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EVALUATING THE HUMAN DISTURBANCE TO KARST ENVIRONMENTS IN SOUTHERN ITALY

OCENJEVANJE SPREMEMB KRAŠKEGA OKOLJA ZARADI VPLIVA ČLOVEKA V JUŽNI ITALIJI

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Abstract UDC 502.6:551.44(450.75)

Fabiana Calò & Mario Parise: Evaluating the Human Disturbance to Karst Environments in Southern Italy

Karst environments are extremely vulnerable to degradation and pollution. Although the carrying capacity of these natural environments is low, a variety of human activities is implemented on karst settings generating impacts at the surface and subsurface. To evaluate the degree of disturbance to typical karst environments in the Mediterranean basin, two areas have been selected in Apulia (south-eastern Italy). The human-induced effects are being assessed by applying a recently developed Karst Disturbance Index (KDI), based on a categorical framework encompassing physical, biological, and social aspects, and the evaluation of a number of indicators for each category. Scores are assigned to the indicators, to assess the severity and the extent of the human impacts on the karst environment. Knowledge of the study areas derives from a combined use of direct experience and field surveys, and the critical evaluation of data available from research articles and local organization reports. Since this approach is an holistic and comprehensive method, different scientific branches and law issues have been considered. The results so far obtained for the study areas highlight the urgent need of a sustainable management of anthropogenic activities: for example, quarrying and stone clearing, both extensively widespread, are among the most dangerous practices for karst surface and subsurface landforms in Apulia. These activities are heavily changing the original karst landscape and causing the partial or total destruction of natural caves. This study represents a preliminary evaluation of the human disturbance to karst in Apulia, but has to be necessarily integrated by further applications in other areas of the region, aimed at a better understanding of the potentiality of the approach and its feasibility in different karst settings.

Keywords: karst disturbance, human impact, Karst Disturbance Index, Apulia, Italy.

Izvleček UDK 502.6:551.44(450.75)

Fabiana Calò & Mario Parise: Ocenjevanje sprememb kraškega okolja zaradi vpliva človeka v južni Italiji

Kraško okolje je izredno občutljivo za uničevanje in onesnaževanje. Čeprav je »nosilna sposobnost« tega naravnega okolja majhna, so na krasu najrazličnejše človeške dejavnosti, ki vplivajo na njegovo površje in podzemlje. Da bi ocenili stopnjo takih sprememb na značilnem kraškem ozemlju v Sredozemlju, je bilo izbranih dvoje področij v Apuliji (jugovzhodna Italija). Posledice, ki jih je povzročil človek, so bile ugotovljene s pomočjo pred kratkim razvitega »indeksa sprememb na krasu«, ki upošteva fizične, biološke in družbene vidike, obenem pa so bili za vsako skupino ovrednoteni številni pokazatelji. Ti so bili točkovani in tako sta bili ovrednoteni intenzivnost in obseg človekovega vpliva na kraško okolje. Poznavanje obravnavanega ozemlja temelji tako na neposrednem opazovanju kot na terenskih preučevanjih ter na kritičnem ovrednotenju podatkov iz strokovnih člankov in poročil lokalnih združenj. Ker gre za celostno in vsestransko metodo, so upoštevane različne znanstvene panoge in zakonodaja. Tako dobljeni izsledki za preučevana ozemlja kažejo na nujnost sonaravnega urejanja človeških dejavnosti, kot sta npr. lomljenje in čiščenje kamenja, oboje je na široko razširjeno in ki predstavljata najbolj nevarno dejavnost za kraške površinske in podzemeljske oblike v Apuliji. Ti dejavnosti močno spreminjata prvotno kraško površje in povzročata delno ali celotno uničenje podzemeljskih jam. Ta študija predstavlja predhodno oceno sprememb na krasu v Apuliji in bi morala biti vključena v bodoče raziskave drugih ozemelj te regije, da bi lahko bolje razumeli prednosti te metode in njeno uporabnost za različna kraška okolja.

