Hard and Resistant as a Rock? Threats to Geodiversity and How to Identify and Evaluate Them

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Abstract

Geodiversity is defined as the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features, including their assemblages, structures, systems and contribution to landscapes. As a whole, it represents a basis for biodiversity and it offers numerous benefits and services to human society. Currently, geodiversity is being intensively used and exploited, however, in the last decades, the geoconservation (an action of conserving and enhancing geological, geomorphological, hydrological and soil features and processes, sites and specimens) is continuously being implemented in regional, national and international nature conservation frameworks and policies. Nevertheless, despite the legislative measures, some threats and risks may still occur and endanger the sites of Earth Science interest. This contribution is focused on the main risks and threats that can endanger geodiversity and geoheritage. It also presents methodological approaches to risk assessment and evaluation of degradation risk which may contribute to the better understanding of the vulnerability and fragility of particular sites of Earth Sciences interest. Practically, the application of these assessment methods can serve as a basis for a more effective management and conservation of geodiversity and geoheritage.

Keywords: *geodiversity, geoheritage, risk assessment, geoconservation; environmental education*

1 Introduction

In the last decades, a growing interest in geodiversity has resulted in numerous studies and projects that confirm its importance both for biodiversity, study of paleoenvironmental changes and human society (Gray, 2013; Tukiainen *et al.* 2017, 2023; Brilha *et al.*, 2018; Gordon *et al.*, 2018; Crofts *et al.*, 2020; Gray *et al.*, 2023, Migoń, 2024). The conservation of geoheritage is already seen as highly important and, although there is still an emphasis on the protection of living nature, geoconservation continuously gets more attention and recognition and it is being incorporated in some local and regional policies (van Ree *et al.*, 2017; Stewart and Gill,

https://doi.org/10.11118/978-80-7701-024-5-0013

2017; Crofts *et al.*, 2020; Gray, 2021; Silva *et al.*, 2022). Despite all these efforts and also despite the facts that a site is legally protected, some threats may occur (Ruban, 2010; Wignall *et al.*, 2018; Crofts *et al.*, 2020; do Nasciemento *et al.*, 2021, Kubalíková and Balková, 2023; Kubalíková, 2024).

Given the fact that for the effective geoconservation it is essential to identify and assess the risks and threats on paticular sites, several methods for evaluating risks and threats have been developer. Usually, the classical geosite and geomorphosite assessment methods include also a degradation risk assessment as a part of overall site evaluation (e.g. Brilha, 2016), however, the works that are focused on proper identification and evaluation of the threats and risks to a geosite are still developing (García-Ortiz *et al.*, 2014; Fuertes-Guttiérez *et al.*, 2016; Ruban *et al.*, 2018, 2022; Selmi *et al.*, 2022; Kubalíková and Balková, 2023; Kubalíková, 2024).

Crofts *et al.* (2020) define several main threats to geoheritage in protected areas, but this classification can be used for any site of Earth Sciences interest: 1) Urbanisation, construction, 2) Mining and mineral extraction, 3) Changes in land use and management, 4) Coastal protection and river management and engineering, 5) Offshore activities, 6) Recreation and geotourism, 7) Climate change, 8) Sea-level rise, 9) Restoration of pits and quarries, 10) Stabilisation of rock faces, 11) Irresponsible fossil and mineral collecting and rock coring. There can occur

