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TOWARDS ESTABLISHING EFFECTIVE PROTECTIVE BOUNDARIES FOR THE LUNAN STONE FOREST USING AN ONLINE SPATIAL DECISION SUPPORT SYSTEM

KAKO PRITI DO UČINKOVITIH MEJA ZA VAROVANJE LUNANSKEGA KAMNITEGA GOZDA S POMOČJO »ONLINE SPATIAL DECISION SUPPORT SYSTEM«

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Chuanrong Zhang & Weidong Li & Michael Day: Towards Establishing Effective Protective Boundaries for the Lunan Stone Forest Using an Online Spatial Decision Support System

The Lunan Stone Forest is the World's premier pinnacle karst landscape, and was established as a national park in 1982. The existing boundaries are essentially arbitrary, based on notional scenic value, and take into consideration neither the physical landscape nor the existing pattern of urban development. Moreover, the location of the boundaries is not clear to the local community, rendering them largely ineffective. Developing an online Spatial Decision Support System (SDSS) potentially provides a way to establish protective boundaries that are meaningful from the perspective of karst science, yet also readily identifiable by the local community within the context of the existing urban fabric. The 7km^2 "core area" of the Stone Forest Park is used to illustrate the use of the SDSS.
Key words: Lunan Stone Forest, karst, conservation, protected area, boundaries, Spatial Decision Support Systems (SDSS).

Izvleček UDK: 551.44:712.23(10)

Chuanrong Zhang & Weidong Li & Michael Day: Kako priti do učinkovitih meja za varovanje lunanskega Kamnitega gozda s pomočjo »Online Spatial Decision Support System«

Lunanski kaniti gozd je najlepši primer »kamnitega gozda« (shilin) na svetu in je bil 1982 razglašen za narodni park. Sedanje meje parka so bile dogovorjene na osnovi zaznavne pokrajinske vrednote in ne upoštevajo niti fizičnih lastnosti pokrajine niti obstoječega vzorca razvoja mesta. Še več, lokalnim skupnostim meje niso jasne in so zato še manj učinkovite. Z razvojem Spatial Decision Support System (SDSS) na spletu je dano orodje, s pomočjo katerega bi bilo mogoče določiti meje varovanega območja, ki bi bile zadovoljujoče z vidika krasoslovja in sprejete s strani lokalnih skupnosti v skladu s sedanjim urbanim razvojem. Na 7 km^2 osrednjega dela Kamnitega gozda je prikazana možnost uporabe SDSS.
Ključne besede: Lunanski Kamniti gozd, kras, ohranjanje, zavarovano območje, meje, Spatial Decision Support System (SDSS).

INTRODUCTION

The Lunan Stone Forest, or "Shilin", is the World's premier pinnacle karst landscape (Figure 1). Located among the plateau karstlands of Yunnan Province, in southwest China (Figure 2), it is widely recognized as the 'type example' of the landscape, demonstrating greater evolutionary complexity and containing a wider array of karren morphologies than other examples, including those of Gunong Mulu (Sarawak), Palawan (Philippines), Mount Kaijende (New Guinea), Madagascar and Chillagoe (Queensland, Australia) (Ford, 1997; James, 1997). Not only is the Shilin significant in terms of its importance to karst science, but also it has enormous aesthetic appeal and cultural affiliation, and it is a major focus for both national and international tourism, receiving some two million visitors annually (Kranjc and Liu, 2001; Zhang et al, 2003).

Despite its iconic landscape status, rapid urbanization, industrial development and the expansion of tourism have resulted in dramatic land use and land cover change in the last thirty years (Zhang et al, 2003). The Stone Forest has been recognized as meriting protection since 1931, when the provincial governor visited, and the central area (350 km^2) was established as a Provincial Natural Protected area in 1981 and as a national park in 1982 (Ford, 1997; Kranjc and Liu, 2001). Despite this, natural vegetation has been replaced by exotic species, wildlife has been displaced and traditional agricultural lands are increasingly being lost to housing and industrial development. Particularly around the two outstanding pinnacle clusters, in Shilin (11km^2) and Naigu (8km^2), hotels have been constructed to accommodate the growing numbers of visitors, and roads have been built, paved and widened to facilitate increased traffic flow. Surface and underground water resources have come under increasing pressure, and quarrying has destroyed much of the fabric of the outlying shilin itself (Huntoon, 1992, 1993; Day, 1997; Kranjc and Liu, 2001; Zhang et al, 2003). More than 50% of the broader stone forest karst has been extensively damaged by human activities, and the remaining areas are coming under increased resource pressures (Day, 1997).