Ključne besede: spremembe na krasu, vpliv človeka, indeks sprememb na krasu, Apulija, Italija.

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INTRODUCTION: THE DISTURBANCE INDEX FOR KARST ENVIRONMENT

Karst, with its surface and subsurface landforms such as closed depressions, sinkholes and caves, is among the most fragile natural environments of the world, and extremely susceptible to any change. Karst systems are non renewable resources but, nevertheless, they are increasingly being disturbed by a variety of human activities generating impacts both above and below ground (Williams, 1993).

Many anthropogenic actions cause great transformations and degradation of karst regions, including quarrying and mineral extraction, deforestation, agricultural practices, illegal waste dumps in natural cavities, tourism in caves. All these activities may result in negative effects on karst, such as pollution and depletion of water resources, changes of the natural morphology and hydrology, decline of animal species, etc. (Parise & Pascali, 2003).

Complexity of karst, where several different categories interact in creating the overall ecosystem, requires to consider and analyse any component of karst, both individually and in the reciprocal relationships with the others, in order to safeguard and manage it in a sustainable way. At this aim, only an holistic, comprehensive approach, addressing physical, economic and social factors, can effectively assess the threats to karst areas (Van Beynen & Townsend, 2005).

In order to reduce the karst system to elements easily studied for the evaluator, this article applies the method recently proposed by Van Beynen and Townsend (2005) to measure factors of karst disturbance (Fig. 1) based on a framework divided into five broad categories, each encompassing more detailed attributes: *Geomorphology* that encompasses surface landforms, soil and subsurface karst; *Atmosphere* that deals with air quality; *Hydrology* that

