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A global review of karst World Heritage properties: present situation, future prospects and management requirements

WCPA World Commission on Protected Areas

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World Heritage Convention

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Cover Image: Karst towers in the Ha Long Bay World Heritage site, Vietnam, have been flooded by a combination of geological subsidence and post-glacial sea level rise. The partly drowned tower karst results in a landscape of hundreds of islands (photo by P. Williams).

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World Heritage Caves and Karst
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PART 1: REVIEW OF KARST LANDSCAPES AND CAVES IN RELATION TO THE WORLD HERITAGE LIST

1.1 Introduction

Nominations of Karst Properties to the World Heritage List

Following IUCN's evaluation report to the 31st World Heritage Committee in Christchurch (2007), the World Heritage Committee noted [Decision 31 COM 8B.13]

that karst systems (including caves) are relatively well represented on the World Heritage List. Worldwide there are a large number of protected karst landscapes with caves and at a detailed level every one of these can assert that it is in some way unique. Therefore in the interests of maintaining the credibility of the World Heritage List, IUCN considers that there is increasingly limited scope for recommending further karst nominations for inclusion on the World Heritage List. In particular, IUCN recommends that the World Heritage Committee should consider indicating clearly to States Parties that further karst nominations should only be promoted where:

- *There is a very clear basis for identifying major and distinctive features of outstanding universal value that has been verified by a thorough global comparative analysis;*
- *The basis for claiming outstanding universal value is a significant and distinctive feature of demonstrable and widespread significance, and not one of many narrow and specialized features that are exhibited within karst terrains. IUCN recommends that States Parties considering karst nominations carry out an initial global comparative analysis* ***prior*** *to proceeding with the development of a full nomination, in order to minimize the possibilities of promoting a nomination that will not meet the requirements of the World Heritage Convention, including those concerning the conditions of integrity.*

1.2 Purpose and Scope of this Review

The purpose of this review is to assist with the implementation of this decision and, in particular, to advise States Parties to the World Heritage Committee on:

1. The scope of karst landscapes and features, including caves, already represented on the World Heritage List;
2. The potential and priorities for further future recognition of karst landscapes and features on the World Heritage List in relation to the relevant World Heritage criteria; and
3. The requirements for integrity and management that should apply to karst landscapes and features on the World Heritage List.

The geographical scope of this report is global, including, but not limited to, the territory of member states of UNESCO. The thematic scope of the study is on sites included, or with the potential to be included, on the World Heritage List in relation to their value as:

- Landscapes that are formed by the primary action of karst processes above and below ground; and
- Karst landscapes and caves of outstanding and universal importance in relation to geoscience, assuming their accessibility and comprehension by civil society.[1]

[1] IUCN considers this does not include sites with interests that are only of a specialised scientific importance.

1.3 Definitions

Karst Landscapes

The word *karst* can be traced back to pre-Indoeuropean origins (Gams 1973, 1991, 2003; Kranjc 2001). It stems from *karra/gara* meaning stone, and its derivatives are found in many languages of Europe and the Middle East. A stony limestone region known as *Kras* (later germanicised to *Karst*) on the border region of Slovenia and Italy was the place where it was first scientifically studied. The area is referred to as the 'classical' karst, but it is part of a larger limestone region with a similar style of landscape that extends continuously southeast along the Adriatic coast to Montenegro and beyond. This wider region attained international scientific prominence through the investigations and publications of Jovan Cvijić (1893, 1901, 1918), regarded by many as the father of modern karst science. This larger region is referred to as the Dinaric Karst (Gams 2003). It is the paramount karst of Europe and the type site[2] of many karst features. Landforms in other parts of the world similar to those found in the Dinaric Karst are by extension known as karst phenomena.

Karst is found on particularly soluble rocks, especially limestone, marble, and dolomite (carbonate rocks), but is also developed on gypsum and rock salt (evaporite rocks). Carbonate rocks outcrop across about 15 million square kilometres of the ice-free continental area of the Earth (11% of the world's land area), but subsurface carbonate rocks involved in karst groundwater circulation considerably extend the active karst realm, to perhaps 14% of the world's land area. Maps and statistics of areas of carbonate rock outcrops are available from the following web address:

- http://www.sges.auckland.ac.nz/sges_research/karst.shtm

Karst landscapes are characterized by sinking streams, caves, enclosed depressions, dry valleys, gorges, natural bridges, fluted rock outcrops and large springs. Karst landforms are produced by rainwater dissolving rock (a process known as dissolution), but other natural processes often intervene, such as river erosion and glaciation, which modify the karst forms and produce intermediate landscape styles such as *fluviokarst, glaciokarst,* etc. Most caves form by dissolution by normal meteoric waters, although some are dissolved by thermal waters enriched by CO_2 and occasionally acidified by oxidized H_2S. Other caves form by dissolution at the interface of fresh and salt water along the coast. Important sources of information on the many features and varieties of karst and caves include encyclopedias by Gunn (2004) and Culver and White (2005) and texts by Ford and Williams (2007), Palmer (2007) and Salomon (2006).

Mammoth Cave National Park, a World Heritage property in Kentucky USA, has the world's longest natural cave network with more than 590 kilometres of surveyed passages. Another World Heritage property, Mulu National Park in Sarawak, contains the world's largest underground cavity - Sarawak Chamber in Good Luck Cave. It has a floor space of 160 000 square metres and a volume of about 12 million cubic metres. The deepest limestone cave in the world is Voronja (Krubera) Cave in the western Caucasus Mountains, which is 2190 m deep.

Most caves are decorated with crystalline deposits such as stalactites and stalagmites (collectively known as *speleothems*). However, speleothem forms and mineralogy vary considerably according to the geological and hydrological context of their deposition. For an authoritative account of their crystal forms, evolution and mineralogy see Hill and Forti (1997).

Karst-like Landscapes

All rocks dissolve in rainwater to some extent, so small scale solution features such as flutes and rock pans are found on even the most insoluble rocks such as quartzite and basalt. Although such

[2] A type site is generally interpreted as the typical, representative or classic location for a particular feature or phenomenon. Type sites can be regarded as the best (or best-known) places that best display a particular feature or phenomenon. They may be the site of the first known example of a newly discovered or newly described feature or phenomenon. They may also provide the namesake for a term.

features are karstic because they were formed entirely by dissolution, the broader landscape of which they are part is not, because terrains made up of relatively insoluble rocks are dominated by landforms produced by other natural processes.

Quartzite fluviokarst: Landscapes developed on quartzites and dense siliceous sandstones occupy part of the continuum between karst and normal fluvial landscapes. In thermal waters the solubility of quartzose rocks approaches that of carbonate rocks and so solutional caves may form, but this is not the case at normal temperatures and pressures. In some quartzite terrains caves develop along the flanks of escarpments or gorges where deep fractures permit the ingress of water and hydraulic gradients are steep. But development of a permanently saturated zone with water filled caves and significant water storage (a typical characteristic of active karst) is generally precluded. The landforms and drainage characteristics of these siliceous rocks is therefore a style of *fluviokarst*, i.e., a landscape and subterranean hydrology that develops within the aerated zone as a consequence of the essential combined effects of dissolution and mechanical erosion and transport by running water.

Some distinctive and outstanding landscapes in quartzites or quartz sandstones and conglomerates feature on the World Heritage List, including Purnululu (Australia), Wulingyuan (China), Meteora (Greece) and Canaima (Venezuela) (see Table 1 at the end of this report). In addition, there are sandstone landscapes with impressive meshes of joint corridors, canyons and ruiniform towers elsewhere, such as the 'Ruined City' in Arnhemland (Australia). Wray (1997) provides a review. The most karst-like of these landscapes are developed on ancient, dense, hard quartzitic rocks. However, softer and usually younger quartzose rocks support related landscapes, such as Danxia landforms (named after a type site) in China, which are developed on 'red beds' (terrestrial sandstones and conglomerates usually of Cretaceous age). Although some quartz dissolution must undoubtedly occur, these are essentially joint directed fluvial landscapes, with structurally aligned corridors and canyons isolating pinnacles.

Pseudokarst: Karst-like landforms produced by processes other than dissolution or dissolution-induced subsidence and collapse are known as *pseudokarst*. A special case is *vulcanokarst* which comprises tubular caves within lava flows. The roofs of such caves often suffer mechanical collapse, which creates enclosed depressions and provides access underground. An outstanding example on the World Heritage List is Jeju Volcanic Island and Lava Tubes (Korea) (Table 1).

Glaciers also have sinking streams, caves, collapse depressions and large springs, but the karst-like features are produced by melting rather than dissolution, so the landscape is a *glacial pseudokarst.* Enclosed collapse depressions can be formed at the surface when patches of permafrost melt, the pitted karst-like landscape being termed *thermokarst*. This will become more prevalent with increased global warming.

1.4 Conceptual Framework

Karst landscapes and features have curious names that are often meaningless to those not familiar with the terrain. The evolution of karst is also unusual, since much of it goes on underground. A brief introduction to karst terms and ideas is therefore presented here in order to facilitate the comprehension of the rest of the document.

Karst is developed as rock is dissolved by water as it flows across the land surface, passes underground and later emerges at springs. In karst rocks the circulating water is able to develop caves by opening up fractures, in contrast to the behaviour of groundwater in other rocks where this does not occur. The main features of karst that result are illustrated conceptually in Figure 1. The primary division is into erosional and depositional zones. In the erosional zone there is net removal of the karst rocks by dissolution alone and by dissolution serving as the trigger mechanism for other processes, such as collapse. Some re-deposition of the dissolved rock occurs in the net erosion zone, mostly in the form of precipitates (such as stalactites in caves and tufa dams in valleys). In the net deposition zone new karst rocks are created, although most deposition occurs offshore.

Karst landform development is closely associated with the hydrological cycle as water passes into, flows through, and emerges from karst terrains. The resulting landforms can therefore be assigned to *input*, *throughput* or *output* roles. Input landforms that discharge water into the underground predominate and their morphology differs distinctly from landforms created by fluvial or glacial processes because of this function. For example, *blind valleys* are a characteristic feature of the input boundary of karst. Some large enclosed valleys with flat-floors termed *poljes* convey water across a belt of karst (and sometimes other rocks) at the surface and so serve in a throughput role. Varieties of erosional gorges at spring heads and constructional landforms, such as *tufa dams*, may be created where karst groundwater is discharged at springs, i.e. they are output landforms. Residual karstic hills, sometimes of considerable height and abruptness and known as *tower karst*, may survive on the alluvial plains below receding spring lines and beside rivers. If found in a coastal context, these towers may be partly or wholly drowned by the sea.

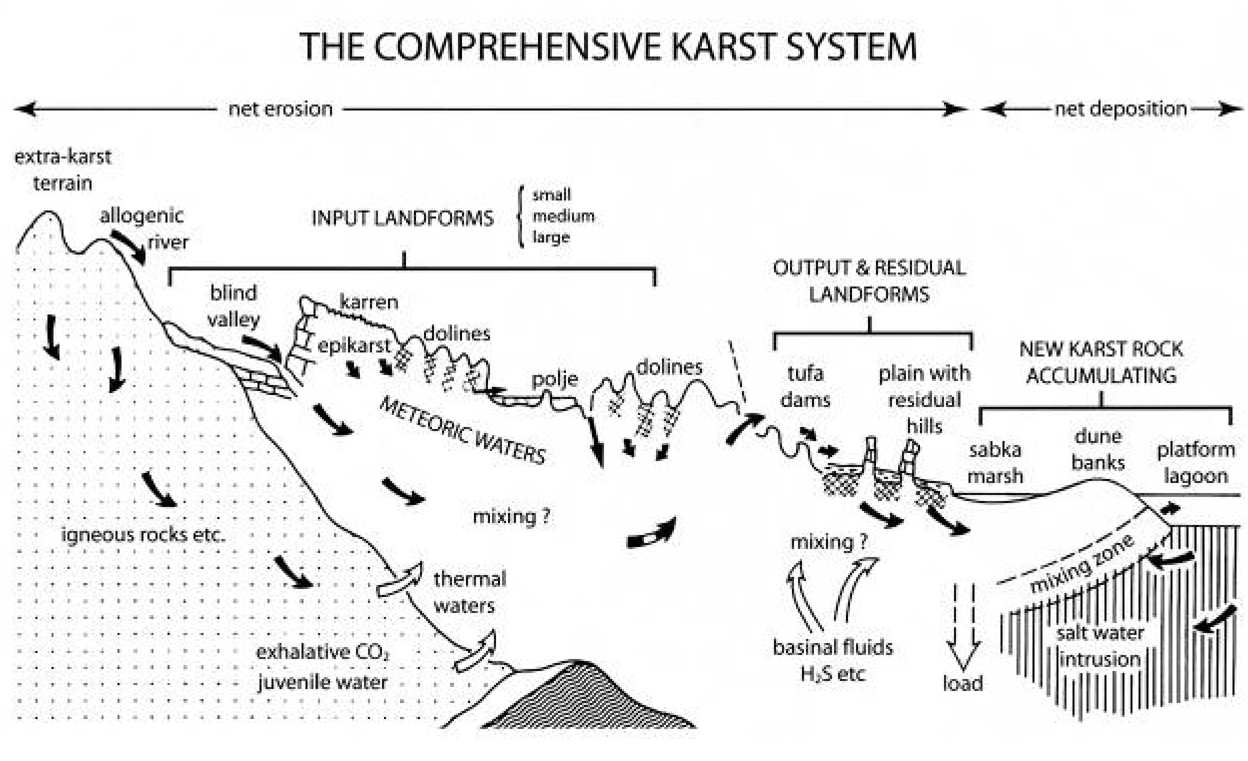

Figure 1. The comprehensive karst system schematically presents a full range of karst phenomena from input to output margins (from Ford & Williams 2007, fig. 1.2).

Most water circulating through karst rocks is of meteoric origin from rain or snow. It generally circulates at comparatively shallow depths, although the deepest aerated zone known is over 2 km deep in the Caucasus Mountains of Georgia, the location of Voronja (Krubera) Cave. Meteoric water usually has a residence time underground from a few days to a year, but more deeply circulating waters can remain underground for a decade or more. Cool meteoric waters sometimes mix with deep circulating waters that have been heated by contact with warm rocks or with waters originating in igneous rocks. Emerging warm waters at thermal springs often precipitate chemical deposits and build travertine terraces and dams. Such constructional features are output landforms. In this report *travertine* is used to describe dense crystalline calcite formed at hot springs or underground and generally lacking framing plant content; whereas *tufa* is used to describe grainy porous carbonate deposits accreting to algal filaments, plant stems and roots at cold water springs and seepages.