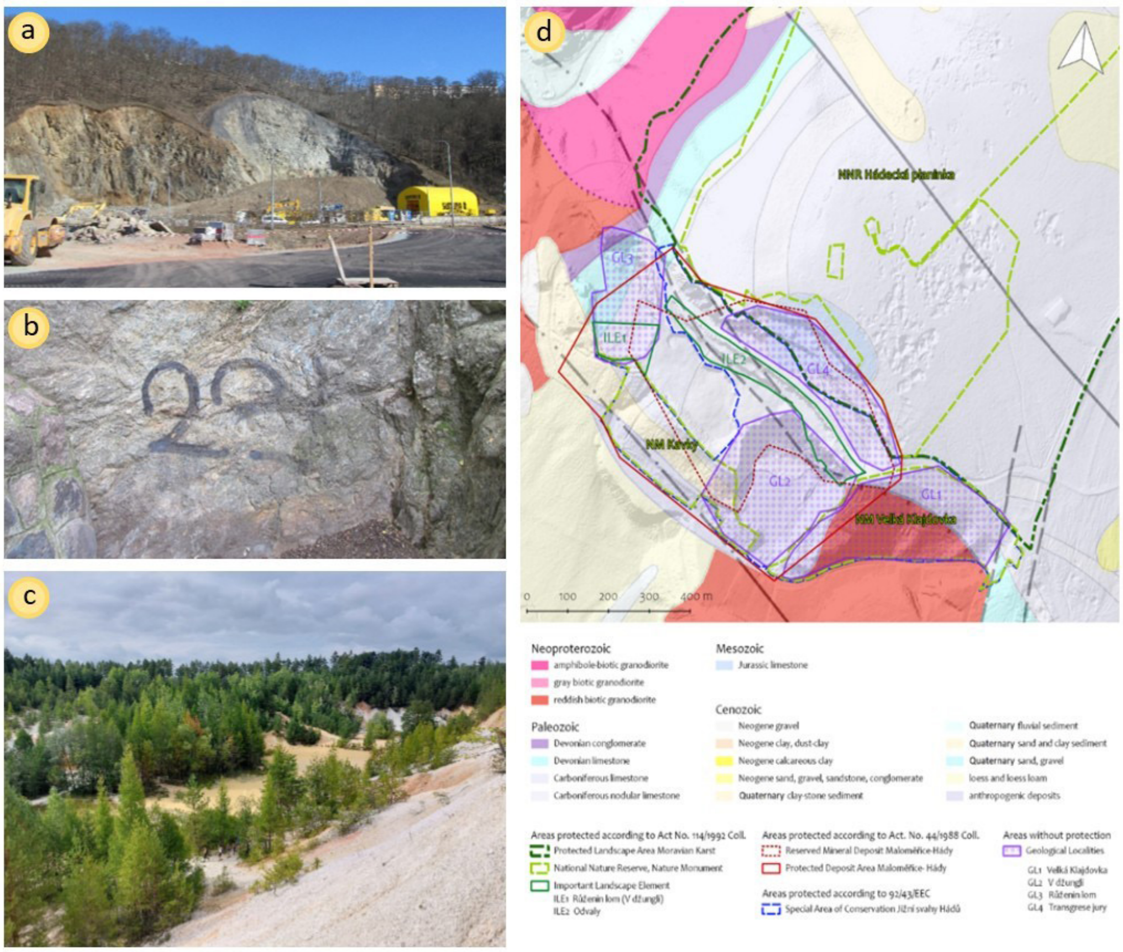

Fig. 1: *Threats on geoheritage and geodiversity: a) construction works (Žabovřesky tonalite quarry with river terraces); b) vandalism (Petrov metabazite outcrops); c) vegetation overgrowth (Rudice sand pit Nature Monument); d) confusion in protection measures (Hády area, Brno).*

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other types of threats such as lack of state or regional finances for management, vandalism, vegetation overgrowth, social pressure regarding the use of the sites or confusion in protection measures (Górska-Zabielska *et al.*, 2020, Kubalíková *et al.*, 2020, Selmi *et al.*, 2022). Specific examples of some threats are displayed on Figure 1.

This contribution briefly presents a methodological approach for a complex assessment of threats and risks including their prioritization on two model sites. Based on the application of this procedure and assessment, some specific management measures are outlined and discussed.