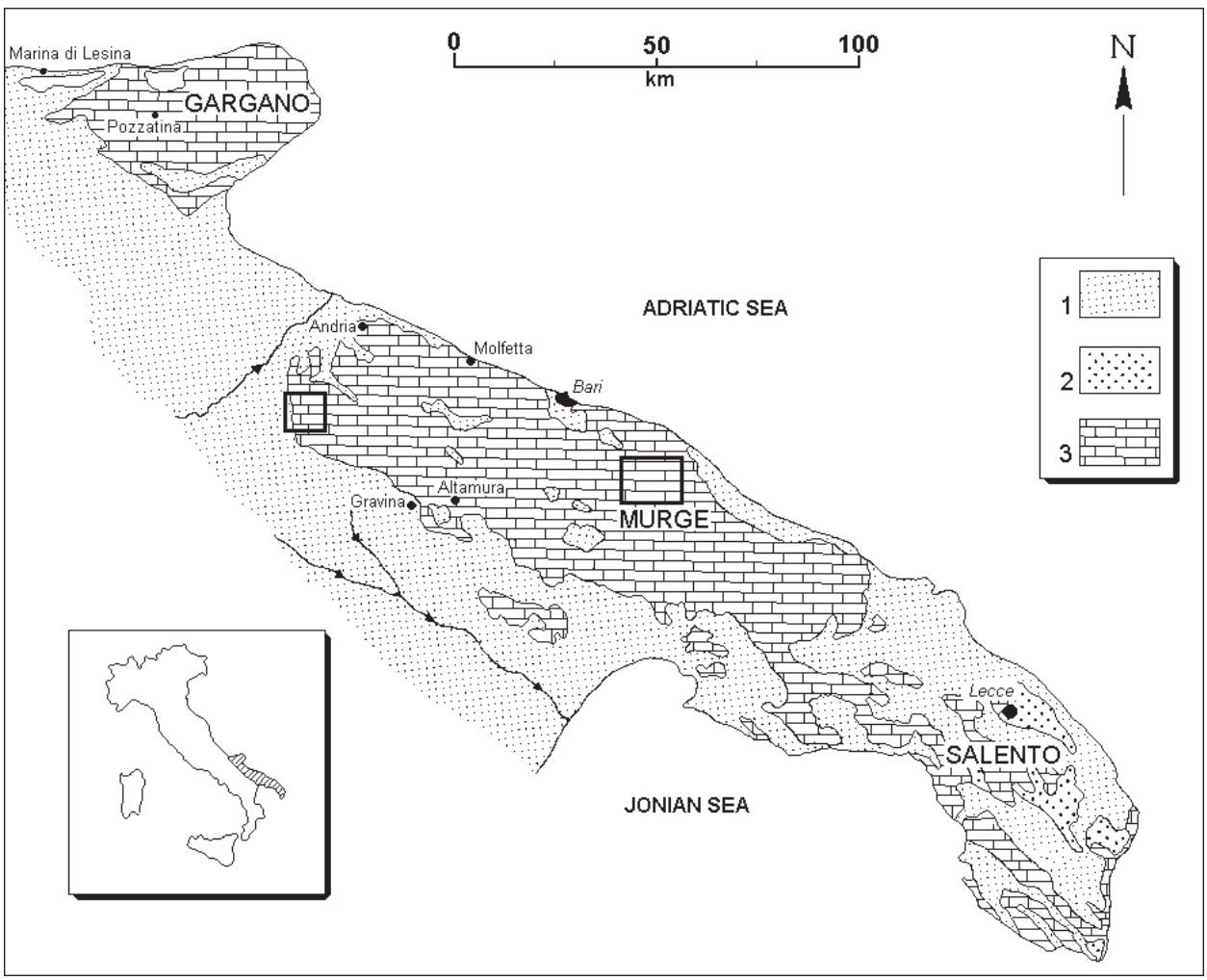

Fig. 2: Geological sketch of Apulia. Explanation: 1) recent clastic cover (Pliocene – Pleistocene); 2) bioclastic carbonate rocks (Paleogene) and calcarenites (Miocene); 3) platform carbonate rocks (Cretaceous). The two insets refer to the study areas.