The assemblage of landforms in a region constitutes, or is normally the key natural component of, a landscape. The precise character of karst landscapes varies around the world as a consequence of lithology (e.g. marble, limestone, chalk, coral, etc), geological structure, and climate. The climatic conditions under which karst evolves is particularly influential in determining the resulting landscape style (Salomon 2006; Ford & Williams 2007); water availability being a key climatic factor in karst evolution. Thus aridity and extreme cold place severe constraints on karst development, because both of these climatic conditions lead to a scarcity of water in its liquid state, thereby limiting dissolution and permitting other geomorphological processes to dominate landscape evolution, e.g. frost shattering in high mountains.

Many karst features in arid and cold zones are the legacy of times in the distant past when conditions were much wetter or warmer. Thus it is not always easy to separate the effects of modern processes from those of earlier times. There may be generations of landscape development superimposed and an inheritance of underlying landform characteristics from climatic conditions experienced millions of years ago. We see this particularly in modern, hot arid zones where evidence often remains in the landscape from more humid times in the geological past. Nevertheless, in spite of the complicating effects of inheritance, broad differences in karst landscape styles are recognized between the humid tropics/subtropics (e.g. karsts of monsoonal Southeast Asia), the hot deserts (e.g. karsts of arid and semi-arid Australia), the humid temperate zone (e.g. the Dinaric Karst), and cold high altitude or high latitude regions (e.g. karsts of Canadian Rockies and Siberia).

Thus in order to evaluate the coverage of karst on the World Heritage List, each site needs to be reviewed in the context of three components:

- its climatic environment and karst style,
- the comprehensiveness of its karst system, and
- its geology and landscape history.

Karsts around the world also have very unusual biological values, because of the interplay of surface and subsurface environments in the context of widely differing biogeographical zones. Karst often occurs by chance in World Heritage properties inscribed for other reasons. In these cases, it is necessary to consider if the karst is of regional, national, or international significance or even perhaps of outstanding universal value. Those karsts with potential or identified international value will be further considered in this report.

Although the focus of this report is on *geodiversity*, one must recognize that karsts are often associated with outstanding *biodiversity* above and below ground with markedly different species assemblages in different parts of the world; the case of East Asia, for example, being described by Vermeulen and Whitten (1999). Endemicity and diversity are the rule, especially in isolated karsts in the tropics (Clements *et al.* 2006). Karst has unusual habitat conditions and often experiences drought at the surface when there is abundant water underground. Although it is unlikely that the biodiversity values of karst would be regarded as the principal basis for recognizing outstanding universal value, important biological values should be identified when World Heritage recognition is being sought (see section 1.7 for biological criteria).

1.5 Karst Landscapes and Caves on the World Heritage List

Properties on the World Heritage List with karst of *outstanding universal value* are identified in Table 1 with an asterisk beside their site number. Other properties listed in the table are likely to contain karst of international significance, although often their values have not been fully scientifically evaluated. The properties listed include both sites in which karst values were the dominant characteristic considered by IUCN during nomination (e.g. South China Karst), as well as sites in which internationally significant karst is but one of a range of outstanding values (e.g. Lorentz National Park). Table 1 mainly features properties inscribed for their natural values, although some are inscribed for cultural values but happen also to contain important karst. There are also numerous other properties on the World Heritage List not identified on Table 1 that have karst of national rather than international significance.

In order to assess the adequacy of the coverage of existing World Heritage karst sites and to identify significant gaps in the global distribution, it is instructive to map the data. Figure 2 shows the asterisked (outstanding value) sites from Table 1 plotted by site number on a world map of carbonate rocks – the principal host rocks for karst. Figure 3 shows the same sites plotted on a graph that depicts their climatic context; what geomorphologists refer to as their morphoclimatic setting (this is relevant because landform styles reflect the climatic process environment that guided their evolution).

World Heritage is concerned with *outstanding universal value*. There is no reason why regions possessing this should occur evenly across the world; thus there is no imperative to seek a uniform coverage. Nevertheless, we see from Figure 2 that there are significant gaps in the geographical distribution of karst World Heritage sites, representation being particularly poor in the following areas:

the Southern Hemisphere, especially in

- *South America,*
- *Africa, and*
- *Australasia and the South Pacific,*

and also in parts of the Northern Hemisphere, notably

- *North, Central and South Asia, and*
- *the Middle East.*

Further, we see from Figure 3 that there are significant gaps in the natural environmental distribution of karst World Heritage sites, there being relatively poor representation in:

- *arid, semi-arid, and periglacial environments.*

Consequently, it is recommended that future nominations for World Heritage listing should give particular attention to outstanding karst areas in these regions and/or environmental settings. We might also note that most karst World Heritage properties are in the net erosion zone, not in the net deposition zone (see Figure 1).

Figures 2 and 3 show the distribution of karst developed on carbonate rocks, but karst is also found on other highly soluble rocks, notably gypsum and rocksalt (collectively known as evaporite rocks). These lithologies are highly soluble compared to limestone, and so significant landscapes in them occur in drier parts of the world (this is not the case in wet zones because evaporite outcrops are reduced there to almost no relief). This is particularly the case for rocksalt, which yields highly distinctive and spectacular karst landscapes in the arid zone, notably in parts of Iran. Gypsum is less soluble than rocksalt and underlies many karst landscapes in parts of the world that are relatively dry but not necessarily arid (Klimchouk *et al.* 1996). The second longest cave in the world, Optimistychna (214 km) in Ukraine, is developed in gypsum and a well developed landscape of doline karst is found across the surface above it. However, we must note here that:

- *karsts on evaporite rocks are totally unrepresented on the World Heritage List*.

In cases where karst features on evaporite rocks are demonstrably of outstanding universal value in relation to geoscience, and are not just of a specialised scientific importance, but are accessible and comprehensible by civil society, then such cases could merit consideration for World Heritage inscription. The same point must also be made in relation to pseudokarst because, although pseudokarst features such as lava caves are represented on the World Heritage List, they are not common, and so merit further consideration.

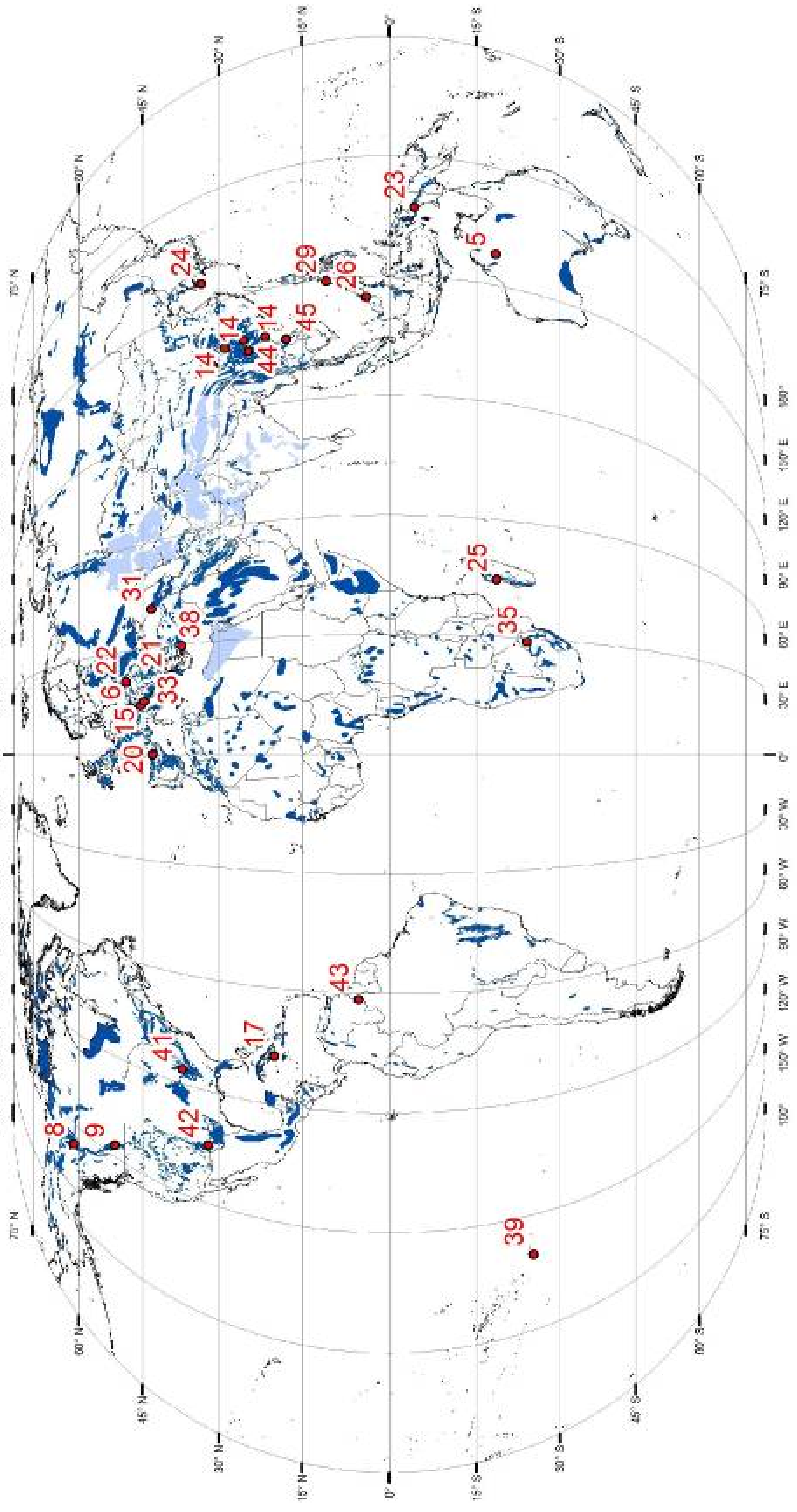

Figure 2. The geographical distribution of World Heritage properties with outstanding karst values (numbered * sites from Table 1) plotted on a world map depicting the distribution of carbonate rocks (the principal host rock for karst). Solid colour indicates that carbonates are relatively continuous; pale colour depicts areas in which carbonates are abundant but not continuous (modified from Williams & Ford 2006).

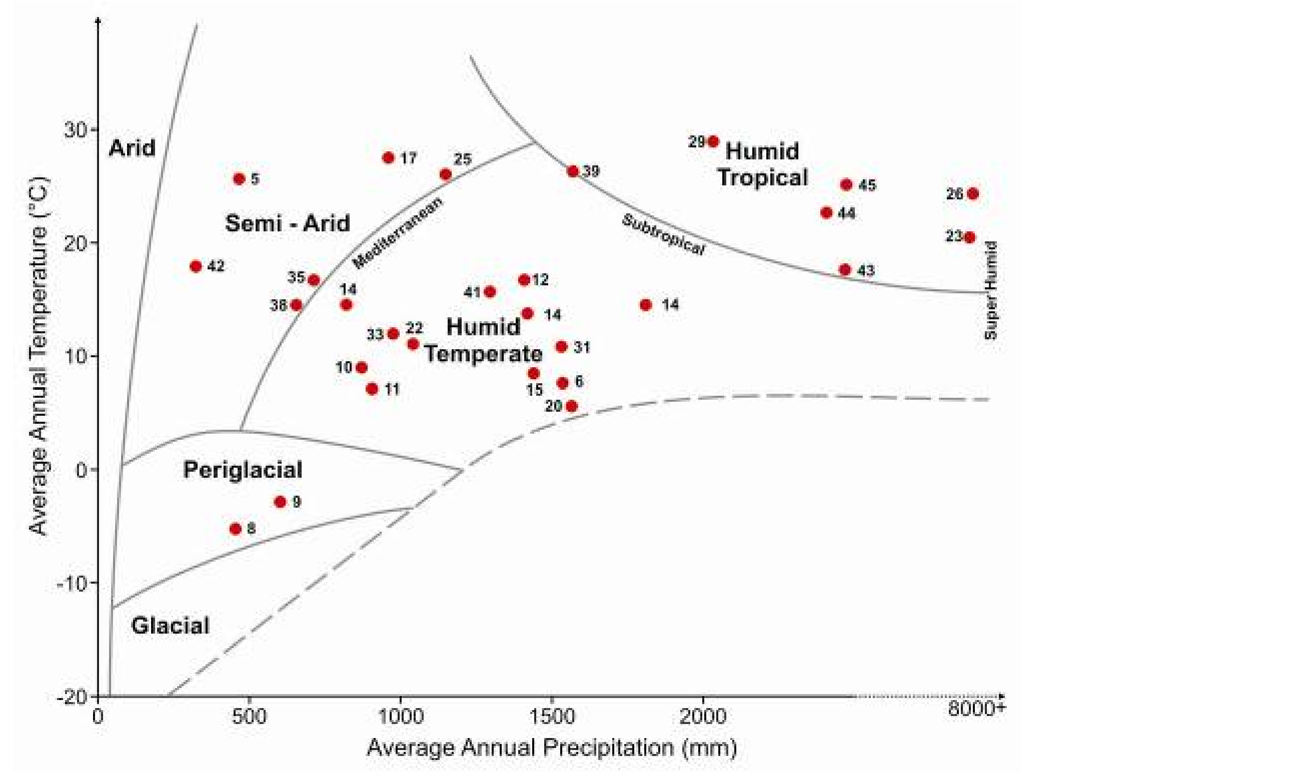

Figure 3. The climatic context of World Heritage properties with outstanding karst values (numbered * sites from Table 1). Plotting positions are approximate because some properties include a wide range of temperature and precipitation conditions. Nevertheless, the distribution reveals that there are relatively few World Heritage karst properties in arid and cold zones.

1.6 Karst Landscapes and Caves on the Tentative Lists of States Parties

States Parties have filed Tentative Lists of potential World Heritage sites in their territories. Therefore consideration should be given to whether properties identified in the Tentative Lists might fill some of the gaps in coverage noted in section 1.5.

