Applying a new methodology for cave degradation assessment in Romania - case study on Rodna Mountains National Park

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Abstract. Cave degradation assessment in Romania might be a challenge due to the variety of harmful anthropic activities: mineral resources exploitation, unsupervised tourism, road network development, abusive deforestation, etc. The present study proposes a new methodology for cave degradation assessment. The methodology combines caves intrinsic characteristics with GIS supraterranean features processing of the cave area. Applying the method on a group of 5 caves located in Rodna Mountains National Park, we managed to separate those in a natural state from those having a degraded ecosystem. Identifying degraded cave ecosystems is necessary for taking future ecological restauration and conservation measures, carried out by natural parks administrations.
Key Words: cave, ecosystem, degradation, semi-degradation, Geographical Information Systems.

Introduction. The growing anthropic activities of the last centuries increasingly affected karst areas. Once the sensitivity to change and the vulnerability of this type of ecosystem is aknowleged, the next step is to evaluate its conservation status. Identification of degraded cave ecosystems is necessary in order to begin their ecological restauration through various projects.

The boundaries of the area affecting the caves ecosystem are found beyond the cavity space, where the surface streams are lost underground and where groundwater comes to the surface (Culver & White 2012). Rouch (1977) also supports the idea that the true ecosystem is not really a “cave” ecosystem at all, but a “karst” ecosystem, equivalent to the entire drainage basin and the highly interconnected and diverse habitats within.

As we can see, the above cited ideas show the amplitude of area potentially reducing the cave ecosystem stability. Further down we detail this aspect with examples of human activities negatively affecting the area of the river passing through or near the cave. A well known example is that of Peak–Speedwell Cavern system (Derbyshire, UK) where due to the increase of sedimentary load, presence of petrochemical products and fertilizers, a general degradation of water quality was observed (Gunn et al 2000).

A negative impact is caused by changes in freshwater systems in the karst regions, which may affect or destroy the underground environment. Some researchers (Negrea & Negrea 2003) mention in this respect the total take-up of small surface water courses for supplying commnities or factories, full capture of springs and construction of dams with accumulation lakes on limestone rocks that flood the caves (Climente’s Cave of the Danube Gates - Archaeological Reserve) or reduce the flow downstream of the dam, unbalancing the underground carst hydrostatic system (Prisaca Dam in the Cerna Valley).

Williams & Robinson (1993) believe that deforestation and agricultural activities can lead to "rocky desertification", which took place on a large scale in parts of the Mediterranean and China. Urich (2002) presents the same idea, showing the direct link between increasing the amount of water runoff and water lost by evapotranspiration due to deforestation. In temperate areas, the quantity of water runoff is considered to be increasing by 35%, resulting in increased power to transport and move soil on slopes.

Speleoturism, practiced in great numbers, may lead to degradation. An example is Scărișoara Glacier (Negrea & Negrea 2003), a cave of great scientific value where the visitors' body warmth contribute to the accelerating ice deposits melting, indirectly determining loss of paleoclimatological records preserved in ice layers. The Valea Crișului Cave is another example for the negative effects of a high visitors influx. Here, all the troglophile species in the vicinity of the cave entrance are lost.

Besides human activities, floods are a natural phenomenon with a high destructive potential (Negrea & Negrea 2003) which might plug the cave entrances or/ and sumps (siphons) with transported debris (gravel, boulders, logs).

Given these pressures on natural caves, it is necessary to establish a methodology for assessing the degree of degradation in the event to ensure appropriate conservation actions. Such methodologies for assessment of cave ecosystem degradation have been proposed by Bovet & Ribas (1992). Hardt (2008) considers, however, these approaches as having difficulty in comparing results for caves located in different localities. More recently, Gomes (2010) presents new techniques for characterizing vulnerable sites by overlaying maps and GIS data, this beeing an useful tool for assessing large areas that cannot be visited personally.

Souza-Silva et al (2015) reassess the fact that "cave environments are characterized by possessing specialized fauna living in high environmental stability with limited food conditions. The fauna is highly vulnerable to impacts, because this condition can frequently be easily altered. Moreover, biodiversity patterns of caves remain poorly understood and protected". Many of the problems in karst environments can better be solved with changes in the human society than intervening in the karst environment. This is preferred because even small changes in the karst systems determine big differences (Brinkmann & Parise 2012).

To protect those compartments is necessary to determine the source and extent of degradation regarding ecosystem restoration and actions needed to prioritize. Studies on anthropogenic changes within karst areas led to the establishment by van Beynen and his collaborators of karst disturbance index (van Beynen & Townsend 2005; van Beynen et al 2007). This index is more useful for karst areas, although it is also considering the characters of the underground.