2 Methods

The methodological procedure can be divided into several steps (for a more detailed description see Kubalíková and Balková 2023, Kubalíková, 2024):

(1) Description of particular site of Earth Sciences interest (geodiversity aspects of the study sites)

(2) Identification and description of threats to a particular site based on field work and literature review (Fuertes-Guttiérez *et al.*, 2016; Crofts *et al.*, 2020)

(3) Degradation risk assessment based on the geosite / geomorphosite approach. (Table 1). Every criterion is assessed within the range of 0–1 points, no weights are attributed. The maximum that a site can reach is 9 points, the limit for considering the site as threatened is established on 5 points.

(4) Assessment of the particular threats on sites by using 5 × 5 Risk Assessment Matrix (Figure 2). Risk Assessment Matrix is a simple tool often used in project planning and regional development strategies. It enables to determine the likelihood (probability) and potential effects (impact) of different types of threats, then a final degree of risk is established allowing to prioritize them (Leveson, 2011). In 5 × 5 Risk Assessment Matrix (Figure 2), the axis X represents 'impact' and axis Y represents 'probability' and their multiplication then shows the degree of particular threat.

(5) SWOT analysis as a tool which provides an overview of the assessment by highlighting strengths, weaknesses, opportunities and threats. It has been practically used in numerous studies focused on geoheritage (Carrión Mero, 2018, Sumanapala *et al.*, 2021) and it may serve as a basis for management, updating care plans or other conservation documents. Moreover, it is quite comprehensible for public and authorities. Based on this, some proposals for risk treatment, further management and monitoring can be designed.

3 Study area

For the purposes of this case study, two sites of Earth Sciences interest situated within the outskirts of the second largest city in Czechia (Brno, approximately 380 000 inhabitants) have been selected: Malhostovické kopečky Nature Monument and Babí lom Nature Reserve. The following description is based on the geological maps (Czech Geological Survey, 2024a), Database of Geological Localities (Czech Geological Survey, 2024b), Demek *et al.* (2015) and Care plans of the protected sites (Nature Conservation Agency, 2024).

Malhostovické kopečky Nature Monument (situated approximately 15 km north of Brno) consist of two isolated limestone outcrops called "Pecka" and "Malá skalka (Drásovský kopeček)" surrounded by intensively cultivated arable land. Geologically, the site is composed of Vilémovice limestone of the Macocha Formation (the same as limestones in nearby Moravian Karst) which contains coral fauna with stromatopors, criniods etc. This limestone

Criterion	Scoring
Integrity	0 – excellent conditions; 0.25 – good conditions; 0.5 – medium, average conditions; 0.75 – bad conditions, but with a possibility to recover; 1 – bad conditions, site is damaged
Accessibility	0 – more than 1 km both from a parking place and stop of public transport; 0.5 – the stop and/or parking in the distance 0.2 and 1 km; 1 – the stop and/or parking place no more than 0.2 km from the site
Current threats and their management	0 – site practically not endangered; 0.25 – low anthropic and natural threats; 0.5 – potential threats, but managed well or possible to decrease; 0.75 – current anthropogenic threats but existing plans how to decrease them; 1 – existing and ongoing processes leading to the destruction of the site with no plans to recover
Legal protection	0 – protected on national level; 0.25 – protected on regional level; 0.5 – protected on municipal level; 0.75 – ongoing monitoring of the site; 1 – no legal protection
Proximity to problematic areas	0 – site located less than 1 km of a potential degrading area/activity; 0.5 – site located less than 0.5 km of a potential degrading area/activity; 1 – site located less than 0.2 km of a potential degrading area/activity
Current use	0 – 1 activity; 0.5 – 2 different activities; 1 – 3 and more different activities
Visitation	0 – low; 0.5 – medium; 1 – high
Number of threats	0 – no threat; 0.25 – 1 threat; 0.5 – 2 threats; 0.75 – 3 threats; 1 – 4 and more different threats
Use limitations	0 – the use is very hard due to limitations difficult to overcome (legal, permissions, safety etc.); 0.5 – the site can be used occasionally after overcoming limitations; 1 – no limitations for public use