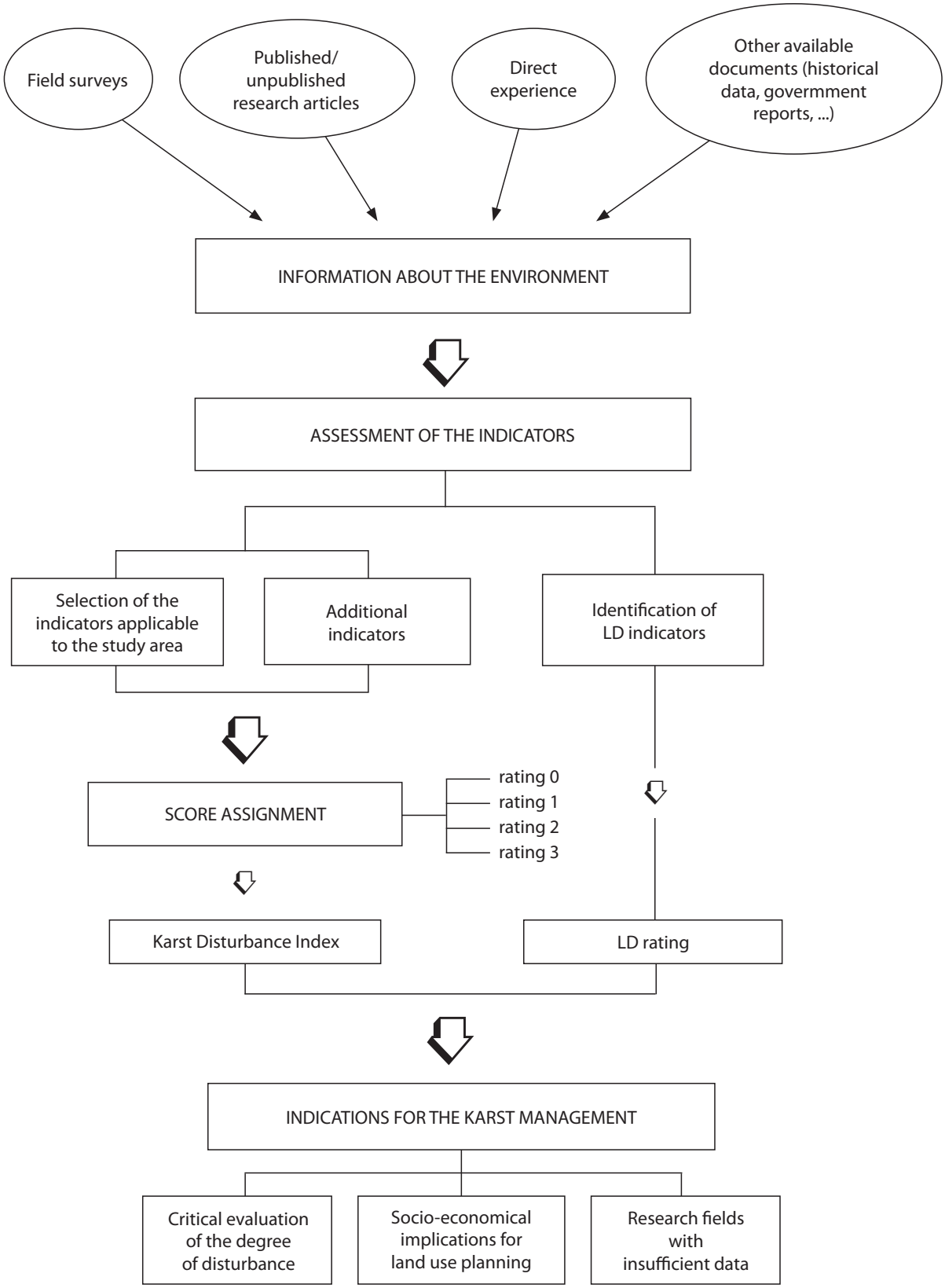

Fig. 1: Flow chart illustrating the methodology followed in this study.

includes surface practices influencing water quality and quantity, and water quality of springs; *Biota* that concerns the vegetation disturbance and the subsurface biota in cave and in groundwater; and *Cultural factors* that include human historical artefacts, stewardship of karst region and building infrastructure.

The degree of disturbance of a certain attribute is indicated through a pre-established set of associated indicators, from those most destructive for surface karst as quarrying/mining (Gunn, 1993), and dumping waste in sinkholes and cavities, to the less apparent but equally dangerous use of pesticides and herbicides in agriculture, and so on. Each indicator, that can be appraised by the evaluator from historical data, field observations, published and unpublished research articles and local government reports, is assigned a score from 0 to 3 based on severity and extent of the variable being considered: rating 0 means no karst disturbance, rating 1 indicates localized and not severe impact, rating 2 widespread and severe impact, whilst when a catastrophic impact is observed rating 3 is assigned.

To determine the degree of disturbance of a particular region, the evaluator should know what an undisturbed karst system is, and assume it as the ideal reference system. This might be relatively simple for some indicators (water quality, extent of quarrying, etc.), but very difficult for others (loss of biodiversity, human-induced condensation/corrosion, etc.). Finding locations without human influence may be extremely difficult, which forces the evaluator to use as baseline those areas with minimal human perturbation.

If an indicator cannot be applied to the study area, it has to be deleted from the evaluation, while if it is relevant in the area but no information is available, a "Lack of Data" (LD) has to be indicated. At the end of the evaluation, the number of LDs divided by the total number of used indicators gives a measure of the confidence of the index: LD rating < 0.1 would inspire high confidence in the determined index, while LD rating > 0.4 suggests that more study is required before application of the index can be carried out in that location.

Once all feasible indicators have been scored, the evaluator calculates the Karst Disturbance Index. Scores are summed and the total is divided by the highest possible score to attain a value between 0 and 1, where the latter indicates an highly disturbed system and the lowest value a pristine system. Classes of Karst Disturbance Index, according to Van Beynen and Townsend (2005), are reported in Table 1.

Score	Degree of disturbance
0.8 – 1	Highly disturbed
0.6 – 0.79	Moderately disturbed
0.4 – 0.59	Disturbed
0.2 – 0.39	Little disturbance
0 – 0.19	Pristine

Tab. 1: Classification of disturbance (after Van Beynen & Townsend, 2005).

