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The World Above, the World Below: The Three-Dimensional, Interdisciplinary Nature of Cave and Karst Stewardship

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Introduction

Karst, the landscape formed by the dissolution of rocks (instead of mechanical weathering), presents unique challenges to land usage and stewardship. Landmark characteristics include the absence of surface streams (or presence of sinking streams), rapid infiltration of water, caves, sinkholes, natural bridges, poor soil development, sharp pinnacles, and rugged terrain. These characteristics can make life unusually demanding. More than any other terrestrial terrain, the surface and subsurface are intimately linked, and responsible management requires a firm grasp of its three-dimensional interdependence.

The chemistry of most karstic rocks (carbonates and sulfates) and their commonly close association with microbial processes have caused many scientists working in the rapidly growing field of geomicrobiology to focus on karst terrains (Northup and Lavoie 2001). The presence of caves has long been recognized as important habitat for rare, and commonly threatened, macrofauna, including bats, salamanders, fish, and many invertebrates (Culver et al. 2000). The importance and sensitive nature of karst aquifers, both to the surface and subsurface ecology of a region (Graening and Brown 2003) and domestic water supplies (Boyer and Pasquarell 1999), adds to the need for a multi-disciplinary approach to karst management.

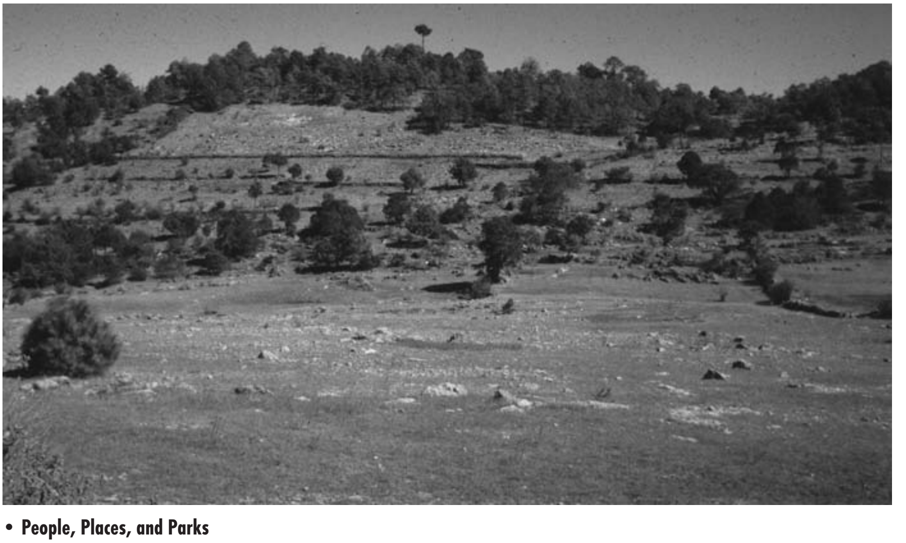
The three-dimensional nature of karst

The very nature of most subsurface karst features depends on their relationship to the surface. Meteoric water infiltrating from the surface forms most caves and other secondary porosity. Altering the surface runoff patterns or soil profile affects the continuing process of speleogenesis (cave formation). Conversely, the karst aquifers that formed by these processes, and which underlie 40% of the United States, are more readily contaminated than other types of aquifers (Assad and Jordan 1994). Water percolates more slowly through clastic sedimentary rocks or the minute fractures or grussified joints in crystalline rocks than it does in the pipe-like conduits of karst. A slower infiltration rate allows some natural filtration as well as chemical and biological degradation of contaminants. Contaminants entering a karst aquifer generally remain unmitigated (Vaute et al. 1997). Depending on flow conditions at the time of contamination, they will quickly re-emerge at surface springs or may remain stored underground until a major storm flushes them through the system. The surface and subsurface hydrology of a karst region must be managed as an intimately interconnected network.

Sustained storage of contaminants in the epikarst and cave stream sediments adds to the complexity of karst hydrology issues. (Epikarst is "the upper weathered zone of enhanced porosity generally at the soil/bedrock contact and functions to store and direct percolation water towards vertical drains or springs in the karst"; Jones 2004: 3.) A hot topic in the field of hydrology focuses on developing a better understanding of how both dissolved and non-aqueous phase liquids that enter karst vadose zones may be stored and moved laterally over a period of years (Loop and White 2001; Mahler et al. 2004). Thus, while the bulk of an oil or pesticide spill entering the epikarst may pulse through the system within a few days, a low-level presence and discharge of related contaminants may affect both the cave stream and surface spring water quality for years.

Changing land use patterns commonly lead to altered drainage patterns and increased runoff. In karst regions, the changes commonly bring more sediments into the subsurface conduits (Mahler et al. 2004). Those sediments can plug up the natural underground storm sewers (i.e., caves) and cause backflooding onto the surface. A compelling example of surface changes causing dramatic changes in the subsurface that result in devastating changes on the surface may be viewed near Yosonicaje, Sierra Mixteca Alta, Oaxaca, Mexico. Widespread deforestation of hillsides adjacent to a large, fertile doline (sinkhole with a broad, flat bottom) caused extensive soil erosion. With nowhere else to go, the sediments flowed into and filled the caves that historically provided good drainage to the doline. Now, the doline contains a lake many months each year, and it is no longer suitable for agriculture. Local farmers must plant their corn on the steep, adjacent hillsides and use the flat-bottom doline for grazing, when it is not flooded (Figure 1).

