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STEPS FOR SPECIFIC VULNERABILITY MAPS, MANAGEMENT & CONSERVATION IN YUCATAN PENINSULA ANCHIALINE SYSTEMS

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A GIS project was developed for cenote management and decision making in the Yucatan Peninsula. Information was obtained through governmental and civil databases, satellite imagery analysis and field visits. Spatial analysis was performed at the scale of 1:250,000 for cenotes and geology; land use and vegetation; soil type; protected areas; urban areas; population size of human settlements and roads. Danger and risk models for ecological degradation of cenotes were developed.

Key words: GIS, risk and danger, cenotes, satellite imagery analysis, management, conservation

INTRODUCTION

Cenotes (sinkholes) are the most dynamic communications between the subterranean habitats and the ground surface. Intrinsic vulnerability refers to the properties of the karst system itself, while specific vulnerability is the degree of vulnerability caused by actual threats, mainly anthropogenic (IAHS, KOVAR, 1998). Due to expanding anthropogenic activities, management and conservation become critical for the conservation of subterranean biology and fresh water resources.

Prior to this project, georeferenced databases (DB) of the Yucatan Peninsula cenotes were scattered and not homogeneous.

The Yucatan Peninsula (YP) SE Mexico comprises three states: Yucatan, Quintana Roo and Campeche (Fig. 1). YP is an emerged plain that is one of the largest karst continuous regions on Earth (39,340 km^2) and it is part of the Yucatan Platform (300 000 km^2). This karst physiographic/geologic unit extends southward to Belize and the Peten in Guatemala (WILSON, 1980) and is characterized by abundant caves and cenotes, particularly in the northern low-lands. Cenotes provide access to the density stratified coastal aquifer system, which includes a fresh water lens formed by infiltrating meteoric waters, floating on top of a saline water zone comprised of intruding marine waters and/or evaporate dissolution. Some cenotes are clearly sections of collapsed cave ceilings providing direct access to the extensive sub-horizontal turbulent flow conduits (SMART *et al.*, 2006), of which more than 1,000 km have been documented along the Caribbean coastal margin (QRSS, 2012). The Yucatan coastal karst sub-horizontal flow conduits (i.e. flooded caves or underground rivers) that have sinkhole access can be classified as anchialine systems *sensus* STOCK *et al*. (1986), since marine water intrudes landward beneath a floating lens of meteoric groundwater.

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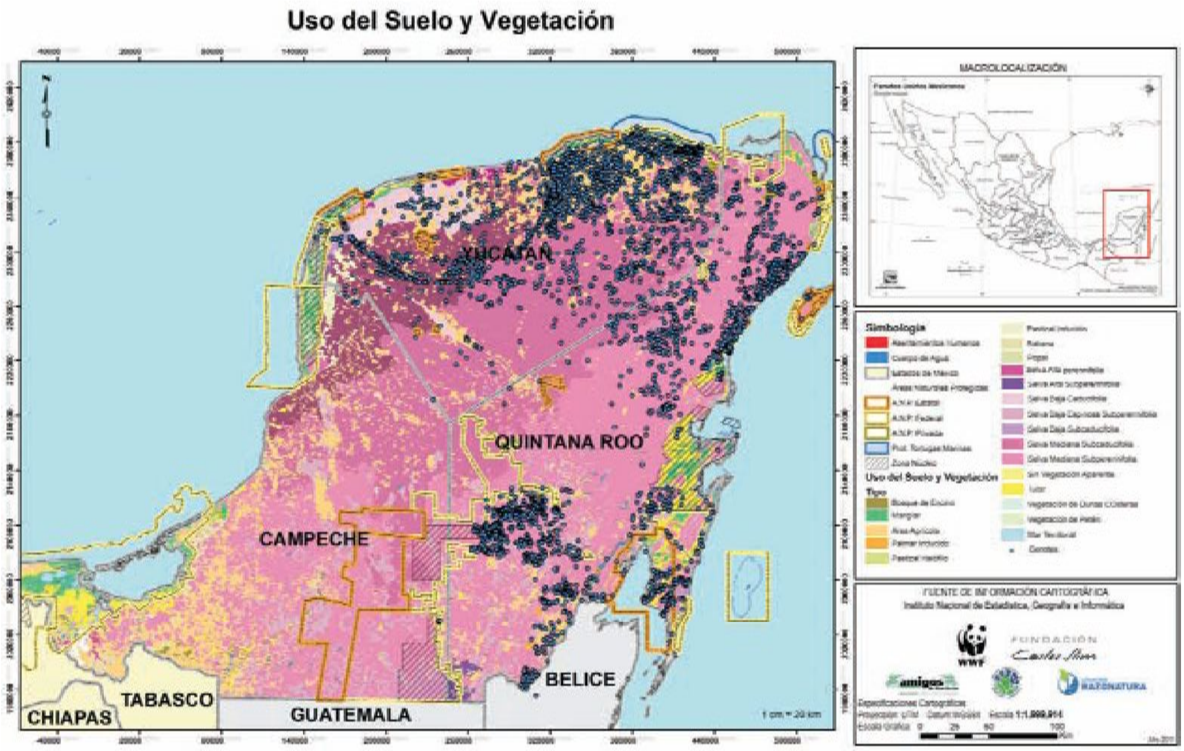