CASE STUDIES IN APULIA

Apulia region is the emerged south-eastern part of the Adriatic Carbonate Plate which is formed by Jurassic-Cretaceous limestones and dolostones covered by Tertiary and Quaternary clastic carbonates, mostly calcarenites, and subordinate clays and sands. From the Lower Pleistocene, the region was interested by a general uplifting, until it reached the present configuration (Doglioni *et al.*, 1994). Apulia is fragmented by high dip, NW-SE striking, faults into uplifted and lowered blocks (Ricchetti *et al.*, 1988). Due to the widespread presence of carbonates, surface and subsurface landforms were extremely involved in karst processes that produced an extensive network of underground cavities and conduits. The landscape is generally flat, characterized essentially by landforms of karst origin, whose best morphological expressions are identifiable on the Murge Plateau of inland Apulia (Neboit, 1974; Sauro, 1991). Over large portions of the region, the natural landscape has been strongly modified by man, also thanks to the smoothed morphologies that facilitated land use changes.

The Murge Plateau is a planation surface cut in the Cretaceous limestones during Paleogene and Neogene. From the highest elevations (678 m a.s.l. near Mt. Caccia), the plateau slowly degrades toward the Adriatic Sea to the east, through steps of marine terraces. Two main districts can be identified: High Murge, which corresponds to the inner portion of the plateau, and Low Murge, closer to the Adriatic coastline. In this study, we apply the Karst Disturbance Index method to two areas, located respectively in the two aforementioned districts.

MINERVINO MURGE AREA (HIGH MURGE)

Selection of the area in the surroundings of the town of Minervino Murge for the present study was dictated, be-

sides its very interesting karst features, by the fact that it is comprised within the boundaries of a recently established natural park *(Alta Murgia Natural Park),* which total surface is around 70,000 ha. The park was established with a National Law in 1998, after many years of debate about the boundaries of the park, and many discussions about the permitted activities within its limits. This part of the Murge Plateau was originally devoted to pasture, and characterized by bare karst landscape with limestone rocks protruding from the ground surface. The few areas where residual soils and *terra rossa* concentrated were slightly incised valleys, locally called *lame,* that constituted a sort of oasis where the farmers were able to perform agricultural practices. In the last decades, two main anthropogenic activities spread out in this area, which resulted in heavy changes in the natural landscapes: quarrying, and stone clearing (Fig. 3). Quarrying is very

Fig. 3: Quarrying and stone clearing are the main anthropogenic activities degrading the original karst landscape at Minervino Murge. The photo shows an overall view of the southern slope of Mount Scorzone.

widespread due to the common use in Apulia of carbonate rocks as building and ornamental materials. Advance of quarrying is carried out without any concern for the natural caves, many of which have been damaged or destroyed by quarrying (Fig. 4). In addition, once the quarrying activity ceases, it is very common the use of the abandoned site for illegal dumping of solid and liquid wastes. The considerations above led to assign high values to the indicators **quarrying/mining** (rating 3) and **industrial and petroleum spills or dumping** (rating 2). As regards the latter indicator, we considered as brownfields (heavily polluted sites) any abandoned quarry where the presence of wastes was detected.

Repeated surveys performed in the last years, integrated with interpretation of multi-year aerial photos allowed to quantitatively evaluate the advance of quarrying activities (Fig. 5), and the areas involved in land

Fig. 4: Intense quarrying activities resulted at several sites in the Minervino Murge area in destruction of caves, as shown in this photo.

use change. This was then integrated by field surveys and speleological explorations, that further highlighted the destruction of a high number of caves in the area. The data so collected clearly show that the area around Minervino Murge is one of the most degraded in Apulia as regards disturbance of the karst environment, with loss of the original landscape and destruction of the natural caves.