Tab. 1 *Set of criteria used for Degradation Risk Assessment. The criteria are based on or have been already used in García-Ortiz et al. (2014), Fuertes-Guttierez et al. (2016), Reynard et al. (2016), Brilha (2016), Selmi et al. (2022), Kubalíková and Balková (2023), Kubalíková (2024).*

PROBABILITY

Highly probable	5 Moderate	10 Major	15 Major	20 Severe	25 Severe
Probable	4 Moderate	8 Moderate	12 Major	16 Major	20 Severe
Possible	3 Minor	6 Moderate	9 Moderate	12 Major	15 Major
Unlikely	2 Minor	4 Moderate	6 Moderate	8 Moderate	10 Major
Rare	1 Minor	2 Minor	3 Minor	4 Moderate	5 Moderate
	Very low	Low	Medium	High	Very high

IMPACT

Fig. 2: *Risk assessment matrix (adapted from Leveson, 2011). The scoring is following: 1 to 3: minor risk (a need to plan and implement the management measures and prevent the increase of the risk, monitoring the risk), 4 to 9: moderate risk (a need to implement management measures and prevent the increase of risk, monitoring the risk), 10 to 16: major risk (a need for action and implementation of management measures), 20 to 25: severe risk (an urgent need for action and implementation of management measures).*

represent a relic of a coral reef and it was tectonically inserted into the older crystalline rocks of Brunovistulicum (granodiorites) and Boskovice Furrow permocarbon sedimentary rocks. Geomorphologically, the outcrops represent "mendips", tectonically limited elevations of resistant rocks outcropping out of the Miocene calcareous clays and Quaternary loess. Both outcrops are affected by karstification (presence of small caves and karren). On Malá skalka (Drásovský kopeček), a small rock arch can be observed (Figure 3a). Pecka is affected by quarrying (Figure 3b). Ecologically, the site is very important thanks to the presence of thermophilic steppe formations with occurrence of endangered (*Pulsatilla grandis*) (Figure 3c) and other important species (*Saxifraga tridactylites*, *Veronica prostrata*, *Muscari comosum*, *Anthericum ramosum*). Geocultural and geohistorical aspects are represented by historical limestone quarrying (especially during the 1930s and 1940s). The cultural aspect is also represented by existence of a legend about petrified wedding that refers to the specific rock outcrops on Malá skalka (Drásovský kopeček).

Currently, the site (both outcrops) is protected as Special Area of Conservation (according to the Habitats Directive 92/43/EEC) and in a category Nature Monument (according to the Act No. 114/1992 Coll. on Nature conservation). It is being intensively used as a favourite tourist destination especially during the beginning of the vegetation season when Pulsatilla grandis is blooming (Figure 3d). The site is often overcrowded and some visitors does not respect the recommendations about the movement that may contribute to the erosion of meso- and microforms. Other threat is represented by presence of litter and dump on Pecka, biking and damaging the rock landforms. Invasive species can be considered a threat as well.

Fig. 3: *Malhostovické kopečky Nature Monument: a) small rock arch on Malá skalka; b) Pecka outcrop affected by quarrying; c) Pulsatilla grandis in bloom; d) the site is a favourite tourist destination.*
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However, concerning the biodiversity, the current intensity of the trampling by visitors affects the objects of protection rather positive as it keeps the steppe character of the site and enable the development of ephemeral and succulent vegetation.