As elsewhere, there is increasing awareness in Lunan of the need to resolve such problems and conserve the karst landscape through the implementation of rational land use strategies (Day, 1997; Zhang et al, 1997b; Kranjc and Liu, 2001). Further impetus has been provided by the support of local, provincial and national authorities for designation of the Stone Forest as a UNESCO World Heritage Site (Song and Li, 1997). Adequate definition of the protected area and the demonstration of effective management are key criteria in this context, and currently represent an impediment to inscription (Ford et al, 1997). Day (1997) suggested that conservation efforts might be focused on the following overlapping categories: provision and protection of water supplies, maintenance of vegetation and wildlife, protection of rocks and soils, tourism management and provision of appropriate infrastructure. Zhang et al (1997b) stressed the need to disturb the land as little as possible, while improving living conditions for the local Sani population. Whatever the specific approach, it is critical that the protected area boundaries be delineated rationally and that they be clearly identified.

PHYSICAL AND CULTURAL LANDSCAPE PATTERNS

The land use and land cover pattern in the Stone Forest is complex, reflecting variations in landforms, water resources and soils, and the human imprint upon these. Variations in the physical landscape have been described previously (Chen et al, 1986; Waltham, 1984; Geng et al, 1987; Song and Li, 1997; Zhang et al, 1997a; Zhang et al, 2003) and will not be examined in detail here. The area has a complex geological history, displaying much greater evolutionary complexity than other pinnacle karst areas (Ford, 1997). The proposed developmental sequence involves continental-oceanic alternation and basalt eruption in the Permian, plantation in the Mesozoic, intermountain basin and lake development in the early Tertiary, and subsequent uplift and exhumation (Chen et al, 1986; Song 1986a,b; Yuan, 1991; Zhang et al, 1997a).

As a consequence of this complex evolution, the limestone pinnacles vary considerably in dimensions, shapes and distribution, exhibiting a unique range of morphologies, including needles, fins, fluted spires, emergent stone teeth and many other forms (Waltham, 1984; Geng et al, 1987; Ford 1997) (Figure 3). Not all of the largest and most dramatic examples are located in the central protected areas. Reflecting its multi-phase evolution, the pinnacle karst occurs across the broader landscape, from hill summits and ridge crests to hillsides and valley bottoms. Pinnacle morphology shows no consistent relation to the broader current landscape, although many of the larger individuals are within the broad valleys, rather than on the uplands (Song and Li, 1997).

There is also no clear relation to current groundwater levels, although there are several small lakes where the potentiometric surface is locally close to the ground surface. Soils are generally lateritic, thin and patchy, although several types are recognized (Lin, 1997). The natural vegetation cover has all but been destroyed, and forest currently accounts only for about 1.2% of the land cover (Zhang et al, 2003). Environmental factors, such as soil type, vegetation cover and geomorphic setting merit consideration in a regional conservation strategy, and should be considered in designation of protective zones (Day, 1997; Zhang et al, 1997b; Kranjc and Liu, 2001).

Figure 1: Lunan Stone Forest Landscape (Karsr Research Institute).

The karst pillars are interspersed with agricultural lands and built up areas, together with roads and other infrastructure (Zhang et al, 1997b; Zhang et al, 2003). The Shilin landscape has a low environmental buffering capacity and is a sensitive, fragile ecosystem (Huntoon, 1992, 1993, 1997). Human activities have already had a profound impact on the landscape, including quarrying of the rock itself, accelerated soil erosion, air pollution and water resource depletion. The combination of urban growth and increased tourism is exerting increased pressure on the landscape (Day, 1997; Kranjc and Liu, 2001). It is generally acknowledged that reversing current land uses, for example by allowing farmland to revert to forest or demolishing existing housing, is not a viable approach to conservation, and thus the emphasis is upon managing the existing situation and planning future development by establishing land use zoning, including the maintenance of existing and new protected areas (Zhang et al, 1997b). Criteria such as the existing urban pattern, population and the existing road network should certainly be considered in this context.

The uniqueness of the Stone Forest landscape also owes much to the local minority nationality culture. The Stone Forest karst has long been integrated into the lifestyle of the local Sani people of the Yi autonomous nationality, who have endowed it with considerable cultural significance (Zhang et al, 1997a). Such cultural criteria also should be considered in the management strategy.

