

NEW PERSPECTIVES ON GEOCONSERVATION
IN PROTECTED AND CONSERVED AREAS

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Geoconservation initiatives for caves, karst, and springs

John Gunn

ABSTRACT

In this paper the focus is on the surface landforms that are found on carbonate karst, on caves within carbonate karst, and on the springs that discharge from carbonate karst. Around 20.3 million km² of the earth's land surface is characterized by the presence of carbonate rocks. Most is potentially karst. These areas have distinctive surface landforms of high geodiversity value, together with over 10,000 km of cave passages, most of the largest springs on Earth, and many smaller springs. Karst areas and caves commonly have high aesthetic value and high biodiversity value, hosting many endemic and threatened plant and animal species. Carbonate karsts are present in 75 World Heritage Properties, 67 UNESCO Global Geoparks, 151 Biosphere Reserves, and 124 Ramsar Sites. However, the areal extent of karst in these and other protected areas, and the

extent of cave and karst geodiversity, are rarely documented. There is a clear need for inventories to inform geoconservation. Two recent IUCN resolutions have important implications for cave and karst geoconservation, and new guidelines for cave and karst protection will be published in 2022.

INTRODUCTION

This paper focuses on the surface landforms that are found on carbonate karst, on caves within carbonate karst, and on the springs that discharge from carbonate karst. The majority of the world's karst has formed by dissolution of carbonate rocks (limestone, dolomite, and marble), although karst and caves are

Deer Cave in Gunung Mulu National Park and World Heritage Property, Malaysia, is one of the world's largest cave passages. JOHN GUNN

present on other lithologies, most notably evaporite rocks. The term *karst* was originally used to describe a limestone region on the border of Slovenia and Italy, but is now used widely by geoscientists and others to denote an area with distinctive landforms and hydrology developed on rocks of high solubility. A key feature of karst areas is underground water movement along preferential pathways (channels) that are enlarged by rock dissolution; when they become large enough for turbulent flow (commonly at a void width of around 10mm) they are known as *conduits*. Over time, some conduits become large enough for human exploration and can then be called *caves*. The groundwater flowing through conduits is discharged by springs.

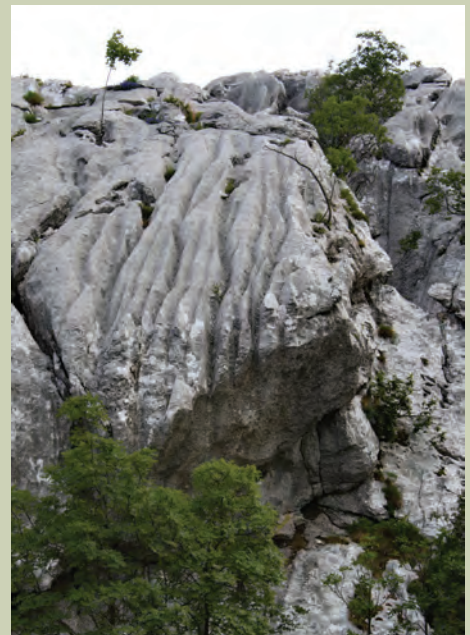
Goldscheider et al. (2020) have estimated that 9.4% of the global ice-free land surface consists of continuous carbonate rocks and a further 5.8% is occupied by discontinuous carbonate rocks, or carbonate rocks mixed with evaporites. This means that around 20.3 million km² of the land surface is characterized by the presence of carbonate rocks, all of which are potentially karst and many of which have distinctive surface and underground landforms with a high geodiversity value. This article is primarily concerned with geodiversity and the primary elements in that diversity. However, it is important to note that karst areas commonly have dramatic scenery and high aesthetic value. In addition, both karst areas and caves commonly

have high biodiversity, hosting many endemic and threatened plant and animal species. Hence, there should be a strong synergy between karst and cave geoconservation and the conservation of biodiversity.