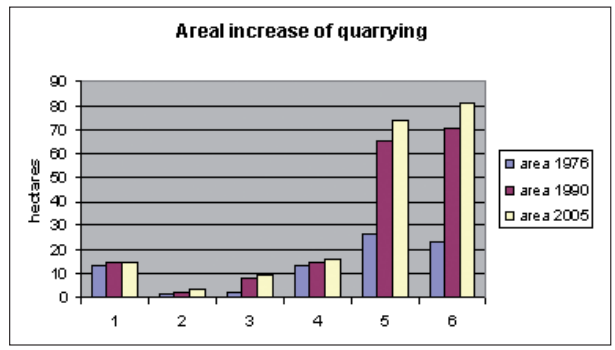

Fig. 5: Areal increase of quarrying at Minervino Murge in the time span 1976-2005. Numbers on the x axis refer to the six 1:5,000 scale topographic maps that were used for air photo interpretation.

The quarrying activity coupled in the last 30 years with intensive stone clearing practices, even favoured by public subsidy from the European Community. These subsidies, addressed to changes in the land use for introducing new crops, resulted in the High Murge in transforming the original bare karst in a landscape which is unnatural for this area, with wide development of cornfields. Most of the rocks resulting from clearing of the fields, and quarrying activity as well, are often dumped into swallow holes and caves (Fig. 6), or piled around karst depressions. Besides the negative effect on the karst landscape, these actions are extremely dangerous for cav-

ers, due to instability of the dumped and/or piled rocks. Thus, the indicators **infilling** and **dumping** were considered, respectively, with rating 2 and 3.

Fig. 6: Stone clearing practices produced the formation of non natural cornfields in the Minervino Murge area, and in piling of rock debris in the proximity of cave entrances (two persons for scale on the rock pile). Other rocks have been dumped as well into the cave, creating a serious danger for cavers, due to instability of the rocks, both outside and within the cave.

At present, thousands of hectares of the original pastures have been transformed, and this has often resulted in later abandonment of the fields, due to intense erosion. In fact, stone clearing is carried out through the use of modern technologies and machinery, able to crush the carbonate rocks destroying the epikarst, and eliminating the soil. When it rains, even on gentle slopes surface runoff develops and intense erosion starts. Erosional processes may be so severe to determine onset of both linear and areal erosion on the slopes, through development of rills and gullies. The indicator **erosion** has been therefore assigned a rating 2. Another consequence of the stone clearing practice is **flooding** in subsurface karst, as a further effect of the land use changes at the surface: similarly than the previous indicator, also flooding was considered to have a severe impact, scored as 2.

Caves in the Minervino Murge area are characterized by vertical entrances, with some meters-deep shafts. Difficulty in accessing the caves, which is limited only to expert cavers, resulted in high protection and safeguard of the caves and the deposits therein from removal and vandalism, and strongly limited other problems related to frequent visits by man. This had important consequences in the attribution of scores to some indicators. In practice, five indicators belonging to different categories were listed as 0.

The category *Biota* was the most difficult to evaluate at the Minervino Murge area. Thorough bibliographical research produced very little results in terms of published articles. Furthermore, nothing was found to allow a comparison at different times of the species richness and density of population, which is required to assign scores to the biota indicators. Thus, four out of the five indicators of this category were considered as Lack of Data.

Vegetation disturbance was the only one that applied to the case study in the Biota category: a score 3 was assigned to this indicator, due to the long history of deforestation in the area, that brought to have today only very few remnants of wood cover (most of these is represented by re-forested areas). Another significant problem is the state of the present vegetation, since lack of maintenance of woods has resulted in a situation highly prone to wildfires, and with several non wealthy trees and plants. To cover even this issue of the vegetation, a new indicator **(State of vegetation)** was introduced, and again a score 3 was assigned.

Many of the problems related to anthropogenic activities in the Minervino Murge area remained unsolved even after establishment of the Alta Murgia Natural Park. This was mostly due to the lack of control by the Local Authorities, combined with a public indifference toward safeguard of the natural environment from large sectors of the population in the area. For these reasons, when evaluating the indicators belonging to the category *Cultural Factors,* some negative scores have been assigned (2 for **Regulatory protection,** 3 for **Enforcement of regulations,** again 2 for both **Public education** and **Building of roads**).