Fig. 1. Yucatan Peninsula Cenotes and probable cenotes mapped on land use and vegetation

The first goal of this project was to gain an insight into current information related to cenotes used for management by stakeholders in the Yucatan Peninsula. The second goal was to reorganize current information into an advanced database system utilizing GIS and to conduct a spatial analysis on a scale of 1:250,000, incorporating the currently existing official cartographic information available for the Yucatan Peninsula developed by INEGI, a governmental agency for geography. The third goal was to create an initial specific vulnerability analysis of cenotes in the region by modeling danger and risk. The final goal was to present a number of recommendations to homogenize data gathering and information management for a Yucatan Peninsula census of cenotes.

The project outcomes include: 1) A consolidated DB of cenotes and probable cenotes (>5000 records); 2) a comprehensive georeferenced database of YP cenotes on GIS; 3) thematic cartography and spatial analysis at a scale of 1:250,000; and 4) a proposal of danger and risk models for ecological degradation of cenotes.

Along with geomatics, a review of present natural and anthropogenic threats, recommendations for a regional cenotes census, as well as management and regulation actions were proposed to CONAGUA, the Mexican federal water agency. As a result of the collaboration with CONAGUA, this project will prove critical in informing specific legislation for management and conservation of cenotes for the YP which is lacking up to date.

METHODS

Interviews with government agencies and non-governmental organizations (NGO) were conducted to gain familiarity with their current efforts and DBs.

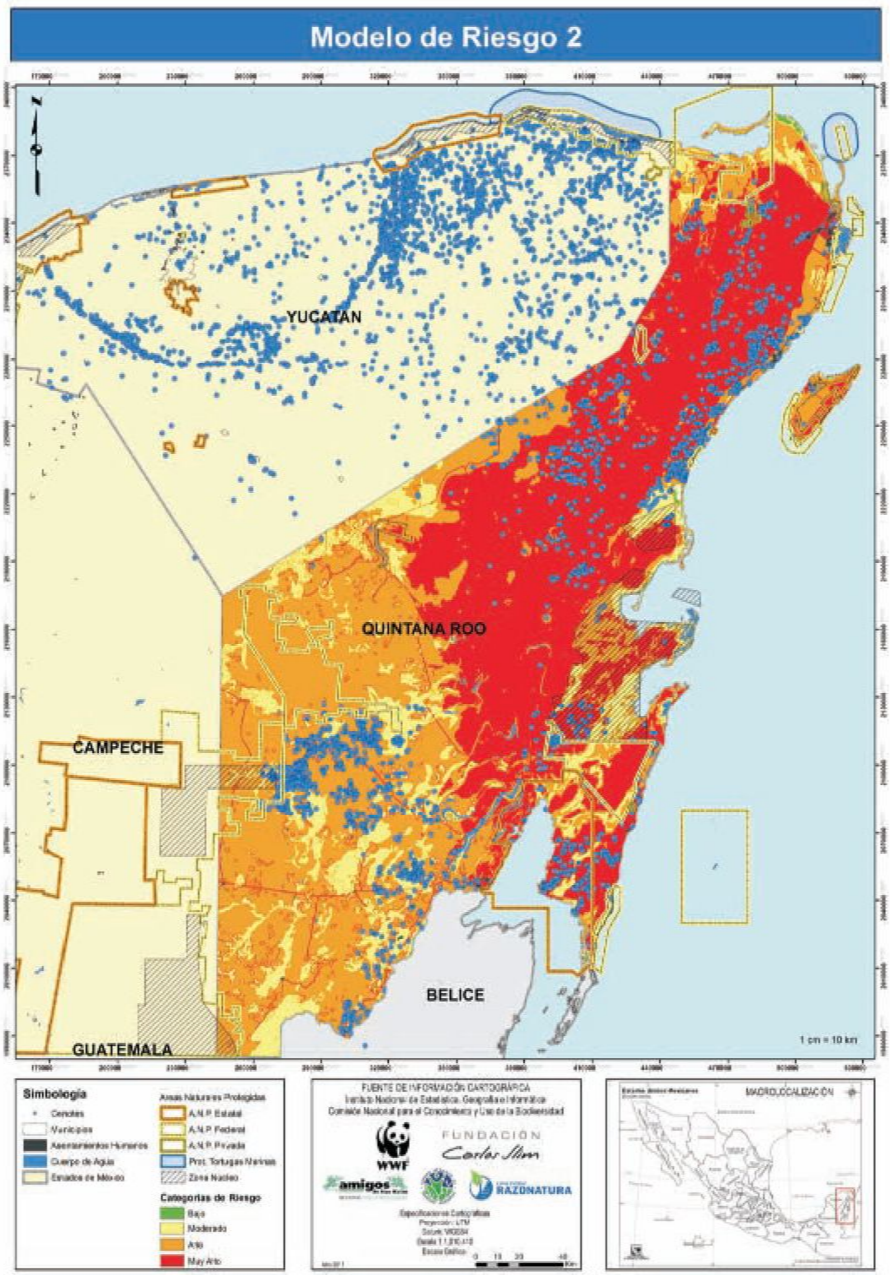

Fig. 2. Risk model for Quintana Roo

SPOT-5 panchromatic and multispectral satellite imagery was processed with eCognition Professional V 5.0 & Erdas Imagine 9.1 for assessment of cenotes spectral footprint as water bodies and/or moisture spots in the semi-deciduous forest.