CARBONATE KARST, CAVE, AND SPRING GEODIVERSITY

In karst areas, streams commonly lose flow, with water sinking into the ground, either gradually over a reach of tens to hundreds of meters or at a single point, and emerging as springs that are sometimes many kilometers from the sink-point. Globally, there are many thousand karst springs, including all of the world's largest springs in terms of average and maximum discharge. The zone between sink and spring may extend beneath non-carbonate rocks that provide no evidence of the karst at depth. Where carbonates crop out, they are commonly devoid of surface drainage and a wide variety of surface landforms may be present depending on climate, lithology, and the presence or absence of superficial deposits. As carbonate rocks are commonly of high purity, the dissolution process yields little material on which soils can form. Consequently, these areas have rocky surfaces on which there are a variety of small solution pits, grooves, and channels, collectively known as *karren*. Where there is a thicker soil cover, most commonly developed on superficial deposits such as glacial till, loess, or volcanic ash, the surface is typically pitted by closed depressions (*dolines*; also known as *sinkholes*) that range in diameter from 2–100m and in depth from 1–650m. Other typical

Karren in Montenegro. © JOHN GUNN



Tiankeng are giant dolines over 100m wide and deep.

Left: Blue Lake, Croatia. Right: South China Karst WHP, Wulong, China. © JOHN GUNN



karst landforms are *blind valleys* that terminate at a stream-sink, *pocket valleys* that commence at large springs, and *dry valleys* that provide evidence of former surface streams. *Poljes* are large (one to tens of kilometers in length) flat-floored and steep-sided depressions in karst areas. In tropical karst areas, positive relief forms include *cones* (hemispherical hills with gentle to steep slopes also known as *mogote* or *fengcong*) and high, sub-vertically walled, isolated towers (*fenglin*).

Caves in carbonate rocks exhibit a very wide range of three-dimensional geometries and passage morphologies that relate to their original mode of formation and subsequent developmental history. Major distinctions are made between *epigenic caves* that are largely formed by water containing dissolved carbon dioxide that descends from the land surface under gravity, and *hypogenic caves* that do not depend on surface sources of acidic water, but are formed by upwards-flowing fluids that recharge the cavernous zone from lower rock units. A third type, *flank margin caves*, form where carbonate rocks crop out at the

coast and dissolution occurs at the interface of fresh and salt water. One feature that distinguishes caves from most other landforms is that as a new passage forms at lower levels in the carbonate rock sequence, the older, relict, passage remains at higher elevation. This passage is preserved until the land surface is lowered to intersect with the top of the cave. Because this may take millions of years, caves have the potential to be extremely long-lived landforms.



Buna Spring (Bosnia and Herzegovina) is one of the largest springs in Europe, with an annual average flow of about 43m³/s. It emerges at the head of a pocket valley. © JOHN GUNN

In addition to the great diversity in geometric shape, caves also contain a large range of clastic sediments and chemical precipitates (*speleothems*) that both add to the geodiversity and can provide evidence for past climates and environmental conditions on the surface.

Karst springs are fed by branching conduit networks that have similarities with surface drainage networks, as there is a hierarchy in which channels are tributary to small conduits that in turn are tributary to larger conduits and, in some cases, to caves. A further difference between karst springs and those in other materials is that deep flow-paths are common with many *vaclusian* springs where the water rises tens and in some cases over 100 meters up water-filled conduits. Reversing springs (*estavelles*), which are only found in karst, function as a sink for part of the

year and switch to being a spring when the conduit system into which they drain is surcharged. In coastal karst areas, conduits that discharged to surface springs during Pleistocene-era low sea levels may continue to operate during present higher levels and form submarine springs (*vruljas*) or intertidal springs. Conversely, higher-elevation conduits that have been drained following valley-deepening may discharge large volumes of water during times of high recharge when lower conduits are surcharged. In other cases, high-elevation karst springs may be perched on less permeable strata. This variety of settings means that karst springs have high geodiversity in addition to commonly being important for water supply.

As will be apparent from the above brief description, cave and karst terminology is specialized and useful guides have been produced by Lowe and Waltham

Majerovo Vriilo, Croatia: A large vaclusian spring explored by cave divers to a depth of 92m below the point of emergence. © JOHN GUNN





Popovo polje in Bosnia-Herzegovina is around 40km long and up to 5km wide. The Trebinjica River, now canalized, flows along its floor. Under natural conditions there were over 500 sinks (*ponors*) and reversing springs (*estavelle*). © JOHN GUNN

(2002) and the US Environmental Protection Agency (2002). Books such as Ford and Williams (2007), Gillieson (2021) and Palmer (2007) and the encyclopedias edited by Gunn (2004) and White et al. (2019) provide additional information.

