Karst Landscapes and the Importance of Three Dimensional Data in Protection of Cave and Karst Resources

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Abstract

Karst and similar landscapes are found in a wide range of biogeographic classes. In the U.S. for example, Everglades, Mammoth Cave, and Hawaii Volcanoes National Parks have little in common - except karst or pseudokarst, and a cultural past (even though these are very different). This diversity of geologic settings makes karst difficult to categorize and work with when designing a national program such as the recent NPS-USGS Geo-Indicators effort. A GIS-based approach with multiple datalayers is the only sane way to understand and convey the many relationships, in X, Y, and Z axes, between component ecosystems and cultural resources within karst and pseudokarst landscapes. Obviously, karst and cultural landscapes cross modern political as well as biogeographic boundaries. Here again, three-dimensional data are the foundation for understanding similar to that in anatomy and physiology: structure and function. In understanding where the most vulnerable "pressure points" exist within karst landscapes, we can target landscape-scale ecosystem management to greatest effect. USGS and the National Cave and Karst research Institute could play an extremely significant role in cave and karst management on a national scale beyond NPS or other agency boundaries via cooperative management of three-dimensional karst datasets analogous to programs in several states.

Karst, Pseudokarst, and Non-Karst Caves

Karst landscapes have characteristic morphology and underground drainage including caves created largely by chemical solution. This is typical in carbonate, sulfate, and chloride rocks, but can also occur in less soluble rocks such as quartz diorite (Jennings 1971) or quartzite (White et al 1966). Karst accounts for approximately 15 % of the earth's land surface, and that in carbonate rocks is most prevalent (White and White 1989). Pseudokarst landscapes may have morphology similar to karst, and often have subterranean drainage and caves, but porosity is created via completely different means. Pseudokarst typically develops in lava, unconsolidated sediments or volcanic ash, talus, ice, and permafrost (Kempe and Halliday 1997). Pseudokarst is most highly developed in basalt flows with lava tubes (Halliday 1960). Ironically, water may or may not penetrate lava tubes, but surface runoff often quickly sinks to resurge at springs via crack systems in the lava fields. Despite the differences in origin, volcanic and solutional caves have environmental similarities that have led to analogous faunas (Peck 1973).

Not surprisingly, ecological similarity means that some of the same threats apply, such as impacts from road construction (Halliday 1996), disturbance to cave fauna by visitors, sinkhole dumps (Kambesis 2000), raw sewage (Halliday 2000), pharmaceuticals, household pesticides (Lao and Gooding 2000) and other sources of contamination. Caves in talus can also be important habitat as explained in Bat Conservation International's "Bats of Eastern Woodlands" report to the U.S. Fish and Wildlife Service (Keeley et al 2001). As an example, cave visitation was recently limited in deference to a maternity colony of Townsend's Big-Eared Bats at Pinnacles National Monument, California. Caves in talus may be part of a pseudokarst landscape, or may be isolated features more appropriately classed as non-karst caves along with erosional sea caves. Non-karst caves, like their counterparts in karst and pseudokarst landscapes, can also be significant geological features important as wildlife habitat or cultural sites.

NPS-USGS Geoindicator Effort

Beginning in March of 2000, the National Park Service (NPS) and U.S. Geological Survey (USGS) began a joint effort to inventory geologic processes potentially influenced by

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human activities in national parks (Higgins and Wood 2001). The foundation selected for this work is a set of 27 earth processes known as geoindicators that may exhibit important changes within a century, and which could be significant in assessments of environmental stability and ecosystem integrity. This excellent set of geoindicators was developed by the International Union of Geological Science's Commission on Geological Sciences for Environmental Planning, and is detailed in Berger and Iams (1996). One of the geoindicators is Karst Activity, which focuses on carbonate and other soluble bedrock terrain. Rather than focus this geoindicator exclusively on solutional karst features, the NPS will broaden the scope to encompass pseudokarst landscapes and isolated non-karst caves. In a similar vein, the national karst atlas proposed by Jack Epstein and Randall Ordnorff of USGS will include pseudokarst landscapes, building on the work of Davies et al (1984). These are important steps toward inclusion of caves and landscapes that function in similar ways despite different origins. Though almost all speleologists were introduced to the field via carbonate caves, general acceptance of a broader array of landscapes and cave types appears imminent. In 1997 the International Union for the Conservation of Nature decided with some trepidation to not include lava caves and other forms of pseudokarst in its publication titled "Guidelines for Cave and Karst Protection." However, the possibility of future inclusion was discussed (Hamilton-Smith 1997). Though the Karst Waters Institute (KWI) does not discuss caves and karst of non-solutional origin in its basic explanation of karst and karst ecology, the Koloa Lava Tube System in Hawaii was included in KWI's 2nd Annual Top Ten List of Endangered Karst Ecosystems (Belson 1999). As well, the excellent map titled "Subterranean Biodiversity of Karst in the United States" by KWI's Dave Culver includes areas with lava tube biota (Culver 1999). Finally, a worldwide web search on pseudokarst reveals that from Texas to Tasmania, pseudokarst is considered significant enough to map alongside classic karst areas.