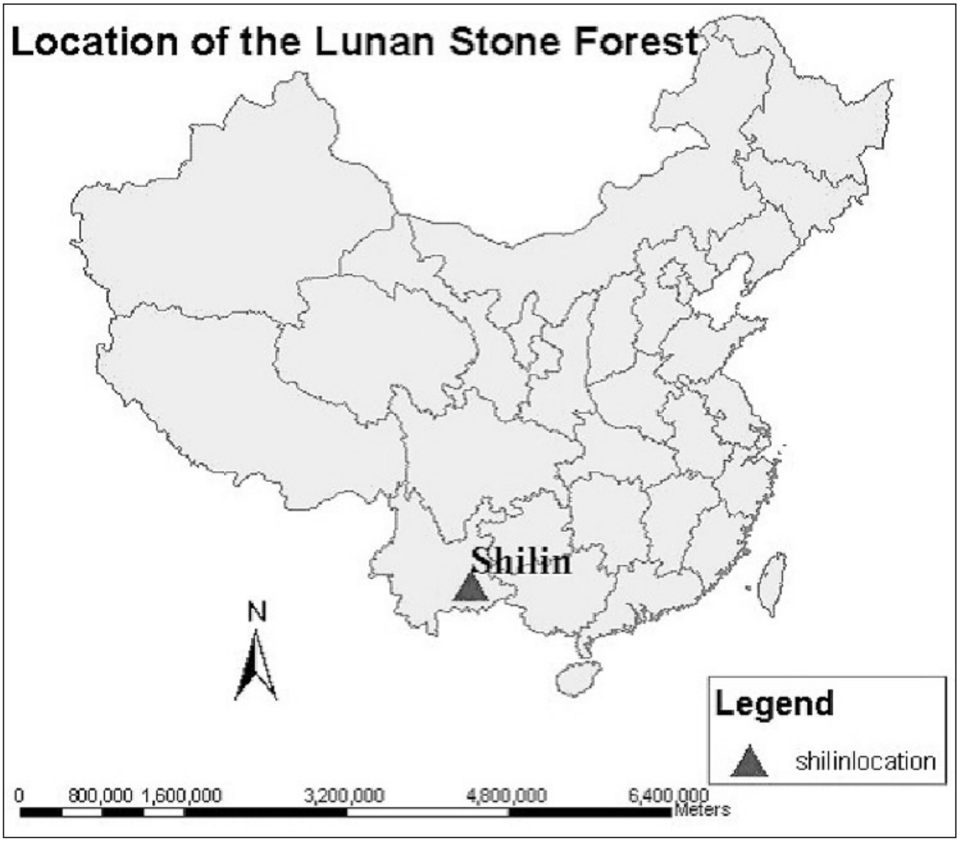

Figure 2: Location of the Lunan Stone Forest.

The Stone Forest landscape should be conserved from the intertwined perspectives of intrinsic appeal, development and management of the resource (Zhang and Li, 1993; Liao and Xu, 1993; Xu, 1993; Song, 1994; Wang et al, 1994; Day, 1997; Kranjc and Liu, 2001). The designation of protected areas and the positioning of their boundaries need to consider multiple criteria, which are not independent.

THE BOUNDARY PROBLEM

In 1984 the national government established three conservation zones in the Stone Forest, reflecting different levels of landscape protection. The core or first level protection zone covers 19km^2 in six separate locations, including the Major and Minor Stone Forest Parks and the Naigu Park, which are the primary tourism focus. The second level zone represents a 28km^2 buffer or transition area surrounding the six core areas, and the third level zone represents an additional 306km^2 buffer (Figure 4).

Figure 3: Stone Forest morphologies.

While this arrangement is broadly useful in conservation of the landscape, there are problems with the designation and recognition of the protective area boundaries. The first problem is that insufficient evaluation was involved in the drafting of the existing boundaries. The designation of these boundaries was based essentially upon a notional assessment of scenic attraction, and it bears neither relation to geomorphic variations of the shilin pinnacles, nor the overall karst landscape, nor does it reflect broader topographic variation. The stone forest karst is conserved essentially because of its recognition as a tourism resource (Day, 1997), but it is not generally recognized that maintenance of that resource is dependent upon the overall health of the broader karst environment. The second problem is that the locations of the boundaries are not clear to local residents, and that there is no consistent enforcement of the existing land use regulations. Location of the boundaries is depicted only on a small-scale (1:1000,000) map (Figure 4), and the boundaries bear little relation to either natural or cultural features, such as lakes, roads or other prominent landmarks. Thus, there is general ignorance of the boundary locations, making it difficult to implement or respect appropriate