Table 2 at the end of this report names 30 Tentative List properties that contain karst of probable international significance, although not necessarily of outstanding universal value. These are identified as a basis for preliminary screening of the karst values included within the Tentative Lists. The available information is at present insufficient to make possible full evaluations of the potential of these sites, and ultimately assessments of whether or not their karsts are of outstanding universal value can only be made if they are proposed for World Heritage. Tentative List properties containing karst judged to be of regional or national significance are not included. However, the table is almost certainly incomplete, firstly, because some countries known to contain important karst areas have not listed their sites and, secondly, because in some cases that have been listed the documentation available is insufficient to determine if significant karst is involved. This applies particularly to properties in Central Asia where carbonate rocks are widespread (Figure 2). Although most properties shown in Table 2 are included on Tentative Lists on the basis of natural values, some are mixed and others are cultural sites. There are also numerous important karsts that do not feature on either the World Heritage or the Tentative Lists. For example, huge areas of karst occur in the Middle East, but are seldom included in nominations because the States Parties concerned have focused on cultural sites; the well known Cockpit Country of Jamaica also does not feature, just to illustrate another case.

From the perspective of the conservation of important karst terrains, three points are significant when considering Tentative List properties:

- *Duplication*: some properties on the Tentative List involve coral reefs and uplifted coral islands, e.g. Table 2: Phoenix Islands (Kiribati), Rock Islands-Southern Lagoon (Palau). These initiatives are to be welcomed but, in addition to their biodiversity value, it is also desirable to have a geodiversity organising theme for these properties (e.g. a series of sites that illustrate stages in the geological evolution and landscape development of coral reefs) that would provide a logical basis for their inclusion in a World Heritage nomination, because some coral and reef sites are already inscribed, e.g. Table 1: Aldabra Atoll (Seychelles), East Rennell (Solomon Islands), Henderson Island (UK), and duplication of values is unlikely to be acceptable. Transnational serial sites may be required to encompass all the desired features.

- *Lack of recognition*: Tentative Lists submitted by States Parties often do not include internationally outstanding karst sites within their territories possibly because their values have not been recognised. A mechanism to bring the conservation importance of sites such as these to the attention of States Parties is required (for example, by written communication by formally constituted and recognised international scientific unions). This applies particularly to countries whose territories include arid to semi-arid zones in a warm temperate to tropical context.

- *Potential for gap filling*: several properties on the Tentative List appear to have the potential to fill some of the gaps noted in section 1.5. Considering their karst geodiversity, the following merit further investigation:

  (a) Band-E-Amir (Afghanistan), Canyon du Rio Peruaçu (Brazil), and Gewihaba (Botswana). The Lijiang River Scenic Zone (China) and Velebit Mountain (Croatia) might best be presented as parts of serial nominations within their respective regions.

  (b) Some properties on the Tentative List are unlikely to be acceptable on the basis of physical karst features alone, perhaps because of duplication of values of ready inscribed properties, but may still justify World Heritage status when nominated in association with their outstanding biodiversity and their wider geodiversity values. Such sites include Great Desert Landscapes (Egypt), Phoenix Islands (Kiribati), Rock Islands – Southern Lagoon (Palau), Réserve de la Biosphère Selva El Ocote (Mexico), Parc Natural de Talassemtane (Morocco), Kahurangi National Park (New Zealand), Svalbard Archipelago (Norway), Lena Pillars Nature Park (Russian Federation). In addition, the three Tentative List properties proposed by Papua New Guinea (Huon Terraces, Kikori River, Sublime Karsts) could form the basis of a serial nomination of this kind.

  (c) Other important karsts contribute to outstanding cultural landscapes, being the combined works of nature and man. The Hallstatt-Dachstein/Salzkammergut Cultural Landscape in Austria (Table 1) provides a good example already inscribed on the World Heritage List. Meriting further investigation in this context are Les Cevennes et les Grands Causses (France), the Burren (Ireland) and some sites in China that could form part of the South China Karst serial nomination. The Classical Karst (Slovenia) is of this type and could also contribute to a transnational karst nomination, as discussed in the next section.

Geopark status (see http://www.unesco.org/science/earth/geoparks.shtm), regional or national recognition may provide a more appropriate avenue for conservation of the remaining sites (UNESCO 2007) Recognition of geological and geomorphological heritage outside the World Heritage Convention is discussed by Dingwall *et al.* (2005).

1.7 Recommendations for Filling the Principal Remaining Gaps

A natural property nominated for inclusion in the World Heritage List will be considered to be of outstanding universal value if the World Heritage Committee finds that it meets one or more of the following criteria, providing it also meets the conditions of integrity (UNESCO 2008, clauses 77 and 78):

(vii) to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;

(viii) to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;

(ix) to be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, freshwater, coastal and marine ecosystems and communities of plants and animals;

(x) to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Section 1.5 identified geographical and environmental regions in which karst World Heritage sites are distributed. It is evident from this that a wide range of karst landscape and cave values are already represented on the World Heritage List. It is also noted here that Part 2 of the South China Karst nomination is in process and so, if successful, further World Heritage sites from humid tropical to subtropical areas may be anticipated. Nevertheless, although karst is well represented in the humid zone, especially in the Northern Hemisphere, the sites currently included on the World Heritage List are not sufficient to represent karst values of the region of Europe from which karst took its name – the Dinaric Karst. The *ad hoc* process by which karst is represented in the region has failed to provide an adequate coverage of its karst features. In addition to this, karsts are poorly represented in:

- the arid to semi-arid zone of the tropics to subtropics,
- the periglacial zone, and
- the Southern Hemisphere.

All the above represent high priority areas for future recognition of karst landscapes and features, including biodiversity above and below ground.

However, one should note that in many karst areas biodiversity values have been damaged through a process of progressive devegetation and soil erosion, termed 'rocky desertification', which turns a region into an ecological wasteland (see case studies by Gams *et al*. and Yuan in Williams 1993). Thus inscription will most likely only be considered in relation to criteria (vii) and (viii) above, although exceptionally criteria (ix) and (x) may apply, especially underground.

Recommendation 1

That States Parties whose territories embrace the Dinaric Karst of Europe consider a transnational serial nomination that would include a representative range of karst values and features of all scales above and below ground from the mountains to the sea. Such a property should represent the international type-site of karst by illustrating a full range of the region's karst features and by providing evidence for their evolution. Explicit inclusion of associated biodiversity values would also be important.

The Earth's two great type areas of karst (the Dinaric Karst and the South China Karst) need to be given the highest international level of protection. This is in process for the South China Karst, where only one State Party is involved and Phase 1 is successfully completed, but international cooperation is required to achieve an equivalent level of conservation of the type area of karst in Europe. Three World Heritage properties, Plitvice Lakes (Croatia), Škocjan Caves (Slovenia) and Durmitor National Park (Montenegro) (Table 1), are part of this wider area, but contain a limited range of features. The Tentative List properties of Velebit Mountain (Croatia) and Classical Karst (Slovenia) (Table 2) would make further contributions to the karst attributes covered, as might some other protected areas, such as Cerkniško Polje (Slovenia) which is a RAMSAR site, and some other properties on the Tentative List.

An international committee would be required to identify and rationalise the best set of complimentary areas that would together make up a serial transnational Dinaric Karst World Heritage property. The countries that would form the core of such an initiative are Slovenia, Croatia, Bosnia-Herzegovina and Montenegro. Such an approach would consider the contribution of the three existing World Heritage properties and could unite them (along with other new sites) as part of a serial nomination.

Recommendation 2

That States Parties whose territories include karst terrains located in arid to semi-arid environments of the tropics and subtropics consider the natural World Heritage potential of their sites, especially if such territories are located in the Middle East, Central Asia or the Southern Hemisphere.

Karst in tropical to subtropical arid to seasonally arid environments is widespread in the Middle East and Central Asia and in parts of Africa, Australia and Brazil. Some outstanding karsts are known in Western Australia (including the limestone ranges of the Kimberley which is an international type-site for seasonally arid karst) and from interior subtropical Brazil, with other examples at the more arid extreme from the Nullarbor Plain in southern Australia and from Yemen to Afghanistan, where there are extensive limestone terrains. Tentative List properties Band-E-Amir, Canyon du Rio Peruaçu, Gewihaba, Great Desert Landscapes, Parc Natural de Talassemtane (Table 2) could be considered further in this context, but there are areas mentioned above and not on the Tentative List that are of equal or sometimes greater conservation value, e.g. parts of the Kimberley and Nullarbor regions of Australia (the landscapes of both regions are discussed in Ford and Williams 2007).

Recommendation 3

That States Parties whose territories include karst terrains situated on continuous or semi-continuous permafrost consider the potential of their sites for natural World Heritage recognition.

Karst in periglacial environments is widespread within the Arctic Circle and some high mountain ranges. For example, huge areas of Siberia contain limestone karst developed on permafrost that is totally unrepresented and scientifically not very well known (see Pulina 2005). Likewise, large areas of karst in arctic Canada have the potential for nomination, notwithstanding the importance of the Nahanni National Park World Heritage site (Table 1). Because of the global distribution of land and sea, similar opportunities are lacking in the Southern Hemisphere. Tentative List properties Svalbard Archipelago and Lena Pillars Nature Park (Table 2) are important sites in this context, but there are sure to be other unlisted areas with karst in Alaska, Canada and Siberia that also merit consideration.

Recommendation 4

That States Parties whose territories include karst terrains situated on evaporite rocks consider the potential of their sites for natural World Heritage recognition.

There are no examples on the World Heritage List of karst on evaporite rocks, possibly because they tend to support relatively unspectacular relief compared to limestone karst. Nevertheless, this is not the case for the salt ‘glaciers’ or *namakiers* of the Middle East (namakiers are the surface expression of salt domes as they are extruded by lithostatic pressure and flow across the surface), because they support impressive karst (with caves). This occurs, for example, in the namakiers of the Larsitan Desert in Iran, where a cluster of such sites could provide the basis for a serial World Heritage nomination, although they are not named on a Tentative List.

Gypsum outcrops in many places around the world and often lies buried at a shallow depth. It is less soluble in rainwater than salt, but much more soluble than limestone. Therefore it supports many caves and interesting surface landforms. It is sometimes also found in the permafrost zone (Pulina 1992). Occurrences are particularly extensive in the Russian Federation, Ukraine and North America (Klimchouk *et al.* 1996). However, with a few notable exceptions, the stratigraphic thickness of most gypsum (and anhydrite) deposits is usually less than 100 m, so relief is limited unless the rocks are folded. Svalbard Archipelago (Norway) (Table 2) includes both evaporite and carbonate karsts in a permafrost context, and contains many other outstanding natural features of the maritime polar environment. It would be a strong candidate for World Heritage inclusion. Evaporite karst also occurs in the Great Desert Landscapes site (Table 2) in Egypt.

Karst landscapes on evaporite rocks tend to be best expressed in the drier areas of the world; thus one or two outstanding sites would also help to reduce the bias of natural World Heritage properties towards the more humid environments.

Recommendation 5

That States Parties whose territories include outstanding examples of pseudokarst consider the potential of their sites for natural World Heritage recognition or for inclusion as one element within a nomination of wider scope.

Karst-like features such as caves, enclosed depressions and large springs are associated with volcanic, glacial and permafrost environments. Some of these features may be outstanding characteristics of the natural landscape of which they are part, even though by themselves they might not merit consideration for World Heritage listing. Their value could therefore be recognised by being explicitly included in a broader nomination.

Recommendation 6

That IUCN facilitates communication between international scientific unions and States Parties concerning advice about important sites worthy of consideration for inclusion on Tentative Lists.

Many sites of outstanding scientific importance have not been included on the Tentative Lists of States Parties, possibly because the significance of these sites has not been brought to the attention of the State Party concerned.

In cases where the features of an area are of outstanding importance to geoscience and are accessible and comprehensible by civil society and not just of a specialised scientific value, then such sites could merit inclusion on the Tentative List, as a precursor to consideration for World Heritage. International scientific unions (such as the International Geological Union, the International Association of Geomorphologists, the International Association of Hydrogeologists, the International Union of Speleology, and the International Union of Biological Sciences) are the best sources of objective authoritative scientific information on such sites, and these unions are well placed to judge impartially the importance of their scientific values compared to other properties on the World Heritage List and Tentative List. International scientific unions should therefore be encouraged to convey well-documented advice on potential Tentative List sites to the IUCN who, after evaluation of the case and the documentation, would convey the advice to the appropriate State Party for further consideration and possible implementation. A parallel process would be appropriate for cultural landscapes and should involve the International Geographical Union. International scientific unions would be expected to communicate fully with appropriate national scientific organisations prior to submitting their proposal to the IUCN.

1.8 Conclusions on Karst and the World Heritage List

There are numerous World Heritage properties with significant karst in humid temperate and tropical regions (Table 1, Figures 2 and 3). Thus there is little scope for inscribing new sites in those environments, especially with Phase 2 of the South China Karst serial nomination still to be completed, unless the karst forms part of a wider nomination. Many of the existing World Heritage properties include outstanding caves with rich and varied speleothem decoration and fossil-rich cave sediment accumulations, and the hydrogeological conditions under which they evolved encompasses a wide range of genetic conditions. Nevertheless, the process of nomination and inscription has been *ad hoc* and, as a result, has led to a suboptimal representation of karst values. This is apparent when considering the Dinaric Karst of Europe, the type region from which karst derives its name, the features and values of which are inadequately represented.

Consequently, and assuming that South China Karst Phase 2 will proceed, the highest priorities for completion of a comprehensive range of karst World Heritage sites are:

- to cover more adequately the karst type region of Europe,
- to fill gaps in coverage in cold regions, arid/semi-arid regions and tropical oceanic regions, and
- to identify evaporite karst sites of outstanding universal value.

Because karsts are already well represented in humid tropical and temperate regions, future nominations of sites from these zones will need to demonstrate that they are amongst 'the best of the best', i.e. of at least equal value to if not better than existing World Heritage properties, and it would also be desirable for them to have karst as just one of a range of outstanding universal values.

It should be recognised that of the many karsts of international value listed in Table 1 most are found in World Heritage properties that were not inscribed specifically for their karst attributes; karst was but one of many important values, biological as well as physical. The Lorenz National Park in Indonesia and Three Parallel Rivers of Yunnan are cases in point. Thus there remains scope for including new karst areas in future World Heritage sites nominated for a range of bio- and geo-diversity reasons. Some sites in Oceania, for example, could meet both geo- and bio-diversity criteria and include karst amongst several outstanding values. Other points to consider in this context are that:

- karst values could be identified in some existing World Heritage sites through re-nomination under criterion viii,
- karst values could be the basis for extensions of some existing World Heritage sites, including across international boundaries, and
- biodiversity values of karst could be better recognised.