Figure 1. Sediments eroded from the deforested hillside in the background plugged the caves in the flat-bottomed doline of the foreground, causing it to flood much of the year. Local people have had to abandon growing crops in the doline and now strive to minimize future problems by maintaining the sediment dams and reforesting the hillside. Photograph courtesy of L.D. Hose.



Subsidence is another common concern in karst calling for a three-dimensional approach to management. Sinkhole development on the surface results from the collapse of a cave, generally caused by changes in the underground environment (Beck and Herring 2001). A lowering water table, petroleum reserve withdrawal (Figure 2), and accelerated speleogenesis due to altered surface drainage patterns are the most common causes. This sequence provides an example of surface changes affecting subterranean processes that, in turn, result in surface alteration. Subsidence, whether catastrophic or gradual, can cause significant economic and safety risks.

Figure 2. Recent subsidence due to petroleum withdrawal in Dragger Draw, southeast New Mexico. Photograph courtesy of L.A. Land.

Most "cave" organisms depend on the surface for their energy and, commonly, part of their life cycle. Many organisms, such as bats and crickets, feed on the surface and use caves for resting and as nurseries (Jones et al. 2003). These organisms depend on healthy maintenance of both habitats. If either their surface or subsurface environment is negatively impacted, the ecology of both environments may be altered. In the case of highly mobile cave-dwelling species, such as bats, alteration of the surface up to several kilometers away may negatively affect them. Deforestation near a cave entrance or between caves and water bodies may cause adverse effects to bat populations by increasing their susceptibility to predation, removing protection from wind and frequent resting places for fledgling fliers, and forcing fledgling and nursing bats to fly further from the roost cave. Similarly, aqueous cave organisms may be hurt by changes on the surface great distances upstream. Deforestation up-drainage may lead to increase sediment influx, harming stream organisms that depend on relatively clear water conditions. Deforestation of the Alaskan Tongass Forest has directly affected the fishing waters, affecting both commercial (most notably salmon) and noncommercial fisheries (Bryant et al. 1998).

Alteration of the cave habitat, resulting in a decline in the cave-dwelling population, can cause significant impacts on the surface ecology. Many vertebrate species that use caves or karst features move freely between the surface and subsurface, and are functional members of both ecosystems. Disruptions in either of these systems will affect the other, and it is more appropriate to consider the surface and the subsurface as different compartments of a single ecosystem. For some vertebrate species, caves provide resources critical to their survival (Strong 2005). Some endangered species of bats depend on a limited number of caves as hibernation sites. Destruction of their cave habitat by direct (quarrying) or indirect (sedimentation resulting from deforestation plugging an entrance) means may drive a species from an area and, possibly, lead to an overall population decline. Even seemingly benign disruption of a subterranean habitat (e.g., tour groups disrupting hibernating or maternal colonies) can lead to similar results (Johnson et al. 1998; Ferreira and Horta 2001).

Many of the concerns associated with karst regions are also associated with non-karstic cave regions. Subterranean conduit flows through lava tubes comprise important aquifers in the Pacific Northwest and Hawaii. Numerous ancient lava flows and associated lava tubes lie in close proximity to housing developments in Hawaii. Contaminants from surface runoff move through the lava tubes and threaten ecosystems, water supplies, and cultural artifacts (Halliday 2003). Destruction and alteration of caves in nonsoluble rocks (e.g., lava tubes and "talus" caves) raise the same concerns as karstic caves.

The interdisciplinary nature of karst

Many management issues involving caves and karst focus on concerns for keeping the ecology of the region as little disturbed as possible (Bowles and Arsuffi 1993). Water quality and quantity affect the living organisms of the region. Changes in subterranean atmospheric or hydrologic conditions alter weathering and precipitation (i.e., geologic) processes underground. Inappropriate use or maintenance of underground septic systems or leaky oil well casings can lead to altered ecosystem dynamics, causing some species to diminish or even disappear while others flourish.

Traditionally, the field of ecology has recognized and studied the impact of physical parameters on living organisms. Until recently, little attention was generally given to the impact of biology (with the glaring exception of human beings) on the physical environment, particularly the lithosphere (rocks). However, the exploding field of geomicrobiology has recognized that life plays a major role in weathering processes on both the surface and subsurface. The interaction is arguably strongest in carbonate and sulfate rocks, the same rocks that most readily form karst (Sasowsky and Palmer 1994). Compelling evidence of life contributing to the formation of its cave habitat in a subterranean version of Gaia has been documented in several sulfide-rich caves around the world, most notably Cueva de Villa Luz in southern Mexico (Hose et al. 2000). While chemoautotrophic organisms in this cave utilize the carbonate anions in the bedrock and the peculiar water and atmospheric chemistry contained in the cave, they also produce the sulfuric acid that dissolves the walls, facilitates massive conversion of limestone to gypsum, and aggressively enlarges the cave (Figure 3).