The present study proposes a new methodology for cave ecosystem degradation assessment in Romania. The methodology was applied on a pilot area located in Rodna Mountains National Park. The purpose of this study is to identify degraded caves and to enhance the results of ecological conservation and restoration activities in this environment.

Material and Method. Rodna Mountains National Park is a natural protected area established by Order no. 7/1990 of the Ministry of Water, Forests and Environment and later confirmed by Law no. 5/2000, being also a Natura 2000 site and UNESCO Biosphere Reservation.

Rodna Mountains National Park was chosen as a case study because of the presence of well defined karstic characteristics and of the previous scientific studies conducted in this area. One hundred (100) caves have been identified here.

The methodology used in the present study is based on the works of Donato (2011), and Donato et al (2014) aiming to define evaluation criteria of geological, geomorphological, hidrological, biotic, archaeological and paleontological characteristics of a cave and to see how the change of these characteristics influences the conservation state of the cave ecosystem.

The selected caves for identifying their ecosystem's state are: 1 - Baia lui Schneider (792 m), 2 - Cobășel (570 m), 3 - Grota Zânelor (4.386 m), 4 - Cave from Mina Blazna (known also as Cave from Galeria 1100-306 m), 5 - Iza (4.410 m) (Figure 1).

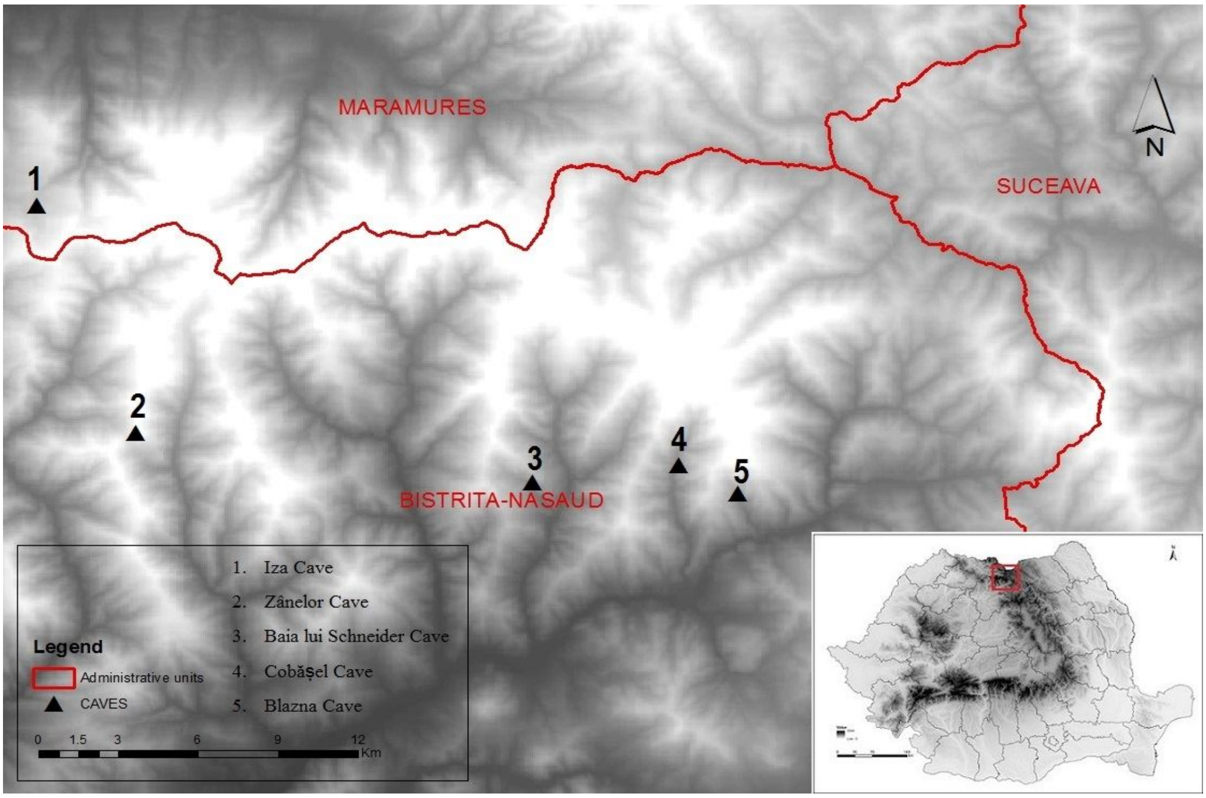

Figure 1. Map of study area. The cave locations in Romania.