Many karst areas have a long history of human habitation and stable landscapes of outstanding special character have evolved and matured. Thus

- some karst areas could be recognised as World Heritage mixed properties and/or cultural landscapes under criterion v.

In spite of extreme human impact on karst having resulted in rocky desertification in some cases, there are many other karsts in which human interaction with the environment has attained an equilibrium and a cultural landscape of unique character has developed.

PART 2: THE REQUIREMENTS FOR INTEGRITY AND MANAGEMENT THAT SHOULD APPLY TO KARST ON THE WORLD HERITAGE LIST

2.1 Conditions of Integrity

Paragraph 78 of the *'Operational Guidelines for the Implementation of the World Heritage Convention'* (2008) requires that for a property to be deemed of outstanding universal value it must meet the conditions of integrity and must have an adequate protection and management system to ensure its safeguarding.

Integrity is defined in Paragraph 88 as a measure of the wholeness and intactness of the natural heritage and its attributes. However, it is appreciated (Clause 90) by the World Heritage Committee that no area is totally pristine, that activities of traditional societies often occur in natural areas, and that these activities may be consistent with the outstanding universal value of the area where they are ecologically sustainable.

The *level of integrity* is also an important consideration, because World Heritage is concerned with best that planet Earth has to offer. Thus inscribed properties are expected to meet the highest international standards.

2.2 Requirements for Integrity that Apply to Karst

The Unusual Characteristics of Karst

When compared to other landscape styles and ecosystems, karst has a number of unusual characteristics that must be taken into account when its integrity is assessed:

1) Karst is unusually complex because it comprises both surface and subterranean features and values and integrates surface and subterranean processes, both biological and physical. Karst also has natural archives of its own history, because palaeokarst features and cave deposits record stages in the evolution of the karst and of the environment and ecosystems around it.

2) Karst ecosystems are fragile because environmental conditions can be extreme. They are usually calcareous (or highly saline in evaporite rocks); periodically arid at the surface (because rainwater sinks quickly underground); and dark and remote from food sources underground while subject to periodic flooding. The subterranean ecosystem is particularly fragile being dependent mainly on energy flows transmitted by water, the quality of which is critically important for survival.

3) Karst integrity depends above all on hydrological conditions, because solar energy input is moderated mainly through the hydrological cycle which powers the karst system (by corroding rock, transporting organic detritus underground, nutrients to plants, etc) and integrates its various parts.

4) Most water passing through karst is introduced by sinking streams. Many of these are derived from impervious catchments that lie beyond the boundary of the karst area [these are termed *allogenic* streams, as opposed to *autogenic* streams that are derived entirely from karst rocks (see Figure 4)]. Consequently, conditions upstream beyond the karst boundary can have a critical influence on the integrity of the karst. Recharge zones are of critical importance and need to be identified and managed. River-borne pollution is a major threat to the viability of vertebrates and invertebrates living in and near rivers in the karst and to other animals that may depend on them for their food. Fragile subterranean species are particularly at risk, and serious damage can occur unwittingly because the major effects are underground and out of sight.

5) Karst drainage areas are not easily delimited. The drainage basins and routes followed by karst water are not obvious, because drainage paths are largely subterranean. Large springs are a feature of karst, but groundwater basins do not necessarily follow surface divides and headwaters

may be derived from sinking surface streams located many kilometres away. Groundwater divides are best considered as zones, because their plan position can shift between high and low water conditions. The flow-through time for water first sinking underground to its reappearance at a spring can vary from days to years depending on the size and nature of the groundwater system.

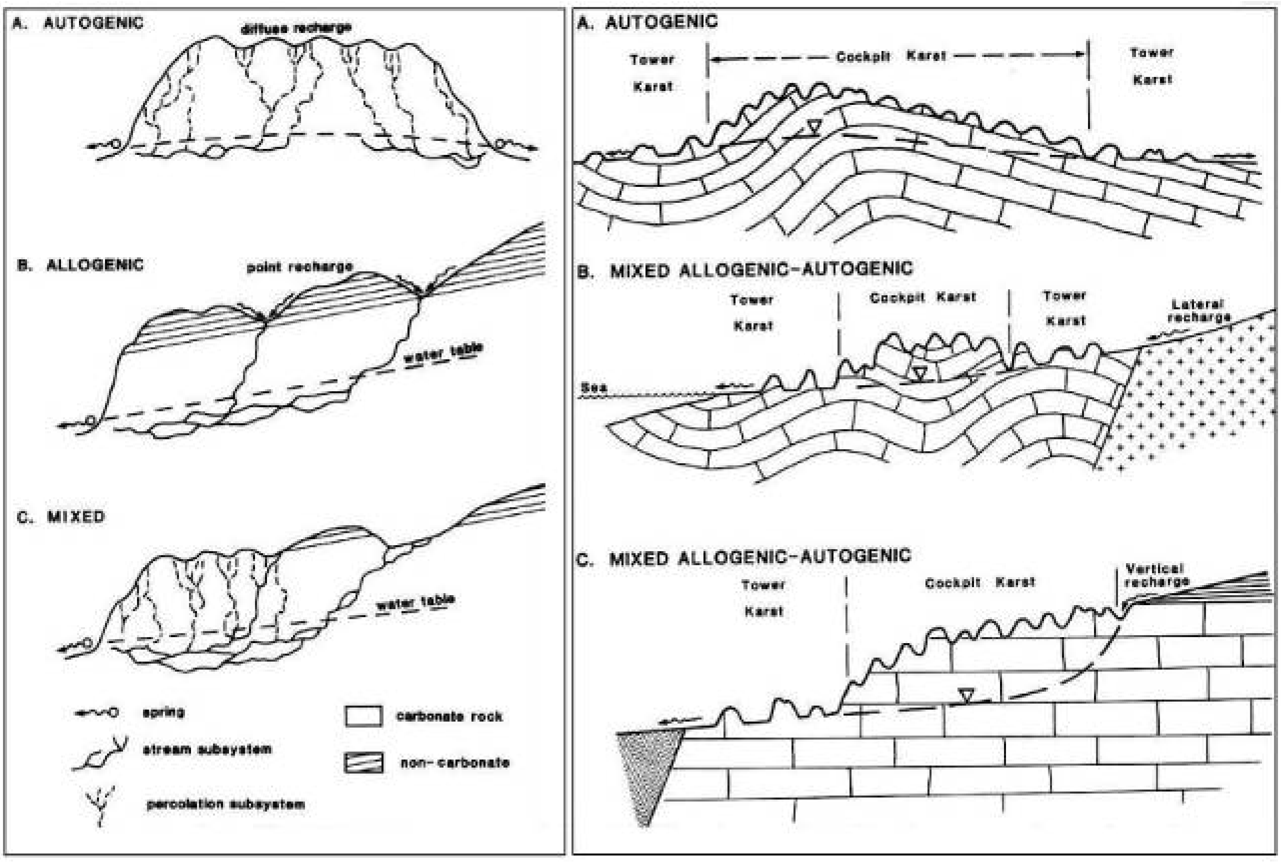

Figure 4. Autogenic recharge is sourced entirely from rainfall that falls within the karst area. Allogenic recharge comes from runoff from non-karst rocks. The diagram on the left shows how allogenic water can be introduced vertically from overlying non-karst rocks; and the diagram to the right illustrates how it can be introduced laterally. Many karsts have a mixture of autogenic and allogenic recharge (from Ford & Williams 2007, figs 4.1 and 9.49).

Requirements for Integrity

There may be superb features and values in an area nominated as natural World Heritage site, but are the conditions of integrity met? To make that judgement requires an assessment of the following:

a) *the wholeness and quality of the natural heritage and its attributes*. In the nominated area, are the features above and below ground the best examples available? Does the range of features fully represent the karst of the region as a whole? Are the karst attributes so exceptional as to transcend national boundaries in their significance and be worthy of being designated as of outstanding universal value? Do they stand up readily to international comparison and could they be described as the 'the best of the best'?

b) *the intactness of the natural heritage and its attributes*. To what extent has the property suffered from the adverse effects of human development or neglect, and does the impact now render the property unable to meet the condition of integrity? Is there on-going environmental rehabilitation that will lead to effective repair of any damage? Does on-going human activity in the area or in the region around it threaten the long-term sustainability of the natural ecosystem?

c) *the adequacy of the size of the property*. Is the size of the nominated area sufficient to ensure that on-going natural processes will continue uninterrupted, so that the region's significant features and values will be maintained for the foreseeable future? Is there a sufficient buffer zone that might absorb the impacts of human activities in the surrounding region?

d) *the prospect of maintaining integrity into the future*. Is the World Heritage area optimally delimited for management? Are the boundaries appropriate for effective protection of the important karst features of the area: both surface and underground; both physical and biological? Is the area adequately protected by effective legislation?

The boundaries of nominated properties require very careful consideration. In any given country sites may involve areas of different legal status – National Parks, Geoparks, MAB sites, etc. – and the already defined boundaries of these properties may be used as boundaries of core zones in areas nominated for World Heritage inscription. However, nature does not recognize administrative boundaries and sometimes areas of equal quality to the proposed core zone extend beyond it. Where possible boundaries should follow natural watersheds (including groundwater divides), because that will facilitate catchment management, especially through the control of water quality in recharge zones and the maintenance of high quality habitat for subterranean species. The largest area practicable should be demarcated to ensure living space for endangered species above and below ground. If necessary, legal boundaries should be adjusted to ensure high level legal status and protection of the core World Heritage area. This will help obviate future problems and so facilitate effective environmental management.

Mining and quarrying affects *the intactness of the natural heritage and its attributes*, and *the prospect of maintaining integrity into the future*. IUCN therefore considers that mining and quarrying is incompatible with natural World Heritage, and this position has been supported by the World Heritage Committee. Integrity issues may arise if mining and quarrying takes place in the zone of influence, or buffer zones, of karst properties. If management has power to influence the location of such activities, then quarries should be located on the downstream side of karst areas. They should definitely not be located in the upstream recharge zone, otherwise polluted water (including silt runoff) will affect karst aquatic ecosystems - often underground and unnoticed. Dust from quarries can also be a problem, so prevailing wind issues need to be taken into account.

2.3 Requirements for Management that Apply to Karst

"The purpose of management of a World Heritage property is to ensure the protection of its "outstanding universal value" for the benefit of the present generation, and its transmission unimpaired to future generations" (Thomas and Middleton 2003, p. 65). World Heritage status often brings considerable tourist pressure that may threaten the integrity of the site, but with good planning and appropriate practices tourism in protected areas can be managed sustainably, as explained by Eagles *et al.* (2002).

Responsibility of the State Party

The inscription of a property on the World Heritage List implies that the State Party will carry the ultimate responsibility for management of the site to the highest level of international conservation practice. It also has responsibility for honouring and implementing any transboundary agreements.

Management of World Heritage properties requires clear unambiguous authority. This does not necessarily sit readily with established interests that may operate at national, provincial (state) and local levels and may involve planning and environmental agencies sometimes with competing and conflicting interests and sensitivities. Thus when the World Heritage property is first nominated for inscription, the State Party should already have made it clear where final responsibilities will rest.

Management Structure

Within any given country three interlinked levels of administration are usually required:

Policy level: one over-arching national authority ultimately responsible for all World Heritage properties with policy-making power that operates within the laws of the country and requires international standards to be applied even-handedly to all properties.

Planning level: a governing body charged with the implementation of national policies applying to all World Heritage sites in the country. It approves management plans for policy implementation at individual property level and delegates authority to individual site managers for their implementation. This body ensures that national policies and standards are applied to all World Heritage sites in the country; this being particularly important in the case of serial nomination sites in different provinces.

Management level: site managers of individual World Heritage properties are responsible for implementing management plans approved by the governing body and should have a role in the development of the plan. Effective implementation to appropriate standards requires strong leadership with clear authority and responsibility, as well as support from the governing body. Park management committees must include representatives of the local people who should also have a significant role in the development of the plan.

A review of options for effective management of protected areas, including assessing management effectiveness and guaranteeing protection, has been undertaken by Thomas and Middleton (2003) and Hockings *et al.* (2006). Specific guidelines for karst and cave protection are provided by Watson *et al.* (1997). Management planning starts with the present situation and asks the question: where are we now? It then proceeds to consider a vision for the area: where do we want to be? Management involves a sequential process of planning, implementation and outcome, at each step there being a process of evaluation. The management cycle is perpetually implemented with a view always to making improvements and getting closer to an ideal outcome. Figure 5 illustrates this process.

A management plan should consider such topics as: documentation of the present situation concerning principal values for conservation, land use, visitors and legislation; documentation of the scientific and aesthetic values of the World Heritage area, threats to them, and actions necessary to preserve them; strategic directions for the next 10 or 20 years; monitoring reserve values and the efficacy of management practices; visitor services, facilities and visitor management; communicating reserve values via interpretation and education; new proposals and their impact assessment; staff management and development; and measuring progress towards attaining goals.

Recognition for good management could be supplied by a process of certification in which individual protected areas are certified/verified against previously agreed basic standards. A certification process could create an important focus on management effectiveness, and achievement of a certificate of good management could provide important political recognition of protected areas and their managers. The Vth IUCN World Parks Congress at Durban 2003 recommended that the WCPA works with partners to investigate options for outlining benefits and costs of certification (see Appendix II in Hockings *et al.* 2006).