Returning to the Karst Activity Geoindicator, there are other relevant areas in need of amplification and inclusion besides the expansion beyond solutional karst described above. Perhaps due to the geological orientation of the originators, emphasis is given to water-rock interactions. It is important to note however that even caves of solutional origin long ago may be dry, and preserve extremely significant archaelogical resources (Watson et. al. 1969, 1974). As an indication of how rich cave passages can be in cultural resources, more than 9000 items have been recorded over the past 8 years in approximately 2.5 miles of upper level trunk in Mammoth Cave (Crothers, Swedlund, and Ward 2000). Among pseudokarst caves, lava tubes have a particularly high frequency of cultural artifacts (Ron Kerbo pers. comm.). The NPS /USGS inventory of geologic processes in national parks will consider subterranean cultural artifacts as both resources to be protected, and as indicators of distortion to the cave environment. Decay of in situ ancient organic artifacts may indicate changes in the cave environment caused by entrance manipulation. Also preserved very well in caves are paleontological and paleobotanical resources. These natural and culturally deposited remains can be used for ecological restoration in caves and on the surface (Toomey et. al. 1998, Olson 1998). Equally important along with cultural resources are cave biota. For example, terrestrial cave ecosystems historically provided refuge for literally billions of bats across the continent. Given the appetite bats have for insects (Whitaker 1993), many species had, and one day could again, have a significant controlling effect on insect populations affecting croplands, orchards, forests, savannas, and prairies. The aquatic cave ecosystem species, like all others, are important in their own right, but community level monitoring data are also an important component of and complement to direct water quality monitoring. Modification of dry cave entrances, creation of open artificial entrances, drilling through passages, damming of base level surface streams, and land-use related impacts in recharge areas can severely affect habitat conditions and therefore biota in cave ecosystems. These effects can ramify into neighboring ecosystems in the karst landscape.

One final point I want to make regarding the Karst Activity Geoindicator is that exemplary caves within karst landscapes are economically significant, especially in terms of tourism. Caves, as perhaps our favorite part of the karst landscape, are regional economic engines. For example, Mammoth Cave National Park had a statewide economic impact of over $116 million in 1994 (Atwood 1995). This economic value, including tax revenues generated, helps to make karst landscapes *worth protecting* to a broader range of people. Even though ecosystems tend to run themselves, with the ever- increasing human population and associated total impact, we must carry out compensatory ecosystem management. And as we all know, ecosystem management is funding dependent. This interdependence of our economy upon intact ecosystems, and ecosystem management upon a strong economy is little appreciated by business and resource managers respectively. Arguably, broad realization of this relationship between ecosystems and economies is most vital in karst and pseudokarst areas. In most landscapes, key resources can be specified with a set of XYZ coordinates, with little possibility for confusion or overlooking key resources. However, in karst landscapes it is possible to have natural or cultural surface features at a given set of XYZ coordinates, a terrestrial cave community or an archaeological site at the same XY but different location on the Z axis, and then cave aquatic habitat with historical objects such as lanterns and bottles at a still lower point along the same Z axis. This is an extreme example, and I use it to make a point, but it is also important to bear in mind that superposition is not a precondition for potentially impacting subterranean resources. Sites far removed but down gradient can be profoundly impacted. The best analogy I can draw is that karst and pseudokarst landscapes are like playing three-dimensional chess instead of the usual mind boggling two-dimensional game. In moving from general to specific, I will use Mammoth Cave National Park as an example.