THE PROTECTION OF CAVES AND KARST

The International Union for Conservation of Nature (IUCN) recently published guidelines for geoconservation in protected and conserved areas as number 31 of its Best Practice Protected Area Guidelines (BPPAG) series (Crofts et al. 2020). These guidelines provide generic advice that is equally applicable to caves and karst together with three case studies that include caves and karst: community-based geoconservation management in Gunung Sewu UNESCO Global Geopark, Indonesia; management of Jenolan Karst Conservation Reserve, New South Wales, Australia; and improvement in water quality of the Reka River, Škocjanske jame Regional Park, Slovenia. More detailed advice for the management of karst and cave protected and conserved areas is also provided. In 1997, IUCN published *Guidelines for Cave and Karst Protection* (Watson et al. 1997), covering both the geodiversity and biodiversity of caves and karst areas. A second edition of these general guidelines (Gillieson et al. 2022, in press) will build and expand on BPPAG 31 by specifically considering the protection and conservation of geodiversity, geoheritage, and ecology in karst and cave areas. They will be addressed under three headings: The Nature of Karst Systems; Human Activities on Karst: Impacts

and Mitigation; and Managing Karst in Protected Areas.

A new initiative that is important for geoconservation in general and particularly for caves and karst is IUCN Resolution 074 (*Geoheritage and Protected Areas*), which was passed at the 2021 World Conservation Congress. In the resolution, IUCN calls on “states, non-governmental organizations, universities, researchers, economic stakeholders and protected area managers to take into account the specific issues linked to underground environments in the definition and implementation of nature conservation policies and to adopt a *holistic approach* to the management of underground natural environments, considering *all relationships between biological and geological elements*” (emphasis added). Although work on the second edition of *Guidelines for Cave and Karst Protection* commenced before IUCN Resolution 074, the guidelines will provide a tool that organizations can use to fulfill Resolution 074.

A second important initiative from the 2021 World Conservation Congress is IUCN Resolution 088 (*Conservation of the Natural Diversity and Natural Heritage in Mining Environments*). This is particularly relevant to caves and karst because carbonate rocks are mined throughout the world as a source of aggregate, as a raw material in the manufacture of cement, and for use in many other industries. Carbonate rocks also host ores, most notably bauxite, fluor spar, iron, and lead-zinc. Carbonate rocks are mostly mined in large open-pit quarries, whereas ores



An example of a through cave in Ethiopia. Here, the Weib River sinks at the entrance to Sof Omar Cave (left) and can be followed through large passage (center) to the spring where it emerges (right). © JOHN GUNN

are commonly extracted underground. Surface mines destroy karst landforms, but may also expose features of geoheritage value. Both surface and underground mines commonly intersect cave passages. The resolution calls on IUCN member states to conserve those mining environments that have high natural heritage value (both geological and biological).

CARBONATE KARST AND CAVES IN PROTECTED AREAS

Carbonate karst systems form part of protected areas at scales from local (for example a reserve with a single cave or cave system), through national (for example the Sites of Special Scientific Interest that receive legislative protection in Great Britain), to those that have received international recognition by the United Nations Educational, Scientific, and Cultural Organization (UNESCO): World Heritage Properties (WHPs), Global Geoparks, Ramsar Sites, and Biosphere Reserves. (Ramsar Sites are recognized by UNESCO, but unlike the others the secretariat is hosted not by UNESCO but by IUCN.)

Traditionally the focus for geoconservation has been WHPs. In 2008, IUCN commissioned a global review of karst WHPs with an assessment of the present situation, future prospects, and management requirements (Williams 2008). In the report, Williams identified 45 WHPs with significant cave and/or karst interest, of which 27 were assessed as containing karst of outstanding universal value (OUV—the base criteria for attaining World Heritage status), together with a further 30 properties on the Tentative List of potential WHPs. In 2019, Williams (pers. comm.) updated the list and added nine WHPs designated after 2007 that were considered to have significant cave and/or karst interest. Of these, three were considered to have OUV

and four were on the 2008 Tentative List. Two further properties from the 2008 Tentative List were added to the South China Karst serial WHP. Of the 54 karst properties on the World Heritage List as of 2019, 49 were carbonate karst and five other lithologies (three quartzite fluviokarst, one conglomerate karst, and one vulcanokarst).