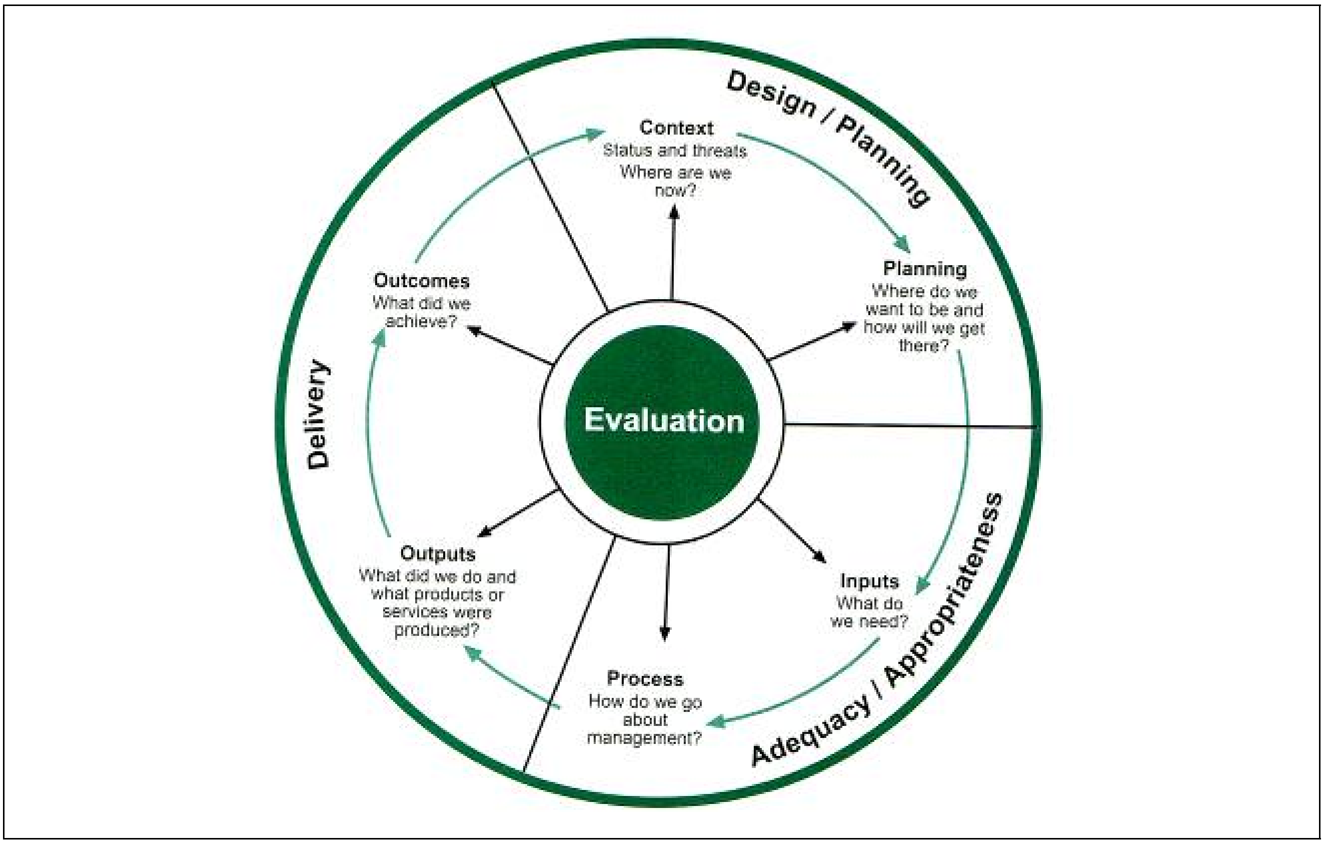

Figure 5. The management cycle proposed by the World Commission on Protected Areas. This illustrates a framework for assessing management effectiveness of protected areas (from Hockings et al. 2006). The cycle starts by reviewing the present context (where are we now?) and then considers management objectives (where do we want to be? and how are we going to get there?). The inputs refer to what is needed in terms of staff, assets and budget; and the management process asks: how do we go about achieving our aims? The delivery stage identifies outputs (what did we do or provide?) and then reviews outcomes (what did we achieve? For example, were the outstanding universal values of the site protected?).

Management Issues in Karst

The management of karst in general is discussed in such publications as Watson *et al.* (1997), Vermeulen and Whitten (1999), and Ford and Williams (2007). The focus here is more narrow: on karst in and around World Heritage properties. Issues in the maintenance of integrity and adequate management of values in World Heritage karst areas are discussed in the context of the Asia-Pacific region in Wong *et al.* (2001).

Runoff from Upstream Areas: It is not an overstatement to assert that water quality management of allogenic streams draining into karst is *the* key issue of environmental management in any karst area. It is critically important in natural World Heritage properties because so much is at stake. The deleterious effects of water pollution, particularly underground, can be widespread and insidious. Its effects can also be long-lived and difficult to remove, because the residence time of polluted water underground can be long and storage can occur in inaccessible places, not only below the water table (in the *phreatic zone*), but also just below the surface (in the *epikarst*).

The transport of water-borne pollutants by an allogenic river sinking at Škocjan Cave World Heritage property in Slovenia was once a very serious problem, but has been largely resolved. It is a potential problem requiring careful management at the Libo cluster of the South China Karst World Heritage property because of agricultural and urban land upstream. Only community education and involvement, agreement to work together, and strict enforcement of standards will ensure the problem is kept under control. Contaminated runoff from the land is affecting values in the Ha Long Bay World Heritage site in Vietnam and shipping lanes through the Bay pose a continuing threat.

The difficulties confronting park managers in such areas are not to be underestimated, because pollution frequently comes from areas over which they have no direct jurisdiction. In terrestrial sites, the best way to deal with the problem is to ensure in the first place that the nominated area boundary is manageable by following the natural watershed. This leaves catchment supervision in the hands of park management. However, sometimes that is impractical because allogenic catchments can be very large and may contain agricultural, urban and industrial centres. In such cases, effective partnerships have to be established with authorities responsible for management of the upstream area with a view to reaching agreement on a total catchment plan of the highest possible standard, effectively enforced and monitored. The maintenance of high water quality is a common good that is in everyone's interests. This also applies to sea waters, as in the Ha Long Bay.

To reduce to acceptable levels the danger that uncontrolled allogenic runoff poses to the ecosystems of World Heritage sites, it is *absolutely essential* to enforce strict and effective water quality management in the catchments of streams and rivers flowing into inscribed areas. No untreated waste water from cities, towns and industries must be permitted to enter waterways that ultimately drain into World Heritage properties. High water quality standards must be set and regular monitoring must be undertaken, both of dissolved materials and aquatic indicator species of water quality.

Monitoring stations should be established at input and output points in the karst system, i.e. where rivers flow into inscribed areas and at springs, because spring water integrates the effect of all contributing water sources in the catchment. Monitoring plans should be public documents and results of monitoring should be published annually.

<u>A Key Tool for the Management of Karst Areas:</u> Because of the paramount importance of catchment management in karst areas, the most important tool for the manager is a hydrogeological map. It should cover the World Heritage property and any surrounding areas that impinge upon it, especially allogenic catchments draining to the karst. An excellent example of this is provided by the hydrogeological map of the Mammoth Cave World Heritage area in the USA. It maps all sinking streams and springs and shows proven paths (by water tracing and cave survey) followed by underground water through the National Park. Cave plans are superimposed on the map. Thus if there is an accidental spillage of a pollutant inside or outside of the park then managers can see where the pollution is likely to go and plan appropriate remedial action.

Every World Heritage property with karst of outstanding universal value should have a hydrogeological map of this kind. It may take several years to develop, but detail can be added progressively as the knowledge base is built up. A scale of 1: 50 000 to 1: 25 000 is appropriate, depending on the size of the protected area. Also highly desirable as management tools are vulnerability mapping and recharge mapping by Geographical Information Systems, because they help delimit protection zones, classify their importance, and thus show where most management attention is required.

Further information on water tracing methods; groundwater vulnerability, protection and risk mapping; and the preparation of hydrogeological maps for karst areas is provided in Ford and Williams (2007).

<u>Restoration of Impoverished Ecosystems:</u> Another important issue that arises in many karst sites is environmental rehabilitation, particularly restoration of natural vegetation and improvement of faunal habitat. Improvements of this sort also restore natural karst process conditions. Problems of biological restoration are not a major issue when inscription is on the basis of World Heritage criteria (ix) and (x), which are concerned with biodiversity, but may arise when inscription is on the basis of criteria (vii) and (viii), which deal mainly with geodiversity (UNESCO 2008), because outstanding physical landscapes may have suffered considerable human impacts on their

ecosystems with the result that environmental rehabilitation may have become a high priority of management.

In the Dinaric Karst and the South China Karst, the world's two most important karst type areas, there have been thousands of years of human occupation. As population pressure has increased, demand for natural resources has exceeded the capacity of nature to renew itself; and so natural plant and animal systems have become progressively degraded. Nevertheless, World Heritage sites may be nominated for their geodiversity values, even when their biodiversity is damaged, provided the impact on vegetation is not too severe and there is real prospect of significant environmental restoration. Land should be retired from agriculture and the recovery of natural vegetation should be encouraged. Only very limited harvesting of natural resources by indigenous peoples should be permitted. The aim is to restore the core zone of the World Heritage area to as natural a condition as possible: to restore the damage inflicted in the past for the benefit of future generations.

In extreme cases human impact has led to an induced ecological desert, the process being called *rocky desertification*. Thousands of square kilometres are affected in this way in both the Dinaric Karst and the karst of southern China (Gams *et al.* 1993, Yuan 1993). Impact of the severity that leads to advanced rocky desertification renders it impossible to find large areas with recoverable ecosystems and the karst process system is severely damaged. Consequently, the best that can be done is to save what remains and actively encourage environmental rehabilitation.

Occasionally rocky desertification has occurred naturally with progressive biological adjustment as climatic zones shifted over geological time. Thus karst landscapes in the arid subtropics often show the legacy of development under more humid conditions in the geological past. These are important sites, because they contain a record of major stages in Earth's history and may provide refugia of ancient endemic species, especially in the groundwater system.

Management of Caves

Tourist Caves: Cave management within World Heritage locations must be to international standards and should be a model for commercial tourist caves elsewhere. Special skill is required to develop a tourist cave to the standards worthy of a World Heritage location. A balance is required between the engineering required to facilitate access and the minimization of engineering for the sake of access. In a World Heritage site, this balance must err on the site of conservation: minimization of impact on natural conditions must take precedence over engineering for mass public access. Further, to maintain a cave in excellent condition, management is required not just of the cave but also of the area above and around it.

The main environmental objectives of cave management should be to keep temperature, humidity and atmospheric carbon dioxide (CO_2) conditions within the natural range of variation, to minimize light available for photosynthesis, and to maintain water quality and quantity. This will safeguard the subterranean ecosystem. Natural vegetation conditions must be maintained directly above and around the cave to protect the quality of infiltrating water and the epikarst habitat (i.e. no buildings or car parks should be located there). Tourist cave lighting sources should be high efficiency lamps to minimize heat input into the cave atmosphere and to minimize light wavelengths suitable for photosynthesis. The duration and spectral quality of lighting should be such as to restrict the development of plant and algal growth (*lampenflora*) around light sources. A green halo around cave lights is a clear indicator of poor environmental management. In a World Heritage site, it is more appropriate to reveal natural colours than to impose artificial tints through coloured lights.

Tourist caves are particularly susceptible to damage both during development, when paths and lighting are installed, and during tourist operation. Decisions made during the development of the cave and during its operation for tourism should always try to ensure the maintenance of natural hydrological and ecological processes and the preservation of cave values and natural resources. If significant variation to measured baseline conditions occurs after tourist visitation commences, then maintenance of World Heritage values must take precedence over tourism, with tourist traffic being modified to reduce human impact to acceptable minimal and sustainable levels, even to the extent of closing the cave. A precedent for this is found at Lascaux World Heritage site in France.

Tourist routes through the cave should be designed to have minimum impact on delicate cave formations (speleothems) and on biological habitats within the cave. Cave sediment floors should be protected by raised pathways to preserve their habitat value, fossil record and sediment history. Cave entrances may be important archaeological sites, and so require special protection. Tourist guides should be aware of these special features, should help protect them, and should explain to visitors the significant features of the cave that led to its inscription on the World Heritage List.

Materials used for tourist infrastructure (paths, etc.) should be non-toxic to biota and largely removable, so that if necessary the cave can be returned almost unspoiled to nature.

There is considerable international experience on tourist cave development, cave conservation, management, ethics, and restoration of damage. A rich source of ideas on these topics is available in Hildreth-Werker and Werker (2006).

Wild Caves: Many natural (or 'wild') caves are found in World Heritage properties with abundant karst. Park managers need to recognize that even the most experienced, careful, and environmentally conscious cavers do inadvertent damage underground, especially in caves with abundant speleothem formations and fossil deposits. Damage caused by search and rescue activity, should that be needed, will make matters even worse. Thus cave exploration needs careful management. The most important principle here is to insist that an experienced speleologist leads the group and that party size is small, usually not more than six, but this depends on the nature and size of the cave. Only electric lights should be used and all rubbish must be carried out.

There is a need to manage access to wild caves to ensure that at least 50% of the known caves or parts of caves within a World Heritage property are protected from random recreational access – including recreational research. Access to special sites should only be for research that cannot be conducted elsewhere, and the research should explicitly contribute to the management of the protected area.

Results of cave exploration and survey are important sources of information for park managers as they help to complete part of the hydrogeological picture and provide data on natural resources within the area; thus careful exploration by experienced cavers should be encouraged provided impact is minimal and results of exploration are reported back to management.

Scientific sampling within the cave should be by permit only, having been well justified, and kept to a minimum. Speleothems may take tens to hundreds of thousands of years to grow but can be removed in minutes. The same approach should be taken to excavating archaeological and fossil deposits that are frequently found near cave entrances. They should only be excavated by experts and for good reason; only part of the deposit should be removed and taken to a mutually agreed safe repository; and results of the research should be reported back to park management. Ecological survey and sampling requires a similar approach and conditions.

2.4 Monitoring

To be reassured that management activities have been effective there needs to be a method of evaluating progress. Monitoring measures change over time; and it is required to provide objective evidence of the effectiveness of the implementation of management practices. Dudley *et al.* (2003) provide a review of options. Monitoring is an essential management tool and is designed to provide reliable information on the current situation that can be compared to 'baseline' conditions, i.e. to the situation that existed before management commenced. By monitoring before, during and after developments, changes can be recorded and there is objective evidence of impacts and improvements.

Sensitive sites and sensitive indicators should be chosen for monitoring. In karst, for example, stream-sinks and springs (input and output sites) should be used as water quality monitoring stations. Apart from a range of chemical and physical measures (e.g. dissolved oxygen, temperature, suspended solids, etc), presence and abundance of sensitive species with a low tolerance to pollution should be monitored. For example, at the surface and in caves, endemic snails, arthropods and plants are examples of sensitive species that can be monitored. Invasive species should also be noted.

Water quality monitoring should cover a range of extreme conditions from drought to flood. Baseline climatological and ecological conditions should be established in the cave *before* development for tourism starts, a year being required to obtain reliable representative records. Climate and atmospheric measurement in tourist caves requires a professional weather station approach. Monitoring stations should be set up at sensitive sites and climatological and ecological surveys should be conducted regularly with results published annually. Automatic monitoring should be undertaken where possible. The objective of management should be to keep temperature, humidity and atmospheric CO_2 conditions as close to the natural baseline values as possible, while at the same time keeping the cave free from invasive species, vandalism, rubbish, and wear and tear.

