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The effectiveness of protection policies and legislative framework with special regard to karst landscapes: Insights from Slovenia

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ABSTRACT

Karst terrain offers a great range of economic assets, provides unique habitats and valuable ecosystem services. Owing to its particular nature, this environment is highly susceptible to destruction. Any interference is likely to have irreversible impacts and disturb the natural balance of the elements (water, soil, flora and fauna) and processes (e.g. corrosion, CO_2 sequestration, speleothem growth) that constitute it. Karst areas must therefore be holistically managed in an appropriate and careful manner. A critical overview of current protection legislation in Slovenia has been prepared, with particular reference to karst areas. The major problem is a lack of harmonised multi-sector policies regulating land use and planning throughout the karst region, the absence of detailed guidelines and insufficient pursuance of karst in all its complexity and vulnerability. A comprehensive management approach for karst areas has been proposed and could subsequently be adopted by other karst-rich countries. Management is based on the enforcement of karst-specific legislation, including provision of detailed management plans and their strict implementation. Common database maintenance, reconciliation between various stakeholders and raising public awareness are additional important parts of the approach.

1. Introduction

Karst terrain accounts for a significant portion of the global land surface at all latitudes and at all elevations. It has been estimated that about a fifth of the world's dry, ice-free land is karst. In Europe karst areas cover about a third of the continent, while south-western China hosts the largest contiguous karst areas in the world, occupying about 500,000 km^2 (Ford and Williams, 2007).

In the past few decades karst landscapes have faced a growing demand for their wide range of economic assets, among which groundwater resources are certainly of the highest importance (Bakalowicz, 2005). Additional primary economic benefits provided by karst landscapes are minerals and rock. In some karst areas major forest resources exist. With technological and economic development, karst areas have grown to be among the most important providers of oil and gas, and have experienced an intensification of agriculture (Gunn and Bailey, 1993; Nicod et al., 1997; Moore, 2001; Peng et al.,

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2011). An increasing demand for clean energy resources calls for intensive use of geothermal energy from karst systems (Goldscheider et al., 2010). Furthermore, numerous caves and other geomorphologically remarkable phenomena have become tourist attractions and prompted the development of tourism (Hamilton-Smith, 2007; Williams, 2008). Some are venerated as sites of religious, spiritual and cultural importance.

At the same time karst areas are a valuable ecosystem, providing special habitats and containing high levels of biodiversity (Kløve et al., 2011). A great variety of species, including some rare and endemic ones, are present both on the surface and underground. Unusual fauna that develop in the light-deficient subsurface environment range from bacteria to crustaceans, spiders, fish and small mammals (Culver and Pipan, 2013).

In addition to the above resources, karst systems provide a number of other ecosystem services, for example carbon sequestration (White, 2013). They also offer opportunities for scientific study and education by providing an insight into past geomorphological, ecological and anthropogenic conditions. These can potentially include undisturbed archaeological sites and well-preserved animal and human remains.

Owing to the peculiar intrinsic characteristics of karst and karst-specific processes, all these natural resources and ecosystem services are particularly susceptible to destruction. Furthermore, the integrity of any karst system depends upon a dynamic interaction between its various components. Any interference with this relationship is likely to have undesirable and irreversible impacts, while disturbance in the natural balance of any of these components may have implications for all the others. Such environments therefore need a holistic approach involving cautious management and suitable land-use planning (Yuan, 2001; Van Beynen and Townsend, 2005; North et al., 2009; De Waele, 2009; Goldscheider, 2012).

Many local, national and international agencies have identified karst and cave protection as a significant area. An early document offering general guidelines on karst protection was produced by Watson et al. in 1997. More recent efforts, which have a mainly scientific basis, have been dedicated to enforcing the equilibrium between proper protection and the growing demands of different interest groups (see, for example, Drew and Hötzl, 1999; Zwahlen, 2004; Fleury, 2009; Van Beynen, 2011; Gutiérrez et al., 2014).

Unfortunately, many protection policies and other legislative frameworks often lack an adherence to new scientific findings. The present paper includes a critical overview of protection policies and legislative frameworks, with particular reference to karst landscapes. The study focuses on Slovenia, a young country within the EU that is considered the cradle of karst science or karstology. The current state of karst and cave protection issues is presented, major shortcomings are illustrated and some cases of karst degradation are reviewed. A comprehensive management approach for karst resources is proposed. In view of the multiplicity and diversity of aspects covered by the topic of protection, only the primary elements constituting karst systems (surface, subsurface and water) are considered in this paper. Additional goals of the present research include improving communication between the various sectors living and working in karst areas, and raising awareness of karst landscapes and the specific characteristics and vulnerability of their ecosystems.

2. What is karst and why it is vulnerable?

Karst is a terrain with distinctive landforms and hydrology arising from high rock solubility and consequently well-developed solution-channel (secondary) porosity. It is normally formed on carbonate rocks, such as limestone and dolomite, or evaporites (Ford, 2004). The key process is aqueous dissolution and, in contrast to processes in other relief forms, in karst terrain chemical weathering dominates over mechanical transport (Jones and White, 2012). Rainwater becomes acidic as it comes into contact with carbon dioxide in the atmosphere and in the soil. As it drains into fractures in the rock, the water begins to dissolve away the rock, enlarging the joints and bedding planes and creating a network of underground conduits (Gunn, 2004). These conduits can vary in size from slightly enlarged cracks to tunnels many metres in diameter and many kilometres in length.

Over time, the process of dissolution leads to the development of dolines, caves and shafts, sinking and underground rivers, large springs and karst poljes typical of a karst landscape (Fig. 1). However, distinctive surface features may be completely absent where the soluble rock is mantled, such as by glacial debris, or confined by superimposed non-soluble rock strata.

Dissolution associated with karst development induces complex underground water drainage, where subterranean flow may limit surface flow. Karst hydrology is generally characterised by rapid infiltration of recharge waters, high permeability of the underground and heterogeneous underground flow along karst channels towards springs. This groundwater flow is often very rapid (up to several hundred metres per hour) and turbulent. Underground pathways are often very complex, may vary due to specific hydrological conditions, and even enable transport over long distances (Ford and Williams, 2007; Worthington, 2009; Ravbar, 2013). Thus every form of contamination in karst areas may reach the underground rapidly and without significant attenuation (Fig. 2).

Karst systems are generally stable environments that have developed over thousands of years. Due to the described peculiarities of karst processes, these landscapes are determined by extreme vulnerability to climatic pressures, human impacts and contamination. Changes in water percolation and subsurface air flow can significantly alter these stable environments, affecting both life forms and the rate of bedrock dissolution. The underground is particularly susceptible to these changes, as it is characterised by relatively constant temperatures and humidity all year round. Once damaged, karst surface and underground environments take a long time to recover, and the process is a difficult one. For this reason, karst must be holistically managed in an appropriate and careful manner.

3. Karst in Slovenia

Slovenia's karst may be considered the *locus typicus* for karst landscapes around the world. The earliest descriptions of unusual karst phenomena and studies of karst processes in