Williams (2008) noted that in addition to the sites on his list there were other WHPs that contain caves or karst of national or regional significance. To identify these, Gunn (2021) examined a database of all WHPs downloaded from the World Heritage website and searched for the keywords “karst,” “limestone,” and “cave.” Surprisingly, the site descriptions for 22 of the 49 WHPs with carbonate karst on the Williams list did not contain the words “karst” or “limestone,” suggesting that this aspect of the geoheritage had not been fully recognized. In some cases, this was most likely because the WHP had been designated mainly for cultural or biological reasons. The Hallstatt-Dachstein/Salzkammergut Cultural Landscape WHP (Austria) is a good example of the former, as there is no mention of karst or caves in the citation, but the Dachstein massif which lies within the WHP is an excellent example of glaciokarst and contains several hundred caves. This WHP was designated in 1997 when the failure to recognize the value of the geoheritage was, perhaps, understandable. However, The Causses and the Cévennes, Mediterranean agro-pastoral Cultural Landscape WHP (France) was designated in 2011 solely on the basis of cultural criteria with no mention of the outstanding karst that includes limestone plateaus, deep gorges, and many dolines and caves. Gunn (2021) also identified 10 WHPs that

were not on the Williams 2019 list, but had the words “karst” or “limestone” in the site description. Of these, seven are not areas with geoheritage interest (four were designated for limestone dwellings, two for rock art, and one is surrounded by, but does not contain, karst). The remaining three include areas of carbonate karst that Williams considered to be of national or regional significance. As Gunn (2021) was primarily interested in groundwater systems, some WHPs with geoheritage interest were excluded from his list. Further analysis undertaken for the present paper has identified 75 WHPs having carbonate karst of geoheritage value. Of these, 26 are considered by Williams to have OUV, 24 were designated primarily or solely for cultural values (including two with karst OUV), 13 were designated primarily or solely for biological values, and eight are coastal properties that have geoheritage and management requirements that differ from inland sites.

A key message from this analysis is that carbonate karst geoheritage is present in 75 WHPs, but in many the extent of this interest may not be recognized and there may be no geoconservation measures in place. Hence, there is a need for inventories (as discussed further below) and for incorporation of geoconservation into site management briefs.

During the late 20th century, an alternative model for geoheritage protection was developed in which tourism-led sustainable development with a “geo” focus was promoted. The label *geopark* was used to

distinguish these areas from the many protected areas with an archeological, historical, or biological focus. Any area is able to use this label, but in November 2015 UNESCO ratified the creation of a new label, UNESCO Global Geopark, to signify its endorsement of particular geoparks as part of a formal international system. As of September 2021, there were 162 UNESCO Global Geoparks and, remarkably, 67 of them contain carbonate karst, which is testimony to the high geoheritage value and touristic interest of karst.

In contrast to UNESCO Global Geoparks, the other two types of UNESCO-recognized protected areas, Biosphere Reserves and Ramsar Sites, have protection of biological interest as their primary goal. However, they may also contain significant geoheritage interest that deserves protection. Gunn (2021) identified 151 Biosphere Reserves in 62 countries and 124 Ramsar Sites in 55 countries containing carbonate karst. An important development that should improve understanding of geoheritage in Biosphere Reserves is the establishment of CaveMAB, “a network of biosphere reserves around the globe that treasure natural and cultural phenomena related to the caves” (<https://cavemab.com/>).

THE NEED FOR INVENTORIES OF CAVES AND KARST

The fact that many protected areas, including those recognized by UNESCO, contain carbonate karst should mean that their karst geoheritage is acknowledged and protected. However, within these pro-

Wan Fenglin in Xingyi Geopark, Guizhou, China: an example of spectacular fenglin-type karst. © JOHN GUNN



tected areas the areal extent of karst is rarely known and so its geodiversity is neglected. An example is provided by a recent report, *Conservation of Limestone Ecosystems of Malaysia* (Liew et al., 2021). This impressive seven-part report provides information on 1,393 limestone sites in Malaysia in terms of “numbers of outcrops, size distribution, location, major clustering of outcrops, anthropogenic activities related to tertiary industries, anthropogenic activities related to primary industries, forest cover of the outcrops, forest cover in a 250m buffer zone around the limestone outcrops, biodiversity information, and a proposal for a roadmap towards the conservation management of limestone outcrops and ecosystems in Malaysia.” However, the focus is almost entirely on biodiversity, and while it is a major advance to know the extent of limestone karst in Malaysia, for the majority of the described outcrops there is no information on the geodiversity. Clearly this is a case where there has been a failure to consider “all relationships between biological and geological elements” as called for in IUCN Resolution 074, discussed above.