The Mammoth Cave Case

Due to high biological diversity, and the most extensive known cave system in the world, a significant portion of South Central Kentucky's world-class karst landscape with its component ecosystems was designated as the Mammoth Cave Area Biosphere Reserve (MCABR) in 1990 by the United Nations Educational and Scientific Organization. Subsequently, an expansion of the reserve was approved in 1996. The central goals of MCABR programs are cooperative conservation of biodiversity, development of a sustainable economy, and environmental education. The first two of these goals are interdependent and require a thorough understanding of the complexity and limitations of both the natural and human ecosystems in the area. The third goal, environmental education, is an essential tool in successfully accomplishing the first two goals.

The conduit aquifer of the South Central Kentucky Karst is a great economic asset to the region because of the caves that are the foundation of the tourism industry. At the same time, this karst landscape is an economic hindrance because of its vulnerability to groundwater pollution, and the greater cost of infrastructure due to unstable bedrock. The path to a sustainable economy in such a complex, vulnerable and multi-layered landscape must be based upon an understanding of how surface and subsurface ecosystems relate to each other, and how these interrelationships may affect the human environment. The first map of Mammoth Cave intended to clarify surface-cave relationships was completed in 1908 by Max Kaemper of Berlin,Germany. Because this project was driven by property issues, the Kaemper map was kept confidential until discovered in the 1970s, but it is still used by researchers today. Subsequently, five scientifically-driven cartographic efforts spanning five decades have contributed toward understanding this complex landscape:

1. A map set titled "The Flint Ridge Cave System", was produced by Roger Brucker and Denver Burns in 1964. This folio cave map included surface topography, and incorporated text on history and geology.

2. A series known as the "Map Card" was first published by the Cave Research Foundation in 1973, and displayed 169 miles of the Flint-Mammoth Cave System within the park. A topographic overlay adapted from USGS quadrangles allowed understanding of surface-cave relationships. The most recent in the series was published in 1993, and shows 342 miles of the Mammoth Cave System in and near Mammoth Cave National Park with a similar topographic overlay.

3. The next step toward a higher level of understanding the regional karst landscape was a map titled "Groundwater Basins in the Mammoth Cave Region", published by Jim Quinlan and Joe Ray in 1981. This monumental work based upon dye tracing and measuring water well depths helped park managers to realize the importance of working with neighbors to help protect park resources. On this map, drainage basin boundaries, groundwater level contours, and probable underground flow routes in and near the park were displayed along with line plots of cave passages in and beyond park boundaries. This

map has supported protection of the endangered Kentucky Cave Shrimp by justifying creation of a regional sewage treatment facility, negotiation of runoff filtration and spill retention structures along Interstate Highway 65, and cleanup of sinkhole dumps in the Pike Spring Basin (Olson 1996, Olson et al 1999).

4. Cartographic delineation of the cave systems within the Biosphere Reserve is a work in progress that none of us alive today will likely see completed. To date, over 535 miles of cave passages have been surveyed within the MCABR, and these were assembled on a single map titled "Caves of the Dripping Springs Escarpment" by Don Coons in 1994. The simultaneous display of surface topography along with line plots of cave passages is a significant contribution toward our understanding of the three-dimensional landscape within the MCABR.

5. An ongoing effort focussed on hydrology is the Karst Atlas Series of maps being developed in Kentucky by Joe Ray and Jim Currens. The first maps in the series became available in 1998, and are maintained as GIS datalayers in order to facilitate updates. The maps in this series display drainage basin boundaries, surface topography, and probable underground flow routes. Line plots of cave passages are not displayed, but sites with known cave streams are indicated with a symbol.

All of the above works have helped to set the stage for what I will call Karst Landscape Ecosystem Management (KLEM) within the MCABR. This is based upon the concept of landscape ecology, which considers the interplay between component ecosystems on a landscape scale. Examples within karst or pseudokarst landscapes include the relationship between forest, savanna, prairie, or desert and terrestrial cave ecosystems, and the connection between aquatic cave ecosystems and surface counterparts. At a minimum, one platform on which cave survey and resource data, drainage basins, and surface topography can be displayed is needed. Additional relevant information useful in KLEM would include, but not be limited to, vegetation and other cover types indicating land use, habitat types, plus an array of GIS-linked inventory and monitoring datasets. Identification of cave passages with intermittent or perennial streams would also be very useful in evaluating potential risks to aquatic ecosystems. The GIS approach taken with the Karst Atlas Series in Kentucky and the proposed National Karst Atlas is the only rational approach since there are limits to how much information can be displayed at one time without confusion. With such three-dimensional data available for display in the combinations needed, we have the foundation for understanding similar to that in anatomy and physiology: structure and function. In understanding where the most vulnerable "pressure points" exist within the MCABR, we can target ecosystem management to greatest effect.