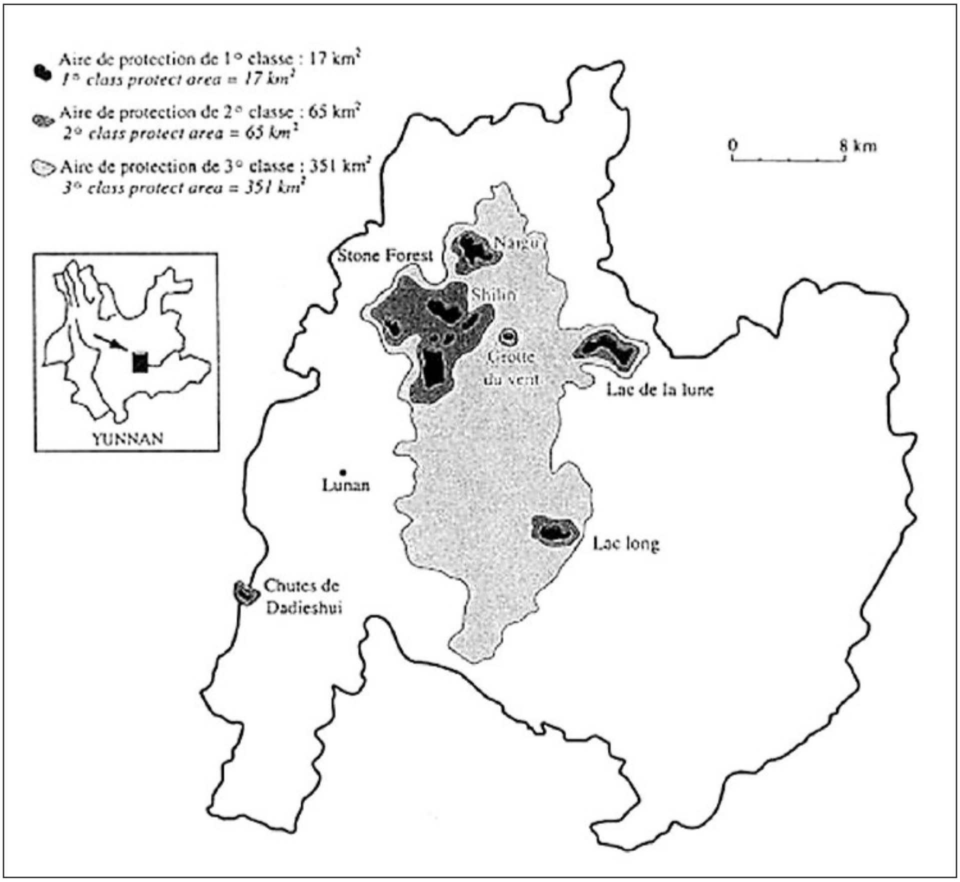

Figure 4: Current protection boundaries (adapted from Kranjc and Liu, 2001).

conservation regulations. Clarifying the location and meaning of the boundaries of the protection and conservation regions is a clear priority (Ford et al, 1997; Zhang et al, 1997b).

OBJECTIVES

The essential objective of this study is to utilize contemporary geographical technology to address the Shilin protective boundary delimitation problems. Within this broad goal, the first specific objective is to provide a rational and comprehensible strategy for boundary delimitation, involving a range of stakeholders including karst scientists, management authorities and other local decision-makers. The designation of the various protected area boundaries should be based on a variety of environmental and social criteria, rather than upon the sole criterion of scenic attraction. The second goal is to render the location of the boundaries clear to the public, by aligning them, wherever possible, with conspicuous landscape features such as distinctive pinnacle formations, water bodies, roads or buildings. Although reconciling these two objectives may prove problematic, the approach allows for maximizing decision-making inputs, and for increased public awareness. Such an approach may assist all involved in establishing, recognizing and respecting the boundaries, and thus contributing to effective management and long-term conservation of the shilin karst landscape.

METHODOLOGY

The Lunan Stone Forest in total covers an area of 350 km2, within which the physical landscape and the pattern of human impacts are heterogeneous. The greatest development pressure, population density and tourism focus are immediately around the town of Shilin itself, in the 7km2 Major and Minor Stone Forest Park area (Zhang et al, 2003). Since appropriate data for the entire Shilin area are not available, this study focuses at present on this "core" area, which contains the archetypal stone forest landforms and which has been longest exploited. The methodology will be expanded to the whole 350km2 stone forest area when data become available.