Even where karst is a primary feature in the designation of a protected area, there is commonly no detailed landform inventory. For example, in the Gunung Mulu WHP, Malaysia, one of the world’s finest karst areas, there is no overall assessment of the individual surface landforms, and in Liew et al. (2021) the entries for Gunung’s Api, Benarat, and Buda, the three largest hills in the WHP, only describe the extent of forest cover with no mention of their spectacular surface karst.

The situation in caves is much worse than on the surface, as in most protected areas there is at best a list of cave entrances but cave lengths and the features that contribute to cave geodiversity, principally cave passage morphology, sediment deposits, and biogeochemical deposits such as biofilms and speleothems, are undocumented. An exception to this, and an example of good practice, is provided by three inventories of special interest features in English Cave Sites of Special Scientific Interest. Two of the reports are not easily accessed, but the third by Farrant and Lowe (2002) is open access. All three reports follow the same format in providing a topographical plan of each cave in the Sites of Special Scientific Interest on which are marked the locations of notable examples of the

three key interest features: passage morphology, speleothems, and clastic sediments. These plans form the basis for geoconservation monitoring, which is undertaken by recreational cavers.

In 2021, a meeting to mark an International Year of Caves and Karst was held at the UNESCO headquarters in Paris. At the meeting the International Union of Speleology encouraged UNESCO to develop inventories of all caves, karst features, and their contents in UNESCO-recognized protected areas. This is supported by IUCN Resolution 074 which requests that its director general and the World Commission on Protected Areas. “mobilise IUCN Regional Offices and the IUCN Global Programme in support of national efforts to collect, compile and publish data on geoheritage and geodiversity in protected areas, *including proper inventories...*” (emphasis added). Similarly, IUCN Resolution 088 “encourages the Member States to draw up *inventories* of the natural and cultural heritage resulting from mining activities, both historical and current, and to take the necessary legal action to conserve them.” If this can be achieved, it will represent a major advance in geoconservation, as features can only be conserved after they have been described and documented.

PROTECTION OF KARST SPRINGS AS LANDFORMS

It has been estimated that 9.2% of the global population, some 678 million people, are karst water consumers (Stevanovic 2019). Much of that water is obtained from springs, with the remainder from boreholes, most of which tap into groundwater that would naturally have been discharged by springs. Consequently, there is an extensive literature on hydrogeological aspects of karst springs (e.g. Kresic and Stevanovic 2010) and on the protection of karst groundwater, including a variety of tools to design source protection zones and to undertake groundwater vulnerability assessments. Despite this there is a global problem of springs drying up or suffering from severely reduced flow due to groundwater abstraction, which may be exacerbated by climate change. In addition, it remains the case that karst springs are particularly susceptible to pollution because groundwater can travel many kilometers underground and karst springs commonly have both local and distal catchments. Examples are provided by Cantonati et al. (2020) who advance the case for improved global stewardship of springs. This is a well-argued paper but, as with the

Malaysian example discussed above, the emphasis is on “springs as a distinctive group of ecosystems” with their value as landforms left unconsidered. The Karst Commission of the International Association of Hydrogeologists has proposed an initiative to select, label, and protect the world’s most important karst springs, and it is intended that this initiative will include consideration of the geological and geomorphological context, and hence geoheritage value, in addition to hydrological function.

CONCLUSIONS

Carbonate karst occupies around 15% of the global ice-free land surface and is present in many protected areas including 75 WHPs, 67 UNESCO Global Geoparks, 151 Biosphere Reserves, and 124 Ramsar Sites. However, the areal extent of karst in these, and other, protected areas, and the extent of cave and karst geodiversity, are rarely documented

and there is a clear need for inventories to inform geoconservation. The International Union of Speleology has encouraged UNESCO to develop inventories of all caves, karst features, and their contents in UNESCO-recognized protected areas. Resolutions 074 and 088 at the most recent IUCN World Conservation Congress advocate production of inventories and these should be a priority in the decade to 2030. Geoconservation efforts should be informed by IUCN’s BPPAG 31 and by the forthcoming second edition of the *Guidelines for Cave and Karst Protection*. Many karst areas and caves that have high geodiversity value are also areas of high biodiversity, and there is a strong case for adopting a holistic management approach in which all relationships between biological and geological/geomorphological elements are taken into account.

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On the cover of this issue

The precipitous rock spires of Meteora World Heritage Site in Greece have a complex geological history. Over the centuries a number of Eastern Orthodox monasteries were built atop them, and today's World Heritage Site recognizes this cultural history as part of the overall geoheritage. | [STATHIS FLOROS](#)