Babí lom Nature Reserve consists of narrow rocky ridge – cuesta (Figure 4a) that runs north--southern direction and it is situated approximately 7 km north of Brno. Geologically it is composed of the quartzose silicified conglomerates (Figure 4b) which belong to the Devonian Basal Clastic Formation (Old Red type, possibly Lower to Middle Devonian). These conglomerates has been tectonically inserted between the metabasalts and granodiorite zone of Brno Massif. Geomorphologically, the rocky ridge represents the main landform of the study site and it is affected by frost weathering, creating distinctive mezoforms (conglomerates are nearly vertically bedded). On the surrounding slopes, the boulder fields and solifluction lobes can be observed. Ecologically, the site is important because of the presence of natural forests and other specific ecosystems: on the rocky ridge, local dwarf boreocontinental pines can be found, debris forests are situated on the slopes together with well-preserved beech forest. Some endangered species can be also found there, e.g. *Lilium martagon* or *Daphne mezereum*. The site has a high aesthetic value thanks to the presence of rocky landforms and views to the wide landscape from different parts of the ridge (Figure 4c) and thus, the site can be considered a viewpoint geosite (Migoń and Pijet-Migoń, 2017). Geohistorical value is represented by the presence of some old pathways with small sacral artefacts around them (the site is

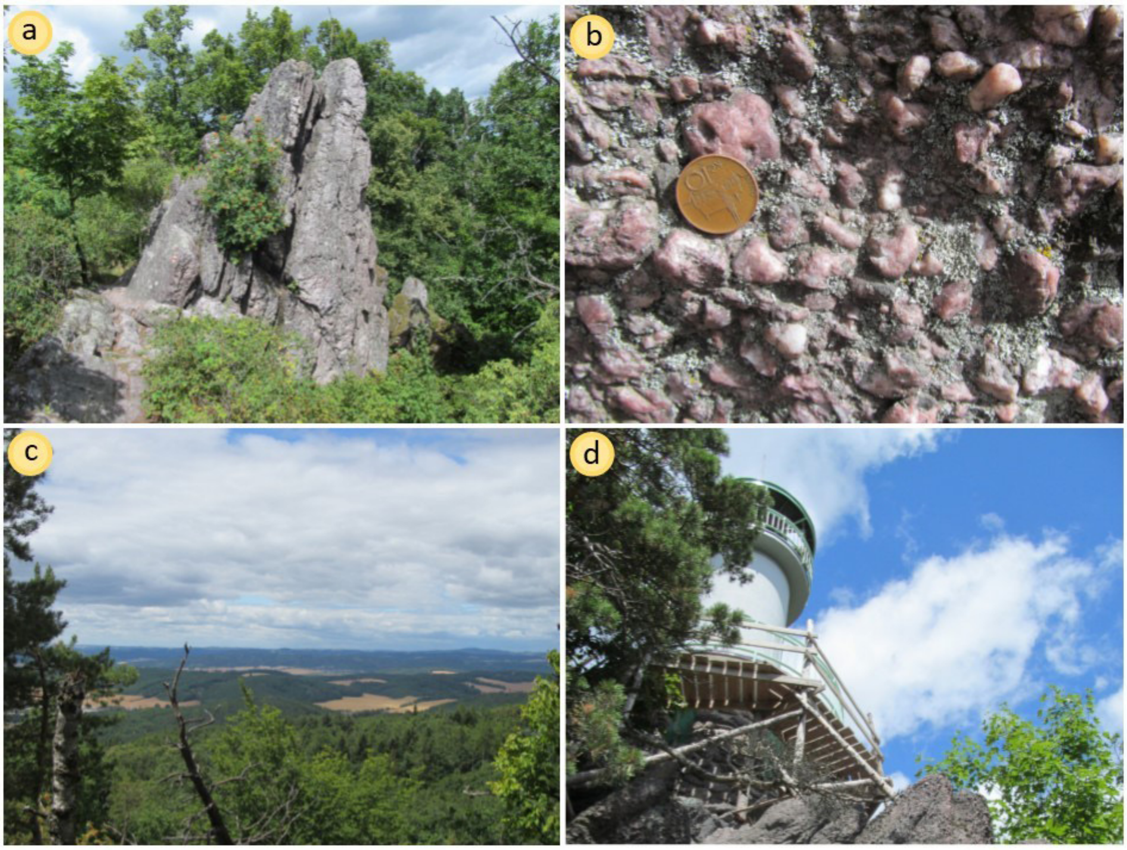

Fig. 4: *Babí lom Nature Reserve: a) rocky ridge represents the main landform of the site; b) red conglomerates of Devonian age; c) thanks to the wide views to the surrounding landscape (in this case towards the Bohemian-Moravian Highlands), the site can be considered a viewpoint geosite; d) a modern watchtower was constructed in 1960 and serves until present.*