The data sources used here consist primarily of a 1:15,000 Shilin distribution map; a 1:15,000 geology map; a 1: 15,000 geomorphology map; a 1: 15,000 land use map; a 1: 15,000 slope map; a 1: 15,000 soil map; and a 1: 15,000 vegetation distribution map. Additional sources include an Ikonos 1 meter high-resolution gray satellite imagery and an Ikonos 4 meter resolution color satellite imagery, survey data from the Administrative Bureau of the Shilin National Park and personal ground observation.

Central to this research is the development of an online Spatial Decision Support System (SDSS), which potentially provides an appropriate tool for resolution of the boundary problems in question. Spatial Decision Support Systems are interactive, computer-based systems designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem (Malczewski, 1997). A typical SDSS has four components: 1, analytical tools, which facilitate data investigation; 2, decision models, which enable "what-if"/scenario investigations; 3, a geographic/spatial database; and 4, a user interface, which provides easy access to the decision models, databases, analytical tools, and a comprehensive display of the output (Densham, 1991).

Combinations of Geographic Information Systems (GIS) and spatial models are typically used in the design of an SDSS. GISystems are used to assemble, store, manipulate, and display geographically referenced information, and are increasingly employed in environmental management of caves and karst (e.g. Szukalski, 2002; Ohms and Reece, 2002; Moyes, 2002; Hung et al., 2002; Denizman, 2003). However, many GISystems possess only comparatively simple analytical functions and lack advanced modeling functions (Goodchild, 1987, 1992; Openshaw, 1990; Anselin and Getis, 1992; Fischer and Nijkamp, 1992; Anselin et al, 1993; Densham, 1994). An SDSS makes full use of GIS graphical display capabilities, spatial data query capabilities, database management capabilities, and tabular reporting capabilities, adding analytical modeling capabilities and expert knowledge input, and providing a user-friendly interface. SDSS research, development, and application has increased rapidly in the last decade (NCGIA 1990; 1996), with SDSS methods increasingly applied in conservation of biological diversity (IBM 1996), water resource management (Beaulieu et al., 2000), land use planning, and forest resource management (Sugumaran, 2000).

Although there are many applications of SDSS, few of these are on the web (Carver, 1998; Wan et al, 1999; Cara et al., 2000; Al-Sabhan, 2003; Lowe, 2004). Online SDSS provide several advantages, such as permitting the public to actively participate in decision-making and informing those with responsibility for decision-making.

In this study, an online Lunan Stone Forest Spatial Decision Support System (SFSDSS) for conservation of the Lunan Stone Forest landscape has been developed (http://129.89.71.203/stoneforest/). Through closely coupling GIS with a Multi-Criteria Analysis (MCA) model, this online SDSS potentially provides assistance to government authorities in the scientific delimitation of different level protection areas within the Lunan Stone Forest landscape. The online SDSS facilitates overlaying the boundary map with landscape features, such as roads, lakes and buildings with which local residents are familiar, thus making the boundaries clearer to the public, and assisting in the observation of conservation regulations. As an online SDSS, the SFSDSS increases both expert and public access to information and involvement in decision-making.

The development environments of the SFSDSS are Visual Basic 6.0, ESRI Mapobjects 2.1 and ESRI Mapobjects IMS 2.0 and ASP (Active Server Pages). The database system is a Microsoft relational database—Access 2002, and a Multi-Criteria Analysis (MCA) model is used in delimiting the protective boundaries. The technical development of the online SDSS and the MCA model have been explained previously (Zhang and Day, 2002), and here we only briefly introduce the MCA model, which is applicable to complex multi-criteria problems that include qualitative and/or quantitative elements in a decision-making process. Here, delimiting the protective boundaries is the spatial problem, with the decision as to whether an area is protected or not being dependent on various environmental and social factors. The MCA model can reconcile these interacting environmental and social criteria, and can comprehensively evaluate whether an area should be protected and what level of protection is appropriate. The model provides decision-makers with a structured environment in which to explore the intensity and sources of conflicts, generating compromise alternatives and ranking alternatives according to their attractiveness. The model also permits inter-criteria tradeoffs to be made. Using the MCA, high scores for some criteria can compensate for low scores for other criteria (Jankowski, 1995). By integrating the MCA model into the system, more comprehensive environmental, social and cultural criteria can be considered in the designation of protected area boundaries. Thus, our SFSDSS overcomes the problems of previous boundary designation, which delimits protection boundary only according to scenic value, giving results that are more representative of the various criteria involved.