Photo-monitoring should be used extensively and regularly at established key sites, especially along tourist routes (above and below ground), because it is an effective way of showing up wear and tear from tourist pressure.

Methods and measures used in monitoring should be readily understood and applied by trained staff. Results of monitoring should be published annually. In a few years time, we will want to know if the World Heritage site is in at least as good a condition as when it was first inscribed. Objective monitoring will provide the evidence. Although tourist pressure creates the potential for environmental impact, it is park management that can prevent or at least limit serious impact - or permit it to occur.

2.5 Conclusions on Integrity

Managing a World Heritage site is a responsibility of global significance undertaken in trust for present and future generations. Therefore it must be carried out to the highest international standards and with the cooperation and support of the local people.

The State Party is ultimately responsible to UNESCO for the success or failure of management of World Heritage properties within its borders. Thus to assist managers and avoid competing or conflicting interests, legal authority and lines of responsibility must be clearly established. To ensure grass root support, local people must have a say in park planning and management, and should share in the benefits of having a World Heritage property in their neighbourhood.

The boundaries of natural World Heritage properties should capture all the outstanding universal values of the area that they represent. The boundaries should also be logical, manageable, and agreed to and respected by the local community. Thus, for example, if a property has been nominated for its natural beauty (criterion vii), then it is essential to maintain all areas essential for maintaining the aesthetics of the area.

Water quality management of allogenic streams draining into karst is *the* key issue of environmental management in any karst area. Hence, protected area boundaries in karst areas should follow natural watersheds wherever possible. In many cases allogenic stream catchments are required to be included in the managed zone to ensure that karst values are safeguarded. If this is not achievable, because of the large size of the allogenic basin, then an effective cooperative agreement for total catchment management must be achieved between park management and the wider community that will protect the World Heritage site from water-borne pollution. This is critical.

All decisions within natural World Heritage properties must be compatible with conservation, its value to posterity being more important than short-term economic gain. Thus most economic infrastructure should be located outside the World Heritage property rather than inside it, exceptions being those related to reasonable, low impact tourist access, especially in tourist caves.

Objective monitoring at key sites should be undertaken as frequently as necessary to assess the effectiveness of policies and management. Results of monitoring should be publicly available and published regularly. Publication should be by the State Party or its delegated authority. External reviews should be conducted periodically under the auspices of the IUCN to evaluate the state of conservation of the World Heritage property and the effectiveness of management. The overall objective will be to ensure that the property is in at least as good a condition as when it was first inscribed on the World Heritage List.

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Photos

Photo 1

The concordant summit of forested cone karst hills in the Libo cluster of the South China Karst World Heritage property in Guizhou, China, clearly defines the elevation of an uplifted erosion surface (photo by P. Williams).

Photo 2

Karst towers in the Ha Long Bay World Heritage property, Vietnam, have been flooded by a combination of geological subsidence and post-glacial sea level rise. The partly drowned tower karst results in a landscape of hundreds of islands (photo by P. Williams).

Photo 3

The tower karst beside the river Li (Lijiang) at Yangshuo, Guangxi, China, is one of the world's great landscapes (photo by P. Williams).

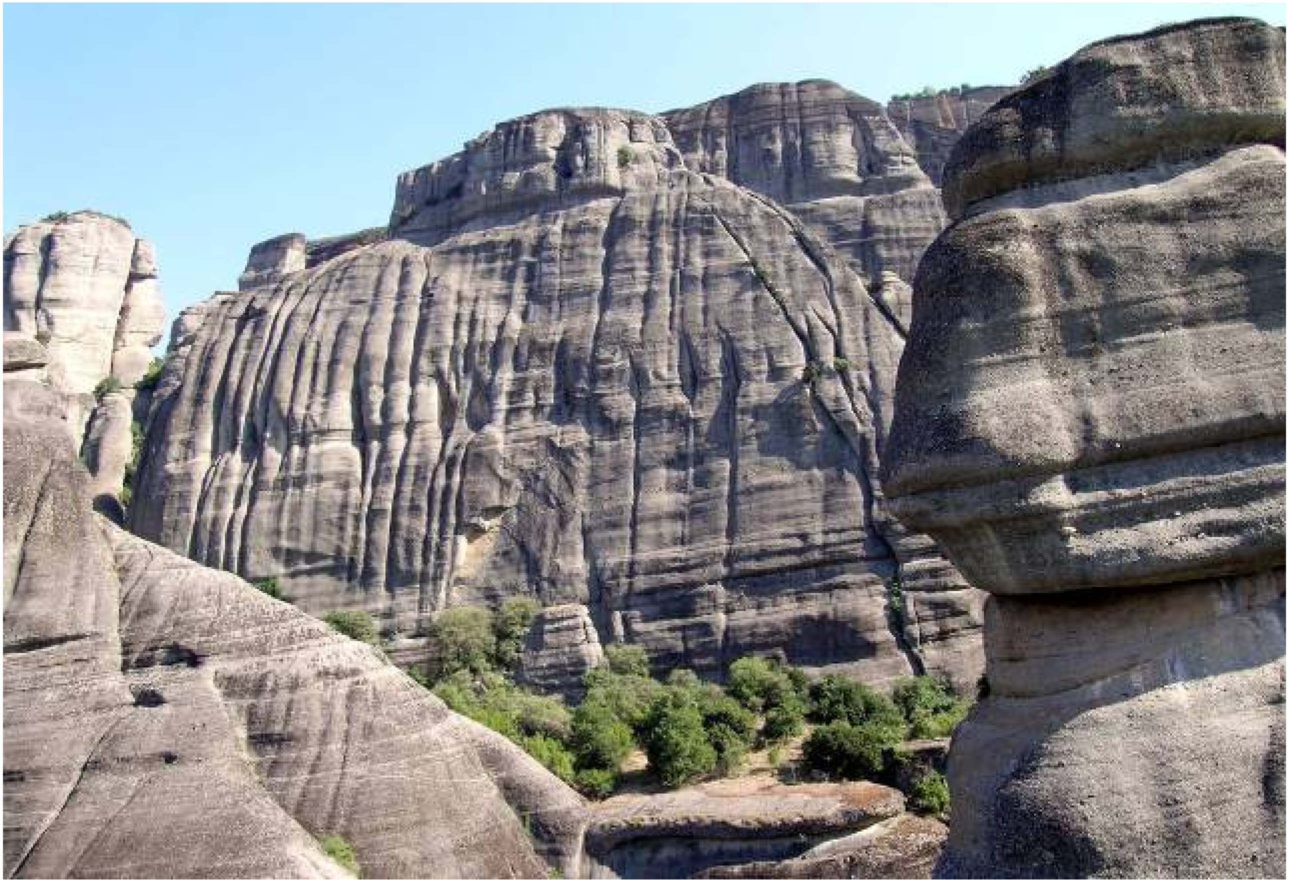
Photo 4

Tower karst landscape beside the river Li (Lijiang) between Guilin and Yangshuo, Guangxi. This is an iconic landscape in China and features on Chinese traditional art and even banknotes (photo by D. Ford).

Photo 5

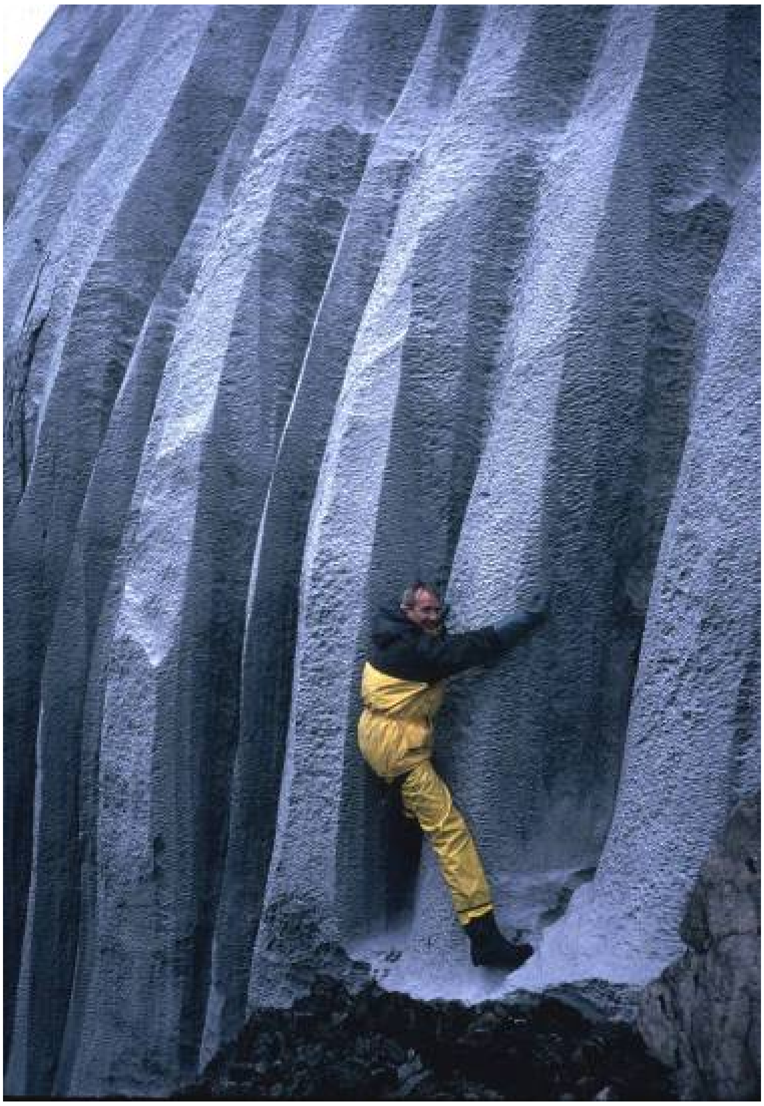
The 'tsingy' of the Tsingy de Bemaraha World Heritage site in Madagascar present an almost impenetrable labyrinth of corridors and pinnacles in almost flat-bedded limestones. Dissolution-sharpened pinnacles up to 90-100 m high are crossed by vertical-walled, joint-aligned forested canyons (photo by A. Clarke).

Photo 6



Pillars and cliffs up to about 100 m high in the Meteora World Heritage site in Greece are developed in quartz conglomerate. The rocks are fluted with vertical wall karren produced by a combination of quartz dissolution and mechanical runoff (photo by P. Williams).

Photo 7



Enormous wall karren are dissolved in marble in the extremely wet environment of the Isla Madre de Dios, Patagonia, Chile (photo by R. Maire).

Photo 8

Limestone pavements in the alpine glaciated Pyrénées-Mount Perdu transboundary World Heritage site between France and Spain (photo by P. Williams).

Photo 9

These mountains in the Northwest Territories of Canada at about 65°N have been scoured almost bare by a continental glacier. The landscape is a glaciokarst in carbonate and evaporate rocks with karstically drained depressions occupying hollows that have been dissolutionally enlarged after glacial scouring. The region is at the boundary of continuous and discontinous permafrost (photo by D. Ford).

Photo 10

A periglacial sinkhole located above permafrost in carbonate glaciokarst terrain near Norman Wells, Northwest Territories, Canada (photo by D. Ford).

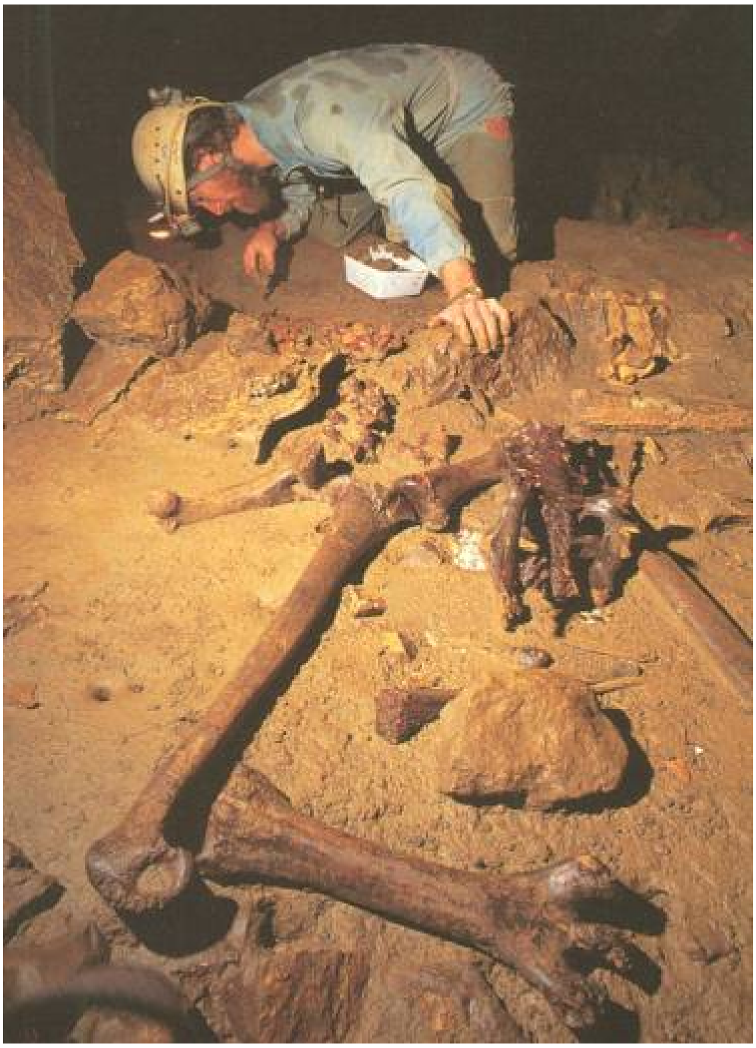
Photo 11

Karst towers rising abruptly from a pediment surface cut across geometrically jointed limestones in the tropical semi-arid limestone ranges of the Kimberley region, Western Australia (photo by J. Jennings).

Photo 12

The horizontal surface of the Nullarbor Plain in southern Australia is the uplifted floor of a Miocene sea. Marine sediments have consolidated into limestones and dissolution has formed caves, the ceilings of which sometimes collapse, permitting access from the surface. The subtropical to warm temperate environment is now arid, but the caves were mainly formed about 5-6 million years ago when the climate was wetter (photo by P. Williams).