For a degradation definition and evaluation, analysing and, if possible, checking the extent to which the cave ecosystem services are affected represents an advantage. Ecosystems' degradation translates into a reduced capacity to provide services. (Millennium Ecosystem Assessment 2005). Ecosystem services, according to DEFRA (2007), represent the wide range of benefits that a healthy natural environment provides to people, either directly or indirectly. These benefits range from life's essentials (clean air and water, food and fuel) to those improving the quality of life and well-being, such as recreation and beautiful scenery.

Human actvities causing cave ecosystem degradation, reducing or totally removing an ecosystem service are presented very well by Williams & Robinson (1993) (Table 1).

The first stage of evaluating cave ecosystems consists in analysing anthropic activities, their effects and impact on karstic areas.

Rapid Assessment Protocol (RAP) of cave environmental impact was built based on the structural model "Pressure-State-Response" (PSR), developed by the Organization for Economic Co-operation and Development (OECD 1993) removing the response indicator from the table and using it only on proposals of resolutions for pressures and changes in the environmental status (Donato et al 2014).

Data sources included the collected information from websites, topographic maps, Ministry of Environment, "Romanian Waters" National Administration reports and interviews with local and State Officials. For the RAP of environmental impact proposed by Donato et al (2014), most of the causes which are leading to habitat degradation were considered (Table 2). Considering RAP-cei values, caves can be classified as:

- intact caves (I) – natural communities, populations and ecological processes are intact, without alterations and anthropic threats (the score is ≤ 7 points);

- stable caves (S) – notable anthropic alterations which can lead to local decline of natural populations. The landscape integrity is maintained, the ecological processes are intact (the score is 8-34 points);

- vulnerable caves (VU) – extinction risk if adequate management measures are not taken. Losing and habitat degradation (the score is 35-61 points);

- endangered caves (EN) – high level of potential extinction. Habitat alteration, losing the habitat can cause environmental changes and modification of ecological processes (the score is 62-84 points);

- critically endangered caves (CR) – with extreme level of potential extinction. Major landscape changes, compromising the native species and ecological processes (the score is 85-109 points);

- extinct caves (EX) – disappeared caves (the score is 110 points).

Table 1

Human activities effects and their impact on karst land (after Williams & Robinson 1993)

Human activities	*Effects in karst land*	*Impact on underground karst*
- deforestation	- disappearance of organisms or associations of organisms	- reducing ecological diversity
- deforestation (reduced evapotranspiration); - agriculture; - urbanization; - industry; - mining quarries or mines	- increase runoff and erosion; - increase the quantity of transported sediment	- increasing soil degradation and erosion - increase of sediment deposition in caves
- agriculture; - urbanization; - industry; - exploitation in quarries or mines; - tourism and recreation; - military activities	- acid rain; - increasing the amount of sediment transported; - wastewater (domestic, from industrial action, tourism or mining); - chemical waste	- deterioration of water quality
- urbanization; - industry; - mining in quarries or mines; - military activities	- removal of rocks and minerals	- destruction of characteristic karst formations
- upstream dams; - pumping groundwater	- lowering groundwater	- soil collapse; - springs dessication; - seawater intrusion;
- dams downstream	- inundation	- inundation of karst systems

In this study, for establishing the degradation level (natural, semi-natural, degraded) we used the RAP-cei indicator. Thus, between 0-34 points, the cave ecosystem is considered as being natural, between 35-84 points, the cave ecosystem being semi-degraded and more than 85 points, the cave ecosystem being degraded.

The needed data to calculate the necessary indicators to assess cave ecosystems' degradation stage were obtained from: speological literature (presence of different invertebrates or vertebrate species, plans and maps of the caves); hydro-geological literature (the dynamic of the water level in karstic holes); topographical maps and orto-photoplans, „Romanian Waters" National Administration reports (assessment of deforestation level above the caves, appreciation distance from the nearest roads or places, quarries to caves, identifying streams entering inside the cave, crossing one or more localities); management plans of national and nature parks from Romania, ANPM Ministry of Environment (topographical maps 1:25.000, orto-photoplans, GIS database – road network, hydrographic network, spatial analyses); questionnaires applied to administration of national and nature parks. The questionnaires included 27 questions, scoring all types of impact.

The values for deforestation above the caves (D) and anthropic modification of nature environment were assessed by using GIS analysis. For the calculation of D indicator, where known extension in the plane and the orientation of the cave, the degree of deforestation is appreciated karst within the limits of the opening projected on the surface.

Table 2

Rapid assessment protocol of environmental impact related to caves RAP-cei (modified after Donato et al 2014). Activities causing impact: mining visitation; agriculture/ranching; tourism/disorderly; damming work; urbanization; engineering.