There are many ways in which decision criteria can be combined in an MCA model. The weighted linear combination is the most popular and convenient way (Rao et al. 1991, Eastman et al. 1993a, b), and is used here. To rank the different protection level alternatives, the following formula is used:

$$S = \sum_{i=1}^{n} W_i C_i \qquad (1)$$

where S is the suitability score with respect to the protection objective, W_i is the weight of the criterion i, C_i is the criterion score of i, and n is the number of criteria. The criteria used here are (a) pinnacle distribution, (b) geology, (c) geomorphology, (d) transportation (distance from road), (e) slope, (f) agriculture activity, (g) lake distribution, (h) human settlement, (i) soil type, and (j) vegetation. The model has its own algorithm to make sure $\sum W_i = 1$. By using formula (1), overall protective suitability scores are determined and the whole area is divided into several different level protection zones.

INTERFACE AND RESULTS DISPLAY

The SFSDSS has an accessible, user-friendly interface that can be used without GIS or other advanced technical expertise (Figure 5). "Help" provides information about how to use the system, and various tools allow users to browse and query background map data. Through the graphic in-

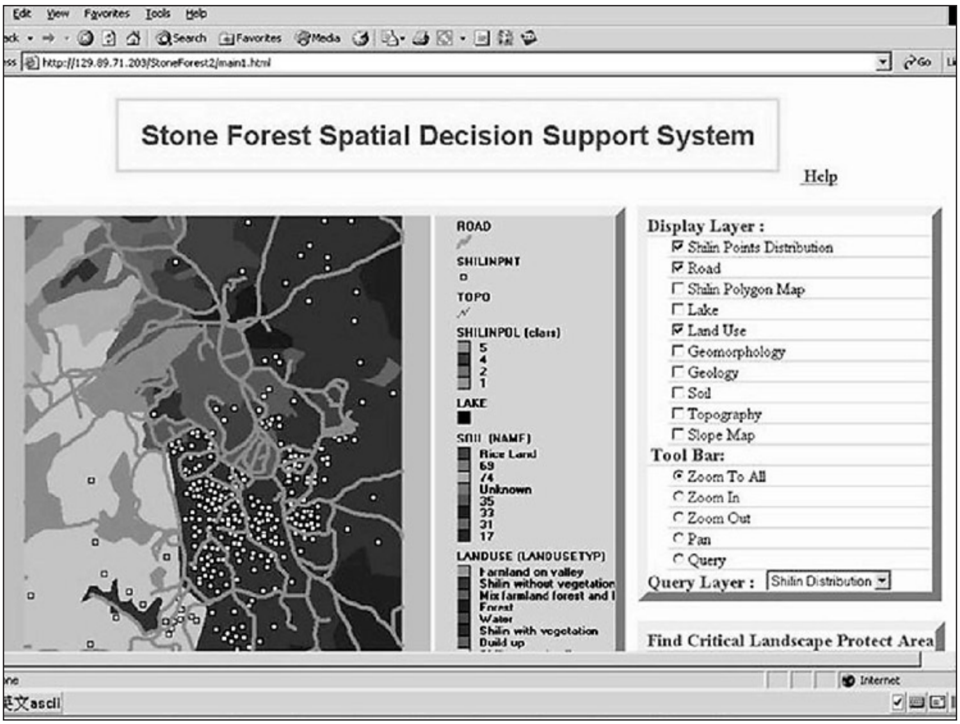

Figure 5: Interface of the Stone Forest SDSS.

terface users can delimit protection boundaries by integrating the interacting environmental, social and cultural criteria. After selecting criteria via a check box and weighting the criteria via a drop down menu, users click the "Run Model" button. The system can easily be adapted to incorporate users' suggestions. Opinions can be saved within the database server, and those responsible for final decisions will have access to these.

Figure 6 shows one protected area boundary delimitation scenario, in which the area is categorized into three different protection levels that are displayed with graduated coloration. Dark denotes the most critical, or first level protection areas, with lighter dark color denoting less critical areas, and white representing the least important areas for protection.