Photo 13



Caves are traps for many animals and so frequently contain rich sheltered fossil sites. This cave in New Zealand contains the bones of a huge bird, the giant Moa (photo by G. Mason).

Photo 14

Troglobic fish and many other organisms occupy caves and underground waterways in karst environments. Many are totally blind and have evolved in darkness for millions of years (photo by D. Elford).

Photo 15

Caves are a major feature of karst environments. The oldest caves are amongst the most ancient landforms of our planet, because of their formation in an underground environment protected from surface erosion. They provide a stable habitat for many organisms and accumulate sediments and speleothems that provide rich and long archives of environmental change. The photo illustrates a subterranean landscape in Guizhou Province, China (photographer unknown).

Photo 16

A cultural landscape in karst near Xingyi in Guizhou Province, China. Paddy fields penetrate valleys amongst tower karst. The compact nucleated settlement rises only marginally above the floodplain surface (photo by P. Williams).

Tables

Table 1. World Heritage properties with internationally significant karst features (*signifies contains karst of outstanding universal value). Many other World Heritage properties contain karst of national or regional significance but are not listed here. Criteria (i-vi) are cultural and (vii-x) are natural. Criteria categories are explained in UNESCO (2008).

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
1	Australia	Tasmanian Wilderness	1982	ii,iv,vi,vii,viii, ix,x	Many small areas of karst in limestone and dolomite, some in alpine zone. Caves often richly decorated with speleothems containing very long palaeoclimatic histories. Complete karst systems.	Cool temperate to alpine rain forest. Much of the area was glaciated in the Pleistocene. High geodiversity and biodiversity.
2	Australia	Shark Bay	1991	vii,viii, ix,x	Located within coastal karst net deposition zone, with outstanding display of living stromatolites.	Warm temperate seasonally arid.
3	Australia	Australian Fossil Mammal Sites	1994	viii, ix	These are vertebrate fossil sites. Riversleigh's fossil deposits are in Oligo-Miocene freshwater limestones set within Cambrian dolomitic limestone bedrock; Naracoorte has Pleistocene fossil deposits in caves in Oligo-Miocene limestones capped by Pleistocene dune limestones. Riversleigh has extensive low relief pinnacle karst and well developed karren, and gorges with rivers actively depositing tufa. It is mainly located on the output margin of the karst system. Naracoorte has numerous caves and collapse features. It is a small site in the karst input zone.	Riversleigh is in the seasonally arid tropics with monsoonal rains. Naracoorte is in the humid temperate zone
4	Australia	Greater Blue Mountains	2000	ix,x	Many small areas of limestone with complete karst systems. Includes extremely old sites such as Jenolan Caves.	Warm to cool humid temperate zone with extensive forest.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
5*	Australia	Purnululu	2003	vii,viii	Outstanding example of quartz sandstone fluviokarst with beehive-shaped hills separated by narrow sinuous gorges. Developed on rocks of Devonian age.	Tropical savannah regime.
6*	Austria	Hallstatt-Dachstein Salzkammergut Cultural Landscape	1997	iii, iv	Dachstein massif of 574 km^2 is an excellent example of glaciokarst. It is a glacially scoured karstic plateau averaging 1850 m that rises to almost 3000 m. It contains hundreds of caves with three open to public, including Dachstein-Rieseneishöhle which is an ice cave.	Humid temperate rising to subalpine and alpine.
7	Bulgaria	Pirin National Park	1983	vii,viii	Rugged mountainous area to 2915 m partly modified by glaciation. Extensive karst with 113 known caves in Proterozoic marbles.	Humid continental Mediterranean climate becoming alpine in the highlands. Coniferous and deciduous forest. Experienced alpine glaciation in the Pleistocene.
8*	Canada	Nahanni National Park	1978	vii,viii	World's foremost example of karst development in cold climate conditions. Contains a spectacular karst landscape, including poljes, caves, and gorges, and hot spring with large tufa mound. Landscape is subject to active frost processes.	Cold continental climate with wide monthly variations in temperature and precipitation. Alpine tundra and mountainous taiga environments with discontinuous permafrost. Rich diversity of vegetation and wildlife.
9*	Canada	Canadian Rocky Mountain Parks	1984	vii,viii	Includes large areas of limestones and dolomites. Outstanding example of glaciokarst terrain. Many karren, subterranean streams, springs and caves. Columbia Icefield partly overlies and intrudes Castleguard Cave.	Located across continental divide between 1036 m to 3954 m. Continental cool temperate alpine climate with mountain permafrost. Rich diversity of vegetation and wildlife.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
10*	China	Huanglong	1992	vii	Hot springs emerging from carbonate rocks have precipitated extensive calcareous travertine deposits along valley floor with numerous rimstone pools. Represents depositional output landforms of deeply circulating karst groundwater system.	Warm temperate continental alpine environment.. Forested valleys surrounded by mountains to 5000 m.
11*	China	Jiuzhaigou Valley	1992	vii	Extensive areas of limestone and dolomite. Carbonate tufa deposits from cold springs have formed a series of tufa-dammed lakes and tufa-coated cascades along valley floor. Represents depositional output landforms of shallow karst groundwater system with significant epikarst water contribution.	Warm temperate continental alpine environment. Forested valleys surrounded by mountains to 4800 m.
12*	China	Wulingyuan Scenic and Historic Interest Area	1992	vii	A mixed quartz sandstone (66%) and limestone (33%) area, most notable for 3100 sandstone pillars and peaks to 200 m high separated by ravines and gorges. Limestone part contains about 40 known caves with rich decoration and two natural bridges, one of which is 357m. high. Includes entire Suoxi karst catchment. Particularly outstanding for its spectacular sandstone fluviokarst relief.	Humid warm temperate climate with deciduous forest. Altitude range 450 m to 1264 m.
13	China	Three Parallel Rivers of Yunnan	2003	vii,viii, ix, x	1.7 M ha site with actively glaciated peaks to 6740 m and gorges in places 3000 m deep. Contains extensive area of glaciated alpine karst, caves to 27 km length, tufa dammed lakes and hot springs with travertine rimmed pools.	Subtropical continental alpine environment, Immensely rich biodiversity.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
14*	China	South China Karst	2007	vii, viii	Three first phase sites of a serial nomination. Wulong (Chongqing) is plateau karst with spectacular tiankeng, natural bridges and gorges; Shilin (Yunnan) comprises stone forests (Yunnan); and Libo has extensive forested cone karst (fengcong and fenglin), poljes, gorges and caves. These three areas provide type-sites for their principal karst features.	Continental humid subtropical plateau (Wulong and Shilin) to subtropical monsoonal (Libo). Extensive natural forest cover at Libo.
15*	Croatia	Plitvice Lakes National Park	1979, 2000	vii,viii, ix	International type-site for tufa-dammed lakes. Carbonate biolith barriers confine 16 lakes up to 0.8 km^2 in area and up to 46 m deep. Mixed limestone and dolomitic limestone catchment area.	Continental humid warm temperate. Mixed coniferous and deciduous forested catchment.
16	Cuba	Viñales Valley	1999	iv	A cultural site set within a humid tropical karst landscape notable as a type locality of mogote karst (tower and cone karst) in a wide flat-floored valley. The region also contains poljes and caves with a rich subterranean biodiversity.	Seasonally humid tropical.
17*	Cuba	Desembarco del Granma National Park	1999	vii,viii	Spectacular staircase of uplifted coral terraces around Cabo Cruz that support ongoing development of karst landforms. Terraces extend from -180 m offshore to 460 m inland and reflect a combination of tectonic and glacio-eustatic processes. Excellent examples of littoral karst. Relatively recent uplift has permitted the commencement of karstification.	Moderately dry tropical with semi-deciduous forest.
18	Cuba	Alejandro de Humboldt National Park	2001	ix, x	A large inland plateau that includes both limestone karst and pseudokarst, but awaits formal scientific evaluation.	Humid tropical forested environment with high biodiversity.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
19	France	Prehistoric Sites and Decorated Caves of the Vézère Valley	1979	i, iii	Some 147 identified and significant pre-historic sites, with 25 decorated caves including Rouffignac and the famous Grotte de Lascaux. Caves much more important for their cultural rather than karstic value.	Humid temperate.
20*	France/ Spain	Pyrénées-Mount Perdu	1997, 1999	iii, iv, v, vii, viii	Outstanding example of alpine glaciated karst to 3352 m with extensive karrenfeld, deep canyons, deep caves and subterranean river systems. Incorporates complete karst systems.	Humid maritime alpine climate to north and drier Mediterranean climate to south with associated complex vegetation zonation.
21	Greece	Meteora	1988	i,ii,iv,v,vii	Sheer towers and pillars 10 to >100 m high developed in early Tertiary deltaic quartz conglomerate often fluted with closely spaced vertical karren (the towers support almost inaccessible monastery buildings). Fluviokarst.	Mean altitude 300 m rising to 1000 m. Mediterranean climate.
22*	Hungary/ Slovakia	Caves of Aggtelek and Slovak Karst	1995, 2000	viii	Area contains 712 caves. Variety of cave types, including Dobšinská Ice Cave, and speleothem forms with stalagmites to 32.7 m high. Surface landscape is a temperate doline karst with some evidence of a prior humid tropical or subtropical influence, which has evolved intermittently since the Cretaceous.	Continental humid temperate.
23*	Indonesia	Lorentz National Park	1999	viii, ix, x	Largest protected area in SE Asia (2.35 M ha). Continuous transect from snow caps (5030 m) to tropical coast. World's best example of tropical alpine glaciated karst. Extensive humid tropical karst occurs at lower elevations. Huge sinking rivers and springs.	From the mountains to the sea. Tropical glaciated alpine to lowland tropical rainforest.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
24*	Korea	Jeju Volcanic Island and Lava Tubes	2007	vii, viii	Oustanding example of vulcanokarst, a special style of pseudokarst. This includes Geomunoreum lava tubes which are notable for spectacular decoration with carbonate speleothems, the carbonate being derived from overlying calcareous dune sands blown in from the coast.	Warm temperate monsoonal.
25*	Madagascar	Tsingy de Bemaraha Strict Nature Reserve	1990	vii, x	Extensive areas of very sharp limestone pinnacle karst known locally as 'tsingy' with joint corridors up to 80 m deep occupied by forest. Traversed by river gorges. May be the world's most spectacular pinnacled terrain.	Tropical seasonally arid.
26*	Malaysia	Gunung Mulu	2000	vii, viii, ix, x	The park has a significant area of karst in Miocene limestone that contains large underground rivers and >290 km of explored caves, including Sarawak Chamber (700 m long, 300-400 m wide and up to 100m high) – the world's largest underground room. Caves contain major speleothem deposits and 1.5 million year sediment sequences. Rich cave biota, especially notable for bats and swiftlets. Surface features include giant collapse dolines and spectacular razor-sharp pinnacle karst (ca 50 m high).	Humid tropical rainforest with 17 vegetation zones covering altitude range to 2377 m..
27	Montenegro	Durmitor National Park	1980, 2005	vii, viii, x	Alpine glaciokarst in south-eastern Dinaric Alps with temperate karst features at lower elevations. Canyons induce deep karstification and some caves contain permanent subterranean ice.	Mediterranean alpine environment from 450 m to 2322 m. Dense pine and beech forests below alpine meadows.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
28	Mexico	Sian Ka'an	1987	vii, x	Situated on the coastal edge of the emerged limestone plain of the cenote karst of the Yucatan Peninsula. Only a small part of this important karst, which contains long and complex flooded cave systems, is within the World Heritage area which was inscribed mainly for biological reasons.	Tropical seasonally humid with semi-evergreen, semi-deciduous forest.
29*	Philippines	Puerto-Princesa Subterranean River National Park	1999	vii, x	Spectacular tropical karst landscape in middle Miocene limestone on Palawan Island extending from mountains to the sea. Contains polygonal karst, towers and polje. Major underground river drains directly to the sea, lower portions of cave are tidal and navigable for 6 km.	Humid tropical rainforest environment. Most significant forest in Palawan Biogeographical Province.
30	Russian Federation	Lake Baikal	1996	vii, viii, vii, x	A major part of the watershed (Irkutsk basin) surrounding Lake Baikal is located on karst, but its World Heritage value has not been scientifically evaluated.	Cool temperate extreme continental climate.
31*	Russian Federation	Western Caucasus	1999	vii, x	A geologically complex region rising to over 3000 m. The northern section consists of alpine karst in Triassic limestones, much of it glaciated. Includes glaciokarst features, many deep gorges and deep caves. Incorporates complete karst systems.	Temperate to alpine continental climate. Largely undisturbed deciduous and coniferous forest and alpine meadows.
32	Seychelles	Aldabra Atoll	1982	vii, ix, x	Four large coral islands enclosing a shallow lagoon. The islands rise to about 3 m above sea level and have well developed littoral karst forms. Inland are extensive areas of 'makatea' style pinnacled karren development. The islands represent the earliest stage of karst evolution.	Seasonally semi-arid tropical maritime climate.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
33*	Slovenia	Škocjan Caves	1986	vii, viii	Located in the 'classical' karst of Europe. The site comprises a sinking river at the end of blind valley, the exposed course of the underground river flowing across the base of deep collapse depressions, and a large river cave with a high canyon passage. It is representative of the input of an allogenic river into a karst system.	Continental Mediterranean climate.
34	Solomon Islands	East Rennell	1998	ix	The site involves the southern third of Rennell Island, a particularly large coral atoll raised to 200 m with its former lagoon now a brackish lake with rugged limestone islands. Karst is scientifically unevaluated but likely to be of international significance in representing the early stage of karstification.	Humid tropical maritime climate (3000-4000 mm) with short dry season. Densely forested environment of Papuan Biogeographical Province.
35*	South Africa	Fossil Hominid Sites of Sterkfontein, Swartkrans, Kromdraai, and Environs	1999, 2005	iii, vi	A cluster of karst sites in Proterozoic dolomite bedrock that contain remains of some of the earliest hominids as well as many other species. The caves contain internationally outstanding examples of cave sediments and fossils that were deposited over an interval of several million years into very ancient karst systems.	Subtropical High Veldt savannah environmnent.
36	Thailand	Thungyai-Hua Kha Khaeng Wildlife Sanctuaries	1991	vii, ix, x	A large and geologically complex forested mountainous region to 1500 m with savannah plains. Karst over part of the area, likely to be important but scientifically unevaluated.	Tropical monsoon climate. Evergreen and semi-deciduous forest in mountains with savannah in valleys and gallery forest along rivers. Outstanding biodiversity values.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
37	Thailand	Dong Phayayen - Khao Yai Forest Complex	2005	x	Contains karst terrain in west of area with gorges and caves, habitat of endemic species of reptiles and bats. Karst scientifically unexplored, but likely to be significant.	Tropical monsoon forest with long dry season.
38*	Turkey	Hierapolis-Pamukkale	1988	iii, iv, vii	Extensive and 200 m high valleyside travertine terrace with rimstone pools formed by carbonate deposition from geothermal water emerging at 59^{o}C. Used as a spa since 2nd century B.C. Possibly the world's earliest karst tourist site still in use. Significant human impact.	Warm temperate Mediterranean environment.
39*	UK: Pitcairn Islands	Henderson Island	1988	vii, x	Raised coral atoll 30 km^2 in area with rough karstified 'makatea' plateau surface at about 30 m above sea level with central depression that may have been former lagoon. Island is bounded by 15 m high cliffs and fringing reef to 200 m wide. Limestone considered late Tertiary in age. An outstanding example of early phase of karstification with intact natural processes, but scientifically unevaluated. Some caves.	Tropical humid maritime climate supporting thick cover of trees and dense undergrowth. The only raised and forested atoll with its ecology intact.
40	USA	Grand Canyon National Park	1979	vii, viii, ix, x	Paleokarst and active karst development occurs in Permian, Mississippian, Devonian and Cambrian limestones and dolomites exposed in the walls of the 1500 m deep Grand Canyon. Doline karst on 2700 m Kaibab plateau north of the eastern Grand Canyon. Tufa cascades mark karst spring sites on canyon walls. Although karst represents only a small proportion of the Park, its caves contain dated evidence for the evolution of the Grand Canyon so are of international significance.	Warm temperature semi-arid montane climate on plateau surface.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
41*	USA	Mammoth Cave National Park	1981	vii, viii, x	The longest cave in the world with 590 km of surveyed river passages, often large in dimension and gently sloping. The karst is developed in Lower Carboniferous (Mississippian) limestone and cave evolution commenced following uplift and exposure 3 to 4 million years ago. Extensive sinkhole plain at the surface. Large springs. Rich troglobitic fauna. The inflow margin of the karst is located beyond the Park boundary.	Humid warm temperate continental climate. Deciduous forest cover.
42*	USA	Carlsbad Caverns National Park	1995	vii, viii	Huge caverns extensively decorated with speleothems are a major feature of the park. The 81 known caves mainly occur in uplifted Permian reef limestones. Outstanding karst extends into neighbouring Guadalupe National Park. The region's caves provide the world's foremost example of evolution by sulphuric acid dissolution, which occurred progressively between 12 and 4 million years ago. Surface topography on back-reef dolomites and limestones is dominated by dry valleys. High biodiversity, including about 1 million bat population.	Subtropical semi-arid continental climate.
43*	Venezuela	Canaima National Park	1994	vii, viii, ix, x	The most outstanding example in the world of cave development in quartzite (Precambrian age). Caves occur to 10.8 km long and 383 m deep. Enclosed depressions and stream-sinks on plateau (tepuy) surface around 2650 m. Springs emerge in tepuy walls. A fluviokarst landscape.	Humid tropical upland rainforest environment.