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situated close to the pilgrimage church in Vranov). The tourist use of the site dates back to the first half of 19th century. Evidence of the construction of the first trigonometric point at the top of the Babí lom can be found in a painting from 1829 and it already shows tourists on the viewing platform. On the maps from 1875, Babí lom is also shown with lookout houses. Later, the site became a favourite tourist destination and the new watchtower was constructed (in 1884). In 1960, the watchtower was rebuilt and after reconstruction in 2023, it serves until now (Figure 4d).

Currently, the site is protected as Nature Reserve according to Czech legislative (Act No. 114/1992 Coll.). It is intensively used for hiking, but thanks to the difficult terrain and limited accessibility, the site is not overcrowded. Some parts of the rocky ridge are used for climbing which has a quite long tradition here. Several threats have been identified: littering, black camping, local occurrence of invasive woody plants, remains of forest monocultures. In the future, there is a risk of more intensive use of the site by specific activities such as biking which may contribute to the degradation of the site.

4 Results

The site has been assessed by using the Degradation Risk method and Risk assessment matrix. Table 2 and Table 3 summarize the results.

Regarding the degradation risk, the site Malhostovické kopečky Nature Monument seems to be more endangered than Babí lom Nature Reserve. It is caused by different degree of integrity (Babí lom is well preserved, while Malhostovické kopečky are already very influenced by human activities), accessibility (very good on Malhostovické kopečky – it is practically possible to park a car on a site, in contrast, Babí lom enables visits rather for well-trained tourists as the slopes are steep and on certain places, the path is not very safe). Due to the fact that Malhostovické kopečky are situated in proximity to several municipalities and active limestone quarry (less than 2 km), the scoring of "proximity to problematic areas" is higher than Babí lom Nature Reserve which is situated in forests. Both sites may be endangered by several

Threat to geodiversity	Prob	Imp	Sum	Prob	Imp	Sum
	Malhostovické kopečky			Babí lom		
Urbanisation	3	5	**15**	1	5	**5**
Quarrying, re-opening the quarry	1	5	**5**	1	5	**5**
Changes in land use management on site and in close proximity	3	5	**15**	2	5	**10**
Recreation, tourism (littering, breaking the rules, construction of tourist infrastructure leading to a more intensive use of the site)	4	5	**20**	4	5	**20**
Collecting fossils and rock specimens	2	4	**8**	1	4	**4**
Confusion in legal protection (different types and authorities)	2	4	**8**	1	4	**4**
Vegetation overgrowth incl. invasive species	4	4	**16**	3	4	**12**
Preferring the protection of living nature	3	3	**9**	3	4	**12**

Tab. 2 *Risk assessment of identified threats (using the Risk Assessment Matrix)*

threats, thus the scoring is quite high. Thanks to the fact that the terrain is more difficult in the case of Babí lom, the scoring of last criterion is better. The total score of the degradation risk assessment shows the significant difference between both sites.

Based on the literature review and field work, several threats have been identified. The most important threat is represented by intensive tourist use and recreation and possible construction of accompanying tourist infrastructure (e.g. single trails in the case of Babí lom). The vegetation overgrowth and spreading the invasive and non-native species can endanger both living nature and geodiversity features (e.g. contributing to the erosion, disruption of rock massive, intensifying slope processes or simply obscuring the visibility of Earth Sciences phenomena). Also, the urbanisation and change of land-use in the case of Malhostovické kopečky Nature Monument represent a threat that needs to be taken into account when managing the site or updating the care plan.