Type of impact	*Symbol*	*Estimated score*	*Achieved score*
Complete destruction of the cave (in this case, there is no need of further analysis, scoring closes here).	CD	0/110	
Partial destruction of the cave.	PD	0/2/4/6/10	
Changes in water dynamics: lowering of the aquifer; partial or complete flooding; drying of karstic lakes and ponds; destruction of cargo areas; obstruction of ducts and consequent flooding or drying.	WD	0/2/4/6/10	
Karst changes: cracks, detachments, broken speleothems, collapse of karstic structures.	KC	0/2/4/6/10	
Alterations of subsurface soil: trampling of delicate formations, pavement compaction.	AS	0/2/4/6/10	
Sound pollution: acoustic overlap and vibration.	SP	0/2/4/6/10	
Pollution of groundwater: eutrophication, presence of pollutants (i.e. oil, suds).	GP	0/2/4/6/10	
Natural vegetation deforestation by fire or other human activities, reduction of organic resources, increase of exotic species, spread of pollutants, soil acidification.	D	0/2/4/6/10	
Masonry work: lighting, walkways, microclimatic changes.	M	0/2/4/6/10	
Disorderly visitation/vandalism: garbage, graffiti, and other types of vandalism.	V	0/2/4/6/10	
Range of impact, considering the most impactful action: If there is no impact – add 0 points; If the impact is local – add 5 more points; If the impact is regional – add 10 more points; Note: local – when the effect is restricted to the site of action; regional – when the effect is spread over an area beyond the immediate vicinity of where the action takes place.	R	0/5/10	
Presence of buildings or environmental changes (such as roads, urban core, mining, agriculture/ranching, etc.) near the cave area or close to streams of water passing through caves: > 2000; 1500-2000; 1500-1000; < 1000 meters.	EC	0/3/7/10	
Total score			

Score refers to the magnitude of the impact, which indicates the severity of the impact on the environment. The magnitude can be of four types: 1 - threat to natural resources is negligible regarding its depletion and the environment and community degradation, being reversible in a short term (up to 1 year); add 2 points; 2 - the use of natural resources is considerable but the depletion of the natural reserves is not possible; the degradation of the environment and the community is reversible in the medium term (1 to 10 years), if immediate actions take place; add 4 points; 3 - the use of natural resources is considerable and the depletion of the natural reserves is possible; the degradation of the environment and the community is reversible in the long term (10 to 50 years), if immediate actions take place; add 6 points; 4 - when the action caused the scarcity of natural resources, and the degradation of the environment and the community does not have many chances of reversibility; add 10 points; 5 - if there are more than one component to be evaluated in each indicator, consider the sum of the scores, for values below 10 and/or give the highest score (10) if the sum of values is greater than 10.

In order to appreciate the magnitude of the degree of deforestation, actual presence of vegetation in areas previously set will compare it with the vegetation on ortho-photos or topographic maps scale 1:25.000. When the orientation direction is not precisely known, the entire area within the circle will be analysed. For this to be done, consider a circle having a radius equal to the maximum distance in a plane between two extreme points of the cave. The circle centre is on one end of the cave's long axis. When the slope of a cave is in the valleys, only the area within the circle, present on the side of the cave, will be considered.

To estimate the influence of anthropic impact (EC), the buffer space analysis was used. The intermediate buffers have been developed with respect to availability in road infrastructure using four distance classes: 1,000 m, 1000-1500 m, 1500-2000 m and cycle through more than 2000 m. The buffer vectors were created around the line type (network roads) to generate a class of impact. The impact of quarries on caves and karst environment was established using four classes of buffer polygons representing quarries. Representation of the zones was made using the limits of polygons, to highlight overlapping areas.

Results and Discussion. The values obtained by the above method are shown in Table 3. Comparing the indicators for the selected caves from Rodnei Mountains National Park, we may separate three categories of impact: natural - less than 34 points (Grota Zânelor Cave, Iza Cave, Cobăşel Cave), semi-degraded – 35-84 points (Schneider's Bath) and degraded – more than 85 points (Cave from Mina Blazna).

If we consider the RAP-cei indicator, the studied caves are distributed in the following classes: intact caves – less than 7 points (Grota Zânelor), stable caves – below 34 points (Cobăşel Cave, Iza Cave), vulnerable caves – under 61 points (Baia Schneider), extinct caves – 110 points (Mina Blaznei Cave).