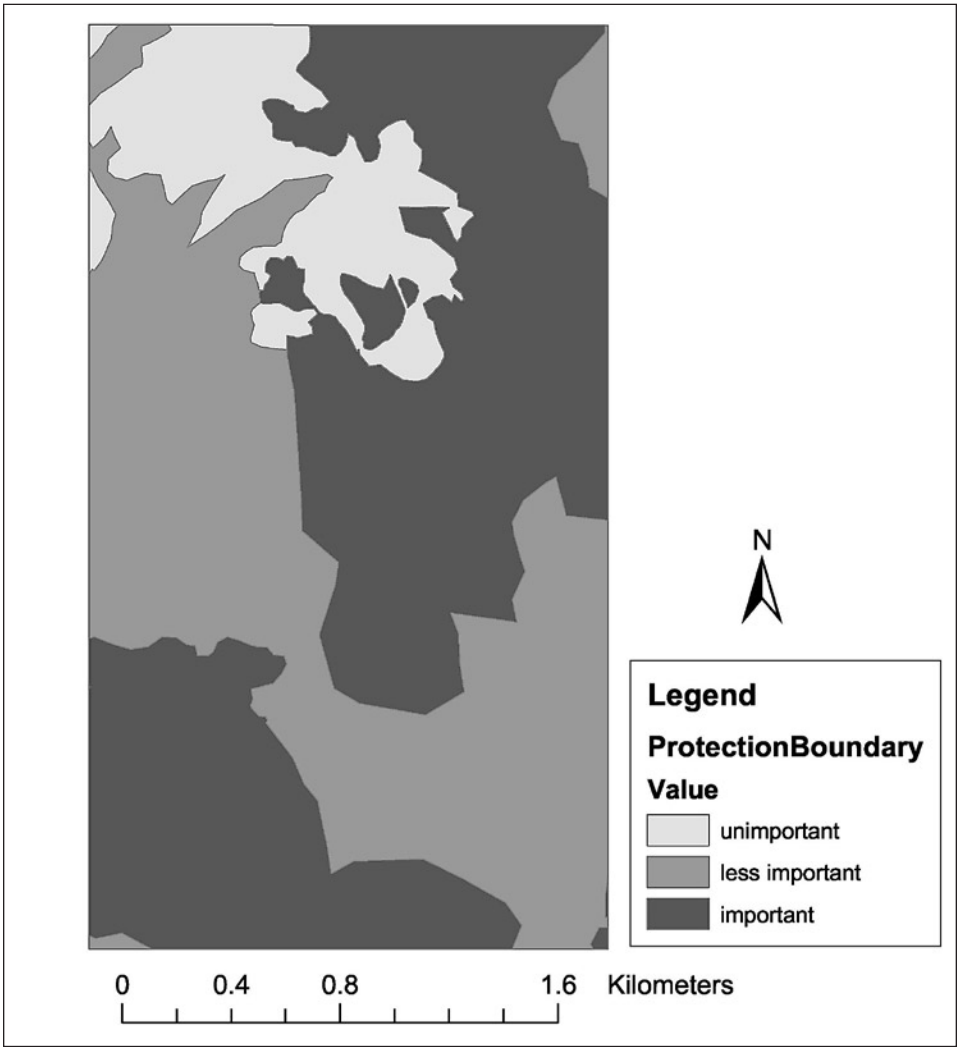

Figure 6: One scenario of three different level protection areas.

Karst scientists, government authorities, NGOs, local residents, tourists and others interested in the Stone Forest may access the SFSDSS through the Internet. They can overlay the boundaries on other maps, such as those showing roads, topography and lakes, thus making clear the relationship between the boundaries and prominent landscape features (Figure 7). This will assist in elucidating the conservation regulations within the respective protection level areas.