The Karst Disturbance Index in the Minervino Murge area was determined using 26 indicators (Table 2), and resulted in a value of 0.49, which means "Disturbed" (Table 1). Four indicators were considered as LDs, that resulted in LD rating 0.15, corresponding to good confidence.

The difficulty in accessing the natural karst caves in the area, due to vertical entrance of most of the caves, has been before mentioned. This difficulty affects the scores of five indicators (shown in italics in Table 2). Interestingly, if we do not take into account these five 0 scores, the karst disturbance index for the Minervino Murge area rises to a value of 0.6 (see values in brackets in Table 2), falling in the upper range of the "Moderately disturbed" class. Accordingly, the LD rating changes from 0.15 to 0.19 because of the lower number of indicators used, but still indicates good confidence of the data.

CASTELLANA-GROTTE AREA (LOW MURGE)

Castellana-Grotte is worldwide famous due to the remarkable, more than 3 km long and more than 120 m deep, caves, which were explored for the first time in 1938, and soon after that became one of the most visited tourist caves in Europe. Discovery of the caves played an

Tab. 2: Karst disturbance index for the two study areas. The numbers between brackets at Minervino Murge derive from deleting the five indicators shown in italics in the table (see text for explanation). For details about each single indicator, the reader is invited to refer to the paper by Van Beynen & Townsend (2005).

category	*indicator*	**MINERVINO MURGE**	**CASTELLANA GROTTE**
Geomorphology	Quarrying/mining	3	2
	Flooding (surface)	0	1
	Stormwater drainage	2	2
	Infilling	2	2
	Dumping	3	2
	Erosion	2	1
	Compaction	1	2
	Flooding (subsurface)	2	1
	Decoration removal	1	2
	Mineral/sediment removal	1	2
	Floor sediment compaction	0	1
Atmosphere	*Desiccation*	0	1
	Condensation/corrosion	0	2
Hydrology	Pesticides/herbicides	1	2
	Industrial and petroleum spills	2	2
	Algal blooms	deleted	deleted
	Changes in water table	1	1
	Changes in cave drip waters	1	1
Biota	Vegetation removal	3	2
	State of vegetation	3	1
	Species richness (cave)	LD	1
	Population density (cave)	LD	1
	Species richness (groundwater)	LD	LD
	Population density (groundwater)	LD	LD
Cultural factors	*Destruction/removal of historical artifacts*	0	2
	Regulatory protection	2	2
	Enforcement of regulations	3	2
	Public education	2	1
	Building of roads	2	2
	Building over karst features	1	2
	Construction within caves	0	2
TOTAL NUMBER OF USED INDICATORS		26 *(21)*	26
KDI		**0.49** *(0.6)*	**0.57**
TOTAL NUMBER OF LDs		4 *(4)*	2
LD RATING		**0.15** *(0.19)*	**0.08**

important role in the tourist development of this small town of Low Murge, that modified its name in 1950, by adding Grotte, and thus becoming the present Castellana-Grotte.

The show cave is only one of the many features of this part of Apulia, where both surface and subsurface karst landforms are widespread (Parise, 1999). The main differences with the first territory dealt with in the present paper are that Castellana-Grotte and the surrounding territory develop at lower elevations (between 330 and 240 m a.s.l.), and the caves are not prevailingly vertical. As for the anthropogenic environment, the show caves, combined with the vicinity to the Adriatic coastline, a further reason of attraction for thousands of tourists during the summer season, produced in Low Murge a much greater presence of man's activities and infrastructures. Several consequences on the natural karst environment had to be registered, including diversion of the natural runoff, and of the water infiltration rate in the rock mass as well, with greater possibility of occurrence of surface flooding (Fig. 7).

Fig. 7: Surface flooding at Castellana-Grotte, as a consequence of a severe rainstorm.