Schneider's Bath is a cave that was formed in a succession of marmorean limestone art of crystalline complex (Devonian-Carbonifer) that make up the most of Rodna Mountains. The cave was created by Secii stream. The total length is 792 m (Sahy et al 2008). The ceiling and walls are mostly covered with a crust of aragonite (partially recrystallized into calcite) that was unfortunately mostly crushed and destroyed by visitors. The cave's degradation state is due to past mining activities and visitors' vandalism, including cutting speleothems for sale. It is also a vulnerable cave that requires conservation and restoration, as well as installation of metal gates to reduce visitors' impact during bats' hibernation, washing existing grafitti and removing the garbage left inside.

Cobăşel cave has a length of 570 meters and a level difference of about 30 meters, existing in deposits as old as Precambrian (Orghidan & Negrea 1984). The cave is rich in dissolution formation (septae) found both on walls and ceiling. Analyzed indexes confirmed to be a natural and stable cave, the human impact being represented by visitors' vandalism. As management measures, it requires placement of metal gates to restrict visitors' access during bats' hibernation, some species being threatened in Romania (eg. *Barbastella barbastellus* bat, Iuşan 2013).

Grota Zânelor Cave is shaped in alternating crystalline limestone and marl (Goran 1981), extension of gallery network, meaning the distance between the two farthest points on horizontal projection, is 267 meters. The branching index (the total length of the cave/extension) is 4.386/267 = 16.42, which is the national record, the most branched cavity in Romania. According to the analysis of the degradation index, it can be considered an intact natural cave, not subject to human intervention, except the exploration period of 15 years.

The cave found in the Blaznei mine has a length of 306 m (Sencu 1968) and has been intercepted by the gallery 1100 of Blaznei mine. According to the analyzed indicators, the cave is considered degraded and extinct because it was filled with concrete at the end of the mining activities in this gallery.

Iza cave has a total length of 4,410 m (Viehmann et al 1979). The limestone that host the karst phenomena is of middle Paleogene age, being placed on top of the metamorphic rocks of Rodna Mountains (Tămaș et al 2011a, b). The analyzed impact indicators reflect very well the natural state and integrity of the cave. This is due to the difficulty of access to the cave, presence of waterfalls and potholes making the access possible only with appropriate equipment. Only the cavers with appropriate equipment visited this cave, tourism being almost nonexistent.

Table 3

The established human activities impacts on the caves environment

Name	*Cave code*	*Location*	*Impact type*											*Sum*
			PD	*WD*	*KC*	*AS*	*SP*	*GP*	*D*	*M*	*V*	*R*	*EC*	
Baia Schneider	1/1025	Rodna (BN)	6	4	6	6	0	0	2	0	10	10	0	44
Cobășel Cave	2/2026	Șanț (BN)	2	2	4	2	0	0	2	0	4	10	3	29
Grota Zânelor Cave	2/1022	Rebra (BN)	2	0	2	2	0	0	0	0	0	0	0	6
Cave from Mina Blazna	3/1026	Șanț (BN)	10	10	10	10	10	10	10	10	10	10	10	110
Iza Cave	1/1029	Săcel (MM)	2	0	2	2	0	0	0	0	4	0	0	10

Conclusions. The degree of degradation analyses of the five caves located in the Rodna Mountains National Park, highlights the existence of three categories: natural caves (Grota Zânelor Cave, Iza Cave, Cobășel Cave), semi-degraded caves (Baia lui Schneider Cave) and degraded (Mina Blazna Cave).

All the affected caves by anthropogenic activities such as mining, speleothems commercialization, as well as tourism, should be included in the management plans which stipulates ecological underground environment restoration and conservation.

To support the ecological restoration of the karst environment, it is necessary to have action plans and manage the custodian or administration sites by removing the household waste, cleaning the speleothems and the engraved walls with graphite, obstructing the access of tourists to certain caves or section of caves, which are vulnerable to anthropogenic impact.

The proposed methods for classifying the vulnerable caves in Romania according to pressures and impacts on the environment, as well as their prioritization in terms of conservation/restoration needs, indirectly contribute to the preservation of the fauna and flora from the caves and especially of the chiroptera species.

By using conservation indexes, it is possible to identify the pressures that determine the impact on the karst environment, their effects and their magnitude as well as the need for conservation and or restoration.

The methodology presented in this study can be used to support custodians and administrators in deciding on which caves can be used for tourism and leisure activities, while others should not. The methodology indicates also the vulnerabilities and needs for the conservation or restoration of ecosystems be kept closed or used only for research or preservation.

The application of these indexes is combined with the use of aerial photographs (Orthophotomap) and geographic information system (GIS) to improve the accuracy in determining the environmental impact in the surrounding areas of the evaluated caves.

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