Through field visits, GPS points of cenotes and other water bodies on the surface were collected.

DBs where filtered through highly detailed visual inspection to compare the files with control points on satellite images.

Official cartography on a scale of 1:250,000 by the INEGI was obtained in collaboration with NGOs. Data included geology, land use and vegetation, soil type, protected areas or conservation priority areas, urban areas, population size of localities and roads sizes.

In order to create homogeneity between resources, additional spatial analysis was conducted at the scale of 1:250,000 in accordance with the existing INEGI data.

All data were consolidated into a comprehensive DB utilizing ArcGIS tools, allowing for the creation of maps and other dynamic data representation.

Finally danger and risk models were based on aggregating predetermined factors that contribute to ecological degradation of cenotes. These were based on fire risk models by JAISWAL *et al*. (2002), SAGLAM *et al*. (2008) and CHUVIECO *et al*. (2010), tailored to the needs of the YP by the authors. The factors considered in the danger model were fire susceptibility of vegetation, soil permeability and rock type and age. The loss of vegetation by fire has a negative effect on the ecological quality of the cenotes. Higher permeability of the soil increases the chance for pollutants to infiltrate. Limestone is more permeable than other rocks and older limestone is more porous than younger limestone. The risk models comprised the danger models with the addition of the potential negative impacts resulting from distance to human factors, including urban or agricultural zones, population size of localities and road sizes.

RESULTS

The comprehensive consolidated DB consisted of resources obtained from a total of 13 collected databases. Of those, nine were from federal or state governmental agencies, one from an NGO and three were produced through the primary research of the authors (SPOT-5 imagery, Google Earth and field visits).

The most common challenges resulted from inconsistencies in data collected from secondary sources such as DATUM and projection errors. The Yucatan state government has been working on a cenote census for many years with a total log of 2,241 records. However, only 793 of those are georeferenced. Through this project, this information was shared with non-government employees for the first time.

Nine SPOT-5 scenes for Quintana Roo (QRoo) resulted in >1,600 records, while the field visits in the same state resulted in 231 cenotes. The assessment through the spectral water footprint of cenotes was not as informative as expected due to the phenomenon that some surface water bodies and moisture spots in the semi-deciduous forest mimic what can appears to be a cenote.

Campeche is the state with the least information.

A comprehensive DB of cenotes and probable cenotes (5,313 records total) (Fig. 1) was generated including information about: UTM coordinates, morphological type, geology, land use and vegetation, land ownership, use and activities and relation to protected areas or conservation priority areas.

Quintana Roo (QRoo) is the easternmost state at the Caribbean coast. In the northern portion 74% of cenotes are in a semi-deciduous forest matrix, however only 42% of those are in primary forest. Semi-deciduous forests show a high susceptibility to fires. In addition, this region has a thin top soil layer (rendzinas) and Mio-Pliocene limestones, accounting for a high to very high danger of ecological degradation for 86% of the cenotes in this area. When human factors are factored in, the risk model shows that 87% of cenotes are in a high to very high risk of degradation. The central portion of QRoo hosts the Sian Ka'an, Biosphere Reserve a UNESCO World Heritage.

There, 79% of cenotes are in the semi-deciduous forest matrix, but only 35% of those are in primary forest, 2.5% of cenotes are in agricultural areas and 2% in urban areas. In brief, 92% have a high to very high degradation danger and 93% are at risk. The southern portion of QRoo shows 68% of cenotes in the forest matrix, but only 21% of those are in primary forest. A total of 32% of cenotes are in agricultural or urban areas. The danger model shows that 76% of cenotes have a high to very high degradation condition, while 79% are at high to very high risk (Fig. 2).

Conclusion

A more accurate, comprehensive and dynamic georeferenced DB of cenotes for YP (GIS project) was provided to CONAGUA, the Mexican federal water agency, in order to inform the responsible water conservation management and decision making authorities of this fragile region. This project will aid in creating specific legislation that supports the management and conservation of cenotes for the YP, which has been lacking to date. Beyond the direct impacts on cenote conservation, this project is expected to have positive umbrella effects on the ecosystems related to the underground and its biota.

The next phase of the project is to generate georeferenced information for anthropogenic threats to improve the risk and danger models.

Finally a joint effort with environmental lawyers and stakeholders sharing sustainable development millennium goals will work towards the legislation process until its promulgation.

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