Strengths	**Weaknesses**
• Presence of important Earth Sciences phenomena • High potential for education • Existing legislative protection • Adequate tourist infrastructure • High added values (ecological, cultural)	• High visitation and tourist pressure, overcrowding in specific periods • Vegetation overgrowth, invasive species • Lack of integrated promotion and educational activities focused both on geodiversity and biodiversity
Opportunities	**Threats**
• Developing a more complex educational activities which may be more effective and enable visitors to see the links between geodiversity, biodiversity and culture • Developing management measures which would involve local people and stakeholders (e.g. via discussion when updating care plans) • Including these sites into the Geodiversity Action Plans for Brno and surroundings	• Construction of accompanying tourist infrastructure that may lead to a more intensive use or overexploitation of the sites and thus contributing to the degradation of the sites • Lack of finances for the existing management measures (e.g. dealing with vegetation) • Urbanisation and land-use changes (in the case of Malhostovické kopečky Nature Monument) Lack of interest of local stakeholders

Tab. 3 *SWOT analysis for both sites including the proposals for management measures*

5 Discussion and conclusions

Generally, the rocks are considered something stable and permanent. Indeed, this attitude has penetrated even into everyday's lives and it is reflected in numerous idioms (Kubalíková and Coratza, 2023). On the other side, like everything, the rocks are subject to permanent change and they are affected by influences of both natural and human origin. Different components of geodiversity are under pressure which should be taken into account when planning and managing natural resources (Crofts *et al.*, 2020).

The geosites situated in the proximity of large cities may suffer from higher visitation and more intensive use (Kubalíková, 2024). Very often, the visitation is accompanied by undesirable activities such as littering, vandalism, camping or construction of a more developed tourist infrastructure that contribute to a more intensive pressure on particular sites. Especially, the construction of a "more developed" tourist infrastructure in relation to looking for another possibilities of how to exploit the site (e.g. single trails, biking etc.) may be a source of future degradation of the site or overexploitation, thus it is of particular importance that these issues needs to be taken into account when revising care plans or other strategic documents.

The threat of urbanisation, changes of land-use and presence of disturbing activities in the proximity of geosite needs to be considered as relevant as well. All these aspects can be included in the development of so called Geodiversity Action Plan (Dunlop *et al.*, 2018) which may also reflect the possibilities and opportunities for a sustainable use of the sites, e.g. for environmental education which represent an important part of any geoconservation effort (Prosser, 2019). Also, making connections between different stakeholders (landowners, authorities, communities, schools, academia) is very suitable to foster the conservation of Earth Sciences phenomena (Worton and Gillard, 2013; Prosser, 2019; Kubalíková *et al.*, 2022; Bussard and Reynard, 2022).

Regarding the promotion and education, it should not be made for each phenomenon separately, but it should be mutually linked, respecting the abiotic-biotic-culture concept of geotoutrism (Dowling, 2013; Dowling and Newsome, 2018) and principles of integrated approach (Kubalíková *et al.*, 2023).

Keeping the sites legally protected or eventually foster the legal protection is also a way of how to set a more effective conservation and management, but it also depends on the cooperation of local stakeholders and state administration. Local visitors, inhabitants and municipalities should also enter the process of updating or revising care plans (e.g. via discussions) and eventually help to identify the possible threats and risks and participate on the design of management proposals.

6 Summary

The paper focuses on the identification and assessment of threats on specific geosites situated in the outskirts of a large city. Based on the complex assessment of risks and threats (geomorphosite method, risk assessment matrix, SWOT analysis), some specific proposals for the future management has been designed and briefly discussed.

In general, these activities may contribute to a more effective conservation of natural heritage and raise awareness of existing and possible threats to geoheritage, which is often overlooked and considered as something stable and resistant.

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Acknowledgement

This work was supported by the programme Dynamic Planet Earth of the Czech Academy of Sciences – Strategy AV21.

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