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DESIGNATION OF PROTECTED KARSTLANDS IN CENTRAL AMERICA: A REGIONAL ASSESSMENT

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The IUCN World Commission on Protected Areas has recognized karst landscapes as important targets for designation as protected areas, and this study is a regional inventory of the Central American karst conservation situation.

Central America is a significant international carbonate karst landscape, covering ~154,000 km², roughly a quarter of the regional land area. The karstlands exhibit considerable topographic diversity, including "cockpit" and "tower" styles, together with extensive dry valleys, cave systems, and springs. Some of the karst areas are well known, but others have yet to receive detailed scientific attention. Many of them have archaeological, historical, cultural, biological, aesthetic, and recreational significance, but human impacts have been considerable.

Conservation and protection legislation is variable in nature and effectiveness, and enforcement is problematic. About 18% of the Central American karst landscape has been afforded nominal protection through designation as protected areas. Regional levels of karstland protection are highly variable, with significant protection in the Yucatan peninsula, Honduras, and Belize; intermediate protection in Guatemala, Costa Rica, and Panama; and, as yet, no protected areas in Nicaragua or El Salvador. The situation remains fluid, and the future of the Central American karstlands is uncertain.

Central America constitutes a significant international carbonate karst landscape, with an area totaling ~154,300 km², or ~23% of its total land (Kueny 2000; Day & Kueny in press). Seventy-five percent of Central America's karst is on the Yucatan Peninsula, with other significant areas in Guatemala, Belize, and Honduras. Considerable geologic, topographic, and environmental heterogeneity characterizes the region, but Central America contains many dramatic karst landscapes, including cockpits, towers, dry valleys, sinkholes, cenotes, and extensive cave systems, plus an impressive marine karst landscape, including the world's second longest barrier reef, off the Caribbean coast of Belize.

In 1997, the International Union for the Conservation of Nature and Natural Resources (IUCN) World Commission on Protected Areas (WCPA) recognized karst landscapes worldwide as being in significant need of protection (Watson *et al*. 1997). This need for environment protection and the establishment of protected areas is also gaining regional acceptance and support through both government and non-government efforts of, for example, the Central American Commission on Development and the Environment (CCAD) (WCMC 1992; Hamilton-Smith 1999).

The World Conservation Monitoring Centre (WCMC) has compiled a database of protected areas in Central America, but does not identify protected karst areas or any other landscape type in its database. Gillieson (1996), however, calls for the establishment of databases that detail protection and conservation efforts in these landscapes. This study addresses these issues by providing an initial inventory and assessment of protected karst areas in Central America.

METHODOLOGY

For the purposes of this study, Central America is regarded as the isthmus between Mexico and South America, plus the Yucatan Peninsula (Blouet & Blouet 1997). This region includes the karsts of Belize, Guatemala, Honduras, El Salvador, Costa Rica, Nicaragua, and Panama, plus those of the Mexican states of Yucatan, Campeche, and Quintana Roo.

The primary objective of this study is to assess the extent to which the Central American karst landscape is afforded at least nominal protection by its designation as protected areas. To this end, two sets of data are employed: one on the extent of the regional karstlands, the other on the location and size of regional protected areas.

Information about the extent of carbonate karstlands within the region is available from a number of diverse sources, including geologic and topographic maps, atlases, previous research, and personal experiences. For a summary of this information, which is of variable reliability, see the list of references, particularly Middleton and Waltham (1986) and Kueny (2000), and Table 1. To ensure consistency, we assume that all expanses of carbonate rocks indicated in geologic sources do, in fact, represent karst landscapes. For this reason, all karst-area data should be regarded as approximate, which may ultimately result in a conservative calculation of the proportion of karst designated as protected areas.

Reliable information on protected areas is equally difficult to acquire, particularly given the wide array of protected-area legislation, variations in size and terminology, and the difficulties of *de facto* verification. The primary source of information is the United Nations List of Protected Areas, which is main-

Figure 1. Location of major karstlands in Central America.

Table 1. Selected sources of information about karstlands in Central America.

Country	Sources
Belize	Day 1993, 1996; Miller 1996; Reeder *et al.* 1996; Middleton & Waltham 1986; Veni *et al*. 1996.
Costa Rica	Instituto de Costarricense de Turismo 1995; Day 1993; Mora 1992; Middleton & Waltham 1986; Peacock *et al*. 1993; Troester *et al*. 1987.
El Salvador	Day 1993; AID 1966.
Guatemala	Day 1993; Middleton & Waltham 1986; Instituto Geografico Nacional 1970.
Honduras	Day 1993; Middleton & Waltham 1986; AID 1966.
Nicaragua	Day 1993; Middleton & Waltham 1986; AID 1966.
Panama	Day 1993; Middleton & Waltham 1986; AID 1967.
Mexico	Day 1993; Middleton & Waltham 1986; Troester *et al*. 1987.

tained and updated by the World Conservation Monitoring Centre (WCMC). These data are supplemented by information on additional protected areas obtained from individual government sources and other studies, particularly those by Day (1993) and Kueny (2000), which do not necessarily conform to UN criteria. Protected areas include national, state, and private parks and forests and wildlife, forest, and archaeological reserves, without regard to issues of effective protection or future status.

Table 2. Karst styles of Central America.

Country	Towers	Cockpits	Sinkholes/ Dry Valleys	Marine
Belize	X	X	X	X
Costa Rica		?	X	X
El Salvador			X	
Guatemala	X	X	X	
Honduras	?	X	X	X
Mexico,Yucatan			X	X
Nicaragua		?	X	
Panama		?	X	X

Figure 2. Sinkholes (dolines) at Uxmal, Yucatan.

KARST AREAS OF CENTRAL AMERICA

The carbonate rocks of Central America (Fig. 1) represent discontinuous carbonate deposition from the Jurassic (208-144 Ma) to the Quaternary (<1.6 Ma). Dissolution of these carbonate rocks has produced a range of karst landscapes including dry valleys, sinkholes and cockpits, residual towers, and extensive cave systems (Table 2; Figs. 2-7). Karst landscapes in Central America have been and still are influenced by tectonic, eustatic, and climatic changes (Weyl 1980; Whitmore & Prance 1987; Gardner 1987; Dengo & Case 1990; Mann 1995) and have also undergone significant alterations as the result of human activity (Day 1993).

The most extensive Central American carbonate karst area is in the Yucatan Peninsula (Fig. 1; Table 3), where >125,000 km² of Tertiary and Quaternary carbonates give rise to a subdued karst landscape characterized by shallow sinkholes, low residual hills, cenotes, and flooded cave systems (Figs. 2-3). A second extensive karst area, including cockpit and tower karst

Figure 3. Cenote, Chichen Itza, Yucatan.

