallax</i> (Hedw.) Zander	+	-	+	+	+
<i>Drepanocladus aduncus</i> (Hedw.) Warnst.	-	-	-	+	+
<i>Drepanocladus polycarpus</i> (Voit) Warnst.	-	-	-	+	+
<i>Dryptodon pulvinatus</i> (Hedw.) Brid.	-	-	-	+	+
<i>Encalypta streptocarpa</i> Hedw.	-	-	-	-	+
! <i>Eurhynchium angustirete</i> (Broth.) T.J.Kop.	-	-	-	+	+
! <i>Eurhynchium striatum</i> (Hedw.) Schimp.	-	-	-	-	+
<i>Fissidens taxifolius</i> Hedw.	-	-	-	-	+
<i>Hedwigia ciliata</i> (Hedw.) P.Beauv.	-	-	-	-	+

<i>Homalothecium lutescens</i> (Hedw.) H.Rob.	-	-	-	+	+
! <i>Hylocomium splendens</i> (Hedw.) Schimp.	-	-	-	-	+
<i>Hypnum cupressiforme</i> Hedw. var. <i>cupressiforme</i>	-	-	-	+	+
<i>Hypnum cupressiforme</i> Hedw. var. <i>lacunosum</i> Brid.	-	-	-	-	+
<i>Leptodictyum riparium</i> (Hedw.) Loeske	-	-	-	-	+
<i>Orthotrichum affine</i> Brid.	-	-	-	-	+
<i>Orthotrichum anomalum</i> Hedw.	-	-	-	+	+
<i>Orthotrichum diaphanum</i> Brid.	-	-	-	-	+
♦ <i>Orthotrichum pallens</i> Brid.	-	-	-	-	+
●*♦ <i>Orthotrichum patens</i> Brid.	-	-	-	-	+
<i>Orthotrichum pumilum</i> Sw. ex anon.	-	-	-	-	+
<i>Orthotrichum speciosum</i> Nees	-	-	-	-	+
<i>Oxyrrhynchium hians</i> (Hedw.) Loeske var. <i>hians</i>	-	-	-	-	+
<i>Oxyrrhynchium hians</i> (Hedw.) Loeske var. <i>rigidum</i> (Boulay) Ochyra & Żarnowiec	-	-	-	+	+
!!♦ <i>Philonotis calcarea</i> (Bruch & Schimp.) Schimp.	-	-	+	+	+
!!*♦ <i>Philonotis marchica</i> (Hedw.) Brid.	-	-	-	+	+
<i>Plagiomnium affine</i> (Funck) T.J.Kop.	-	-	-	-	+
<i>Plagiomnium cuspidatum</i> (Hedw.) T.J.Kop.	-	-	-	-	+
<i>Pohlia melanodon</i> (Brid.) A.J.Shaw	-	-	-	-	+
<i>Pohlia wahlenbergii</i> (F.Weber & D.Mohr) A.L.Andrews	-	-	-	-	+
! <i>Pseudoscleropodium purum</i> (Hedw.) Broth.	-	-	-	-	+
<i>Pylaisia polyantha</i> (Hedw.) Schimp.	-	-	-	-	+
<i>Rhynchostegium murale</i> (Hedw.) Schimp.	-	-	-	+	+
<i>Rosulabryum capillare</i> (Hedw.) J.R.Spence	-	-	-	-	+
<i>Schistidium crassipilum</i> H.H.Blom	-	-	-	+	+
! <i>Thuidium assimile</i> (Mitt.) A.Jaeger	-	-	+	-	+
<i>Tortella inclinata</i> (R.Hedw.) Limpr.	-	-	-	+	+
<i>Tortella tortuosa</i> (Hedw.) Limpr.	-	-	-	-	-
<i>Tortula muralis</i> Hedw.	-	-	-	+	-
<i>Tortula subulata</i> Hedw.	-	-	-	-	+
Total:	3	0	13	29	60

Investigated stations: I – area prepared for exploitation, II – area of exploitation, III – restoration intensive; IV – restoration extensive; V – restoted area.

STRESZCZENIE

W roku 2012 przeprowadzono badania z wykorzystaniem mszaków do oceny wartości przyrodniczych w wyrobisku kopalni wapienia “Górażdże” w województwie opolskim. Badania pozwoliły zebrać informacje na temat:

(a) różnorodności taksonomicznej mszaków, ze specjalnym uwzględnieniem gatunków chronionych i zagrożonych, pozwalających lepiej zrozumieć mechanizmy kształtujące bioróżnorodność na tego typu obszarach

(b) opracowania sposobów ochrony mszaków na obszarach wyrobisk poeksploatacyjnych, które pozwolą lepiej zachować tę część dziedzictwa przyrodniczego województwa opolskiego,

(c) modyfikacji procesu rekultywacji którego poszczególne etapy stworzą odpowiednie warunki dla rozwoju gatunków chronionych i zagrożonych.

Na terenie wyrobiska stwierdzono występowanie 64 gatunków i dwóch odmian mszaków, w tym aż 17 gatunków objętych w Polsce ochroną prawną, zagrożonych na terenie województwa opolskiego, Polski a nawet Europy. Na szczególną uwagę zasługują stanowiska takich gatunków jak *Leiocolea badensis*, *Marchantia aquatica*, *Orthotrichum patens*, *Philonotis calcarea* i *Philonotis marchica*. Wytypowano 3 miejsca godne ochrony. Badania nad efektywnością rekultywacji w odniesieniu do różnorodności gatunkowej prowadzono na 7 powierzchniach, 5 zlokalizowanych na terenie wyrobiska i 2 (jako powierzchnie referencyjne) położonych w lasach gospodarczych i rezerwacie przyrody “Kamień Śląski”, leżących obok wyrobiska. Dla każdej powierzchni obliczono wskaźnik różnorodności biologicznej H' Shannona-Wienera. Ustalono, że na terenach o ekstensywnej rekultywacji, gdzie w dużej mierze zachodzi spontaniczna sukcesja, wskaźnik ten jest wyższy niż na terenach z intensywną rekultywacją. Takie ustalenie ma duże znaczenie praktyczne, ponieważ pozwoli obniżyć koszty rekultywacji, przy jednoczesnym zachowaniu wyższej bioróżnorodności. Porównanie różnorodności gatunkowej na powierzchni o cechach naturalnych (rezerwat “Kamień Śląski”) z powierzchnią na terenach zrehabilitowanych wykazało, że różnorodność biologiczna jest wyższa na tej ostatniej. Oczywiście, charakter flory jest inny, w rezerwacie występuje szereg gatunków o charakterze ‘reliktów puszczańskich’, natomiast na terenach zrehabilitowanych dominują gatunki hemerofilne.

Niemniej bogactwo siedlisk i rozległy obszar stwarza korzystne warunki do spontanicznego rozwoju niektórych gatunków chronionych i zagrożonych oraz możliwość przeniesienia na ten teren wielu gatunków z siedlisk narażonych na zniszczenie w województwie opolskim. W ten sposób wyrobisko kopalni wapienia “Górażdże” może stać się ważną ostoją chronionych i zagrożonych mszaków na terenie Opolszczyzny.