No.	State Party	World Heritage Property	Inscribed	Criteria	Key Karst Features	Environmental context
44*	Vietnam	Ha Long Bay	1994, 2000	vii, viii	The world's most extensive and best-known example of tropical tower karst invaded by the sea. The Park area includes about 1600 islands, some with caves. Incorporates areas of fengcong and fenglin karst. Significant human impact from surrounding development.	Humid tropical monsoonal environment.
45*	Vietnam	Phong Nha-Ke Bang National Park	2003	viii	Extensive and complex karst development in dissected plateau environment to 1290 m above sea level that continues across border into Laos. Long history of karst landscape evolution, possibly since early Mesozoic. Major caves and underground rivers and extensive enclosed depressions (polje).	Humid tropical monsoonal environment with largely undisturbed evergreen primary forest. Rich biodiversity.

Table 2. Tentative List properties with significant karst features. Criteria categories are explained in UNESCO (2008). N refers to unspecified natural criteria. Mixed refers to a combination of natural and cultural criteria.

No.	State Party	Tentative List Property	Criteria	Key Karst Features	Environmental context
1	Afghanistan	Band-E-Amir	vii, viii, ix, x	Large tufa dammed lakes in arid mountainous environment.	Continental arid warm temperate with strong seasonality.
2	Brazil	Canyon du Rio Peruaçu, Minas Gerais	vii, viii, ix, x	Possibly longest known canyon of karstic collapse above a multi-level river cave with outstanding speleothem decoration. Huge collapse dolines, natural bridges, springs, and stone forest. Prehistoric art on cave walls; occupation from 12 000 BP.	Continental seasonally arid tropical. Deciduous xerophytic forest.
3	Botswana	Gewihaba	viii, ix	An area of 380 km^2 with groups of cavernous dolomite hills rising above arid sandveld. Caves contain wind-blown sand, but are rich in fossils and speleothems indicating humid conditions in the past.	Tropical arid Kalahari Desert
4	Bulgaria	The Vratsa Karst	N	Extensive karst with caves in rugged West Balkan mountainous area.	Humid continental sub-Mediterranean climate.
5	China	Heaven Pit and Ground Seam Scenic Spot	vii, viii, ix	Uplifted peak-cluster depression karst with deep narrow gorge (“seam”) several kilometres long and, several hundred metres deep, underground river, large collapse depression (“Heaven Pit”) over 500 m deep and large spring emerging from canyon wall and cascading 46 m.	Subtropical monsoonal climate with wide altitudinal range. Rich biota and rare underground species.
6	China	Jinfushan Scenic Spot	vii, viii, ix	Large area of mountainous karst rising to 2251 m surrounded by high cliffs. Extensive and large cave systems with evidence of previous nitrate mining.	Subtropical humid continental alpine environment with extensive primary forest (552 km^2 protected core area plus 441 km^2 scenic area) supporting endangered animal species.
7	China	The Lijiang River Scenic Zone at Guilin	N	World famous tower karst area along Li River valley between cities of Guilin and Yangshuo. Includes peak forests on alluvial plains and steep cone karst along the Lijiang valleysides. Numerous caves.	Subtropical humid monsoonal climate. Extensive areas of secondary forest.

No.	State Party	Tentative List Property	Criteria	Key Karst Features	Environmental context
8	China	Yangtze Gorges Scenic Spot	Mixed	Very impressive river gorge landscape. Gorges are often incised through thick outcrops of karstified limestone with at least 174 caves. Precipitous tributary gorges, also in limestone.	Transitional between subtropical humid monsoonal climate and humid temperate zone.
9	Croatia	Kornati National Park and Telašćica Nature Park	vii, viii, x	A partly submerged karst of about 150 mainly limestone and dolomite islands within an area of 320 km^2 of the Adriatic Sea. Salt lake of 0.23 km^2 is a drowned karst depression.	Mediterranean warm temperate climate with dry summers. Severe human impact on natural vegetation since the Paleolithic.
10	Croatia	Velebit Mountain	vii, viii, ix, x	A major karst massif within the famous Dinaric Karst. 2000 km^2 region from mountain summits (1757 m) to the Adriatic Sea. Composed largely of well karstified carbonate rocks with wide range of karst phenomena involving complete karst systems, including submarine springs (vrulje).	Mediterranean warm temperate climate with dry summers and wet winters. Area includes biogeographically contrasting Adriatic and continental slopes.
11	Egypt	Great Desert Landscapes	vii, viii, ix	Patches of karst occur within a desert landscape. Sinkholes and caves are common in Tertiary calcareous sediments on the Diffa Plateau that separates the Qattara Depression from the Mediterranean coastal plain. Wadi Sannur Cave may be the world's largest natural subterranean chamber in evaporite rocks (Eocene alabaster).	Hot subtropical desert.
12	France	Ensemble de grottes à concrétions du Sud de la France	vii, viii, ix	19 caves or groups of caves with an exceptional mineralogical heritage from the aesthetic, scientific and rarity point of view. Some speleothem types are unique in the world. The caves or sites constitute individual meteoric water hydrogeological systems.	Humid warm temperate.
13	France	Les Cevennes et les Grands Causses	v, vi	The region includes four of the Grands Causses (Méjean, Sauveterre, Cause Noir, Bégon) which are limestone plateaux with well developed karst arguably typical of the unglaciated temperate zone. The plateaux are delimited by steep cliffs that bound deep limestone gorges.	At the interface of Mediterranean, Atlantic and Continental climatic influences.

No.	State Party	Tentative List Property	Criteria	Key Karst Features	Environmental context
14	Hungary	Hydrothermal Caves and Thermal Karst Systems of the Rózsadomb Area	viii	Seven hypogene caves to 7.4 km in length dissolved by ascending hydrothermal water. Caves include both CO_2 and H_2S types, so are remarkably diverse for a grouping in a small area. Unusual semi-spherical dissolution cupolas. Sometimes well decorated with gypsum and botryoidal speleothems.	Continental warm temperate climate. Caves in an urban area.
15	Iran	Alisadr Cave	vii, viii, ix	Tourist river cave with 2.4 km of boating. Outstanding example of cave development largely by corrosion notching. Large rooms and numerous speleothems.	Sub-humid to semi-arid warm temperate continental climate.
16	Ireland	Burren	Mixed	Heavily glaciated limestone hills with caves and outstanding examples of naturally terraced bare limestone pavements. Wealth of archaeological sites.	Cool temperate oceanic climate. Distinctive flora.
17	Italy	The Murge of Altamura	iii, vii, viii	Karst tablelands and emerged coastal terraces in SE Italy. Numerous caves one with important early human archaeological site. At least 4000 dinosaur footprints exposed in a quarry.	Warm temperate Mediterranean climate. Almost bare of vegetation.
18	Kiribati	Phoenix Islands World Heritage Area	vii, viii, ix, x	Eight low reef islands and atolls. Planning to be part of a serial transnational Central Pacific Islands and Atolls World Heritage Area, also involving Cook Islands, French Polynesia and USA.	Tropical humid oceanic.
19	Mexico	Réserve de la Biosphère Selva El Ocote	N	In Chiapas region of S. Mexico. Limestone mountains to 1500 m. High escarpments, deep canyons and many karst features. Some archaeological sites in caves.	Warm humid tropical to temperate humid climate according to altitude. Important biodiversity with ten types of vegetation represented.
20	Morocco	Parc natural de Talassemtane	vii, x	Limestone mountain peaks, gorges and caves.	Mediterranean climate with endemic forest.
21	New Zealand	Kahurangi National Park, Farewell Spit and Canaan karst system	vii, viii, ix, x	Contains glaciated marble mountains (to 1875 m) with karstically drained cirque basins and caves to 45 km long. Large karst springs, one with exceptional clarity, displaying tidal fluctuations and groundwater residence time averaging 8 years.	Temperate rainforest environment becoming alpine with altitude.

No.	State Party	Tentative List Property	Criteria	Key Karst Features	Environmental context
22	Norway	Svalbard Archipelago	v, vi, vii, viii, ix, x	A high-Arctic archipelago including Spitzbergen Island with patches of well-studied active carbonate and gypsum karst developed above and below permafrost. Outstanding example of karst in a polar maritime environment.	Cold high-Arctic maritime climate. Ice fields in mountains and tundra vegetation near coast.
23	Palau	Rock Islands – Southern Lagoon Management Area	iii, iv, v, vii, viii, ix, x	A partly submerged karst of about 424 limestone islands plus coral reefs within an area of 600 km^2. This includes 397 emerged steep islands and 27 low islands along barrier reef. About 50 saltwater lakes within the 'Rock Islands' represent karst basins inundated by post-glacial sea level rise.	Tropical humid oceanic environment with extensive primary forest.
24	Papua New Guinea	Huon Terraces – Stairway to the Past	iii, v, vii, viii, ix, x	Outstanding and scientifically well known example of emerged staircase of Quaternary coral terraces giving way inland to the karstified Finisterre and Saruwaged Ranges.	Tropical humid environment with secondary grassland on terraces and extensive primary forest inland.
25	Papua New Guinea	Kikori River Basin/Great Papuan Plateau	iii, iv, v, vii, viii, ix, x	A mainly karstic region of more than 20 000 km^2 from alpine zone to sea level. Cone karst of Darai plateau rivals the best in the world and is punctured by volcanoes giving rise to volcano-karst.	Tropical montane to lowland rainforest environment with outstanding biodiversity.
26	Papua New Guinea	The Sublime Karsts of Papua New Guinea.	v, vii, viii, ix, x	A series of sites in three different Provinces, two in the central highlands and one on the island of New Britain. All are well karstified with outstanding examples of sinking rivers, caves, huge springs, pinnacles and enclosed depressions with interior drainage.	Humid tropical rainforest environment becoming temperate to alpine in the mountains.
27	Philippines	Chocolate Hills Natural Monument (Bohol Island)	vii, viii	Remarkable example of almost symmetrical cone karst on a relatively flat to rolling surface to 500 m above sea level. About 1776 hills have the same general dimensions and shape. They constitute an excellent example of advanced karstification on uplifted coral limestone.	Tropical humid environment with dry season (when grass-covered hills turn brown).
28	Russian Federation	Lena Pillars Nature Park	vii, x	Low plateau up to 300 m of flat lying Cambrian limestones, dolomites, marls and shales in Lena River basin. Frozen karst and thermokarst in permafrost 100 – 500 m thick.	Sub-Arctic extreme continental and dry climate. Taiga forests in valleys.

No.	State Party	Tentative List Property	Criteria	Key Karst Features	Environmental context
29	Serbia	The Tara National Park with the Drina River Canyon	x	Mountains to 1600 m and sharp relief cut by deep canyons. Limestone walls in places over 1000 m high along Drina valley. Extensive karst.	Cool temperate to alpine continental climate. Largely undisturbed deciduous and coniferous forest and alpine meadows.
30	Slovenia	Classical Karst	ii, v, vi	The 'Classical Karst' is the area in which scientific investigations of karst were first conducted and from which the name was derived. It covers almost 500 km^2 mainly in Slovenia (and extends into Italy). Well known for its closed depressions, stream-sinks and caves. 2000 years of occupation have transformed it into a cultural landscape.	Continental Mediterranean climate.