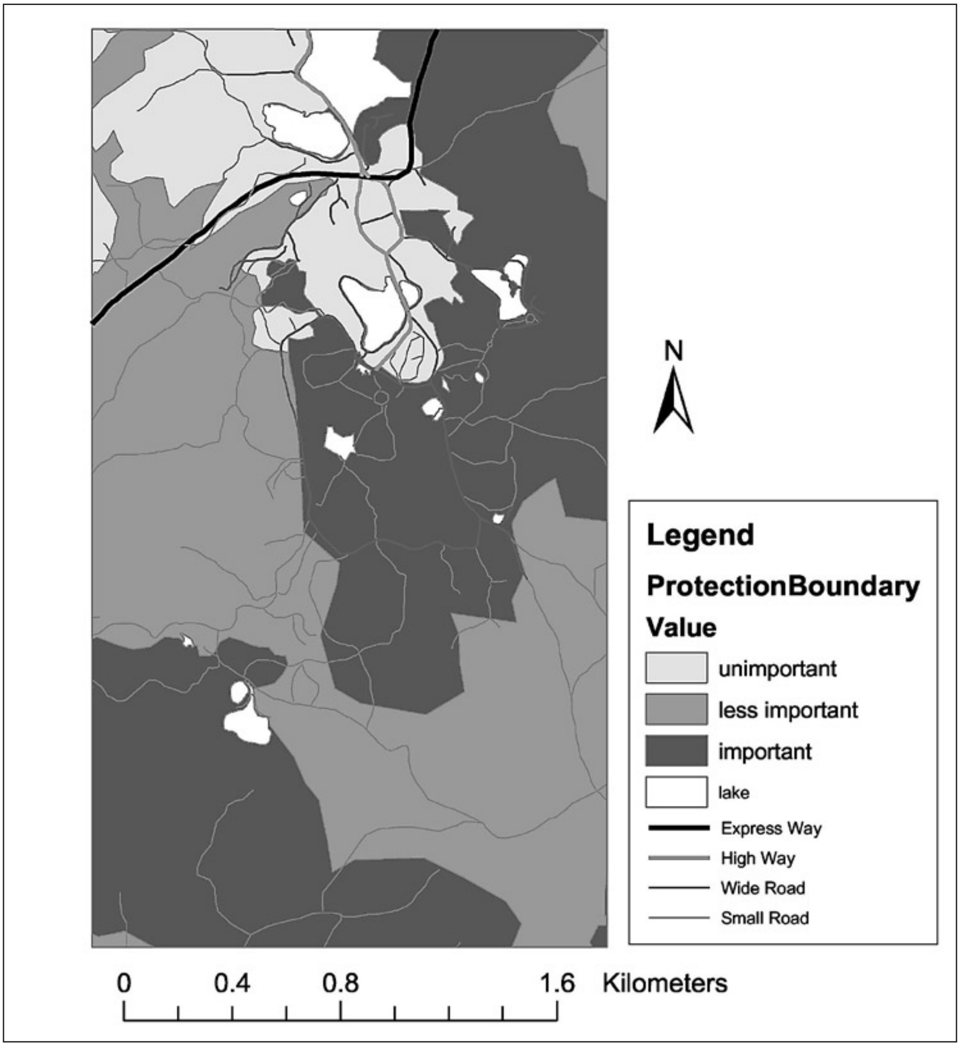

Figure 7: Roads, lakes and topography overlain on protective areas.

SYSTEM IMPLEMENTATION

Future conservation of the Lunan Stone Forest is a considerable challenge, representing a comprehensive spatial social-ecologic problem. Although it is fundamental to maintain the intrinsic integrity of the physical karst ecosystem, human demands should be reconciled with this where possible. Failure to recognize or respect conflicting parameters may ultimately lead to crisis, involving not only destruction of the physical karst fabric itself, for example through uncontrolled quarrying or construction, but also destruction of attendant soils, vegetation and water resources, accompanied by scenic decline, cessation of tourism, loss of local revenue and jobs, and urban decline. Addressing existing and future issues through the use of the SDSS may alleviate environmental, economic and social disruption by making clear the spatial dimensions of sustainable land uses.

The SFSDSS is designed for three essential purposes: 1) to assist a variety of experts and decision-makers in understanding the landscape so that rational protective boundary delimitation can be implemented; 2) to provide various audiences an opportunity to participate in the boundary delimitation decision-making; 3) to inform residents and visitors of the boundary locations. To implement these goals, the SFSDSS provides analytical tools enabling data investigation. Through the interface (Figure 5) users, including decision-makers, can display and overlay different attributes, and can zoom in, zoom out, pan or query these attribute maps. Thus they can access varied information about the physical and human characteristics of the landscape, permitting integration of social and natural factors within the context of establishing future protected area boundaries and implementing management legislation. Similarly, residents and visitors can determine readily the location of protective boundaries and their grades via the online SFSDSS. New policies and regulations also can be disseminated easily and quickly, rendering timely compliance more like.

CONCLUSION

The Lunan Stone Forest is an iconic karst landscape, with considerable scientific, recreational and cultural significance. Because of its inherent ecological fragility and ongoing human disruption, especially burgeoning tourism development, the landscape is increasingly stressed and in need of protection. Protected areas have been established, but their boundaries are essentially arbitrary and their locations unclear. The delimitation of rational, explicit and recognizable protected area boundaries is paramount to facilitating future conservation and management strategies, and a Spatial Decision Support System promises to be useful in this context.

An online SFSDSS has been developed to allow rational boundary delimitation reconciling sundry interacting environmental and social criteria. Through overlaying, boundaries may be located in an optimal way, accommodating the appropriate criteria and aligning with prominent landmarks. Scientists, governmental authorities, NGOs, residents and visitors can participate in the decision making without needing extensive technical experience. Suggestions and opinions can be contributed to a database and incorporated in final decision-making. The online SFSDSS also allows residents and visitors to learn and understand about the protection boundaries.

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