Some vertebrates, particularly fish and salamanders, are obligate cave-dwellers that generally rely on organic food resources transported into the caves from the surface. Flowing water transporting organic debris is an example of an interaction between biology and hydrology in karst regions. Vertebrates and invertebrates that move between surface and subsurface environments provide another mechanism for energy transfer. When they defecate in the caves, they provide a resource for a variety of invertebrates and microorganisms. Even subsurface karst voids with no obvious surface opening are likely influenced by water input from the surface. Although some subterranean ecosystems are based on chemoautotrophic bacteria (Hose et al. 2000; Boston et al. 2001), even the most extreme examples utilize an energy component derived from surface sources (e.g., free oxygen, nutrients, etc.).

The disciplines of paleontology and archaeology have strong connections with caves throughout the world. Many karst areas and caves have valuable and irreplaceable paleontological and paleoecological resources (Schubert et al. 2003). The relatively constant temperature and humidity of the cave environment provide conditions conducive to the preservation of bones, some soft tissues of animals, and dung deposits that can be analyzed to provide knowledge of past biological communities in the vicinity of a cave. The same conditions also preserve archaeological or more recent cultural material. Many caves have preserved material tracing the evolutionary and cultural history of humans. The Paleolithic cave paintings of Europe are well-known examples, but U.S. caves also contain valuable prehistoric material. Russell Cave National Monument in Alabama and Grand Canyon National Park preserve extensive records of prehistoric times (Emslie et al. 1987; Schubert 2003).

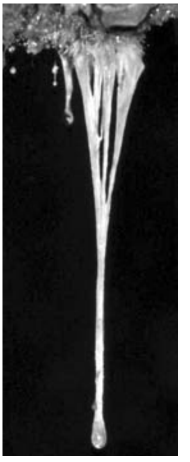


Figure 3. This pendulous, microbial community of chemoautotrophic bacteria is called a "snottite" (Hose et al. 2000). It produces strong sulfuric acid, which dissolves the bedrock and enlarges its subterranean home, Cueva de Villa Luz. Photograph courtesy of L.D. Hose.

In contrast to the excellent preservation environment that caves generally provide for paleontological and archaeological remains, there are many documented instances of microbial attack on human artifacts, including cave paintings (Schabereiter-Gurtner et al. 2002). These effects are being studied by several groups in an attempt to develop means of amelioration of such damage to irreplaceable cultural and paleontological materials. Clearly these are instances where the native bacterial flora of the cave, which themselves are features worthy of protection, are also threatening archaeological resources worthy of protection.

Because of the physical proximity of different resources, special care must be taken when conducting scientific research in caves. Archaeological excavations could obviously damage paleontological resources without proper attention, but disruption of cave sediments could also adversely affect the biological community. Although it might not always be possible, it would be desirable to have specialists from many disciplines participating in a project to ensure that the maximum amount of information be gained with a minimum of disturbance to the resources.

Applied research specifically targeting cave management practices is lacking (Seiser 2003). Consideration and evaluation of the cave visitors' experiences is an understudied but critically important aspect of any cave and karst stewardship program with an ecosystem management approach. Such evaluations should not only include knowledge gained and retained, as well as the experiential aspect of a visit , but also how the visitors perceive the resource and management activities from a visual context (e.g., barriers, signage, trails).

Education is viewed as a critical component in cave and karst stewardship programs. Public education and engagement of citizens has been shown to be absolutely essential to protection of karst aquifers regardless of the relative efficacy of technological solutions to pollution problems (Ekmeki and Gunay 1997). Education programs targeting local community members and landowners, as well as tourists who visit these regions, regardless of cave-related activities, are needed. Inclusion of visitors helps promote cave resource protection beyond the borders of cave regions. In addition, there is a growing need for karst and cave stewardship programs targeting federal and state land managers. These programs need to address the environmental components of karst and caves, as well as the human dimensions, including but not limited to tourism, recreational, and environmental protection legislation (Seiser 2003).

Conclusion

Management of visitation to wild and show caves often focuses on in-cave activities. However, surface activities and structures need to be evaluated regarding appropriateness for protection of the subsurface environment and entire ecosystem. Parking lots and buildings can affect surface runoff. Potential contamination from restroom facility leakage must be a concern in terms of the ecosystem, visitor experience, and groundwater resources associated with the cave. Consideration should also be given to the need to provide easy access to wild caves (e.g., a road versus a trail). Trailhead parking lots may be located in a more appropriate location distant from the cave. While cave visitation can serve as an educational/interpretive activity focused on the cave environment and ecosystem protection, visitation needs must be weighed against potential surface and subsurface impacts.

It is imperative that land stewards in karst regions approach their tasks with a persistent three-dimensional, interdisciplinary outlook. Responsible management of karst, as with marine, lacustrine, and fluvial environments, requires a firm grasp on both its three-dimensional and interdisciplinary cross-linkages. In addition to protecting caves and karst areas from adverse human actions on the environment, managers must also protect these resources from poorly conceived projects that focus on a single aspect of cave and karst sciences.

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