In the process of assembling information useful for KLEM, it is crucial to manage it in a way that minimizes opportunities for misuse of this information. A sensitive information protection strategy must be a deliberate part of any plan for what and how information will be made available in order to reduce risk to the very resources we seek to protect. Most obviously, cave entrances should not be indicated except in the most general way as on the Karst Atlas Series, and line plots of caves short enough that the entrance location is easily deduced should not be included even on datalayers with (theoretically) restricted circulation. This information must be managed in the same secure manner as archaeological sites or rare species locations. One minimum risk approach that would provide basic information relevant to developers and the public is the Geographic Exploration System (GES) in which images composed of different datalayers can be acquired, but the cartographic data from which it was derived cannot. Such basic map sets would be a boon to environmental educators. Hard copy output from this type of graphic display could be (and maybe should be) used for place mats in area restaurants. This could be part of environmental education efforts within the MCABR that would not place any resource in jeopardy.

As well, GES could become an important tool to use in the economic development decision-making process. Kentucky Geological Survey Division of Oil and Gas Inspectors need to be aware of where cave passages exist both for the protection of caves, and to help well drillers avoid loss of drill bits, or other expensive situations. In the permit review process of the Kentucky Pollution Discharge Elimination System, it is crucial that cave and karst features are known and considered because of the rapid

transit of water and contaminants in karst aquifers. Similarly, quarry operators are better off avoiding underground voids in order to avoid the environmental and economic costs associated with the impact of these operations on endangered species habitat, local water supplies or archaeological sites.
Research grade three-dimensional GIS coverage of the MCABR would have both greater capabilities and vulnerabilities. The ability to view cave passages from any angle is certainly crucial to understanding passage development, but we must insure that these same data cannot be used to acquire and misuse sensitive resource information. Perhaps most crucial, cave surveys and digital elevation models for surface topography may someday be precise enough to identify current or potential entrances. Cave Geographic Information Systems (CGIS) are certainly useful for all branches of research, but information on all vulnerable resources must be kept secure. One recent development designed to facilitate dissemination of cave survey data to those who need it while providing adequate security is the establishment of the Kentucky Speleological Survey (KSS) (Florea 2000). In partnership with the Kentucky Geological Survey (KGS), certain types of cave survey data will be maintained, and made available to the public and government agencies with concurrence of the KSS. Because the data are the property of KSS and not the KGS, they are exempt from Freedom of Information Act requests. This type of arrangement, already established in Virginia, Illinois, and Missouri, could lead to a national program with USGS and the National Cave and Karst Research Institute. This could be accomplished via affiliations between state geological surveys and USGS, or more directly through cooperation with the National Speleological Society and Cave Research Foundation. Recognition of the importance of three-dimensional datasets for KLEM on a national scale by USGS could take cave, karst, and pseudokarst management to a new level. This would be highly significant both within agency-managed units and beyond.

CONCLUSION

The public in general and planners in particular need to be aware of critical points of wildlife habitat and other natural or cultural resource vulnerability in karst and pseudokarst landscapes plus areas with non-karst caves. Using this approach will reduce the frustration economic developers face when dealing with cave and karst environments. Overall, the potential benefits of GIS supported Karst Landscape Ecosystem Management on local and national scales would far outweigh any potential damage caused by misuse of three-dimensional datasets. This discussion is relevant to all agency-managed areas with karst, pseudokarst, or non-karst caves, and to the far greater lands beyond. USGS is ideally prepared to assist the land management agencies in sustainable stewardship of caves, karst and pseudokarst because its mission is truly national in scope rather than being limited to certain parcels scattered across the country.

Even if the only gain from GIS supported Karst Landscape Ecosystem Management was increased awareness and understanding of regional drainage and cave resources, the effort would be worthwhile. Such increased awareness and understanding could help with matching the highest impact land uses with the least vulnerable sites. With such an approach, we can maximize our chances of realizing an ecologically sustainable economy. This is not yet an urgent political issue, but it will become so with time.

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