Without entering into the details of every single indicators, it has to be noted that in the Castellana-Grotte area no score 3 was assigned (Table 2), but, at the same time, none indicator had score 0, which means that some negative effects from human activities had to be registered within each indicator of all the categories. For example, the quarrying activity is not so intense as in High Murge; nevertheless, small quarries are present in the area, locally very close to significant subsurface karst features. In some cases, anthropogenic activities are still producing negative effects, irrespective of the existing laws and prohibitions (Fig. 8).

Due to the easiness in accessing the caves, many of the indicators that in the first study area had score 0, in this case presented problems, because of vandalism, removal of sediments and materials, and floor sediment compaction. At the same time, access of man into the caves also had negative consequences for the biota environment.

Fig. 8: Pozzo Cucù cave (Fig. 8a) is one of the most remarkable caves in the Castellana-Grotte territory. Even though the cave was declared of interest for the European Community, due to its peculiar cave ecosystem, some anthropogenic works (Fig. 8b) strongly altered the natural landscape above the cave in the last years.

Besides these problems, the presence of the Castellana show caves adds further negative effects, as usual in show caves frequented by high number of tourists (Cigna, 1993; Pulido Bosch *et al*., 1997; Aley, 2004): changes in the cave environment, development of lampenflora as a consequence of the lighting system, construction within caves for trails and pathways, and so on.

The Karst Disturbance Index in the Castellana-Grotte area was therefore determined using 26 indicators, and resulted in a value of 0.57 (Table 2), corresponding to the upper range of the "Disturbed" class. Two indicators were considered as LDs, that resulted in LD rating < 0.1, corresponding to high confidence

DISCUSSION AND CONCLUSIONS

Determining the karst disturbance can be very difficult because of the inherent complexity of karst systems, and subjective because it requires interpretation of the karst environment by the expert, depending upon her/his background. For example, a geologist might concentrate on geomorphology, neglecting the subsurface biota or the water quality. Since the method lists all the categories for which data should be collected, and uses pre-established indicators, the need for the evaluator to decide what is important to measure is strongly reduced. Furthermore, the utilized scoring system limited to four possibilities reduces much of the uncertainty associated to multi-level scoring systems, and prevents the evaluator from consistently choosing a middle value, forcing him to be more decisive.

It has to be stressed that this approach is based upon some simplifying hypothesis: first, the index is considered to be applicable for all karst regions, regardless of the difference in karst types; secondly, any change to the karst environment is evaluated as caused by human impact. Karst is, however, characterized by natural variability over space and time (Williams, 1993); application of the index to heterogeneous areas, where two or more types of karst are present, should be performed with great care. In addition, it is sometimes difficult to discriminate between human-induced environmental changes and those caused by on-going natural processes.

A final, but not less important, assumption of the method is the availability of data; actually, this varies from region to region, and depends on the thoroughness of studies and research undertaken for that specific area. Through the Lack of Data, the index includes this aspect and allows to provide a measure of the adequacy of the available information, and to highlight those karst regions where more research activity is needed.

Notwithstanding these simplifications, the Karst Disturbance Index can be adapted to any karst region, and this also contributes to improving the ability to compare the degree of disturbance to karst among different locations. It can serve as a standard tool for the evaluator (a karst scientist having the experience needed to interpret the available data) to provide a quantitative measure of the human impact, and it might help local administrations to contrast the increased human pressure and to address the sustainable management of karst environments.

The present study, through implementation of the Karst Disturbance Index to two areas in the Apulian karst of southern Italy, has shown the usefulness of the approach for a preliminary evaluation of the degree of disturbance in karst, as an help toward a better understanding of the impacts to the natural environment deriving from man's activities. At the same time, the need of more detailed research and analysis in disturbed karst areas was well highlighted in both the areas, where a strong contrast occurs between the existing laws for protection and safeguard of the environment, and their real enforcement. This latter, in particular, has produced and, sadly to say, is still producing as well, heavy degradation, destruction of caves, and frequent loss of the karst landscape in several sectors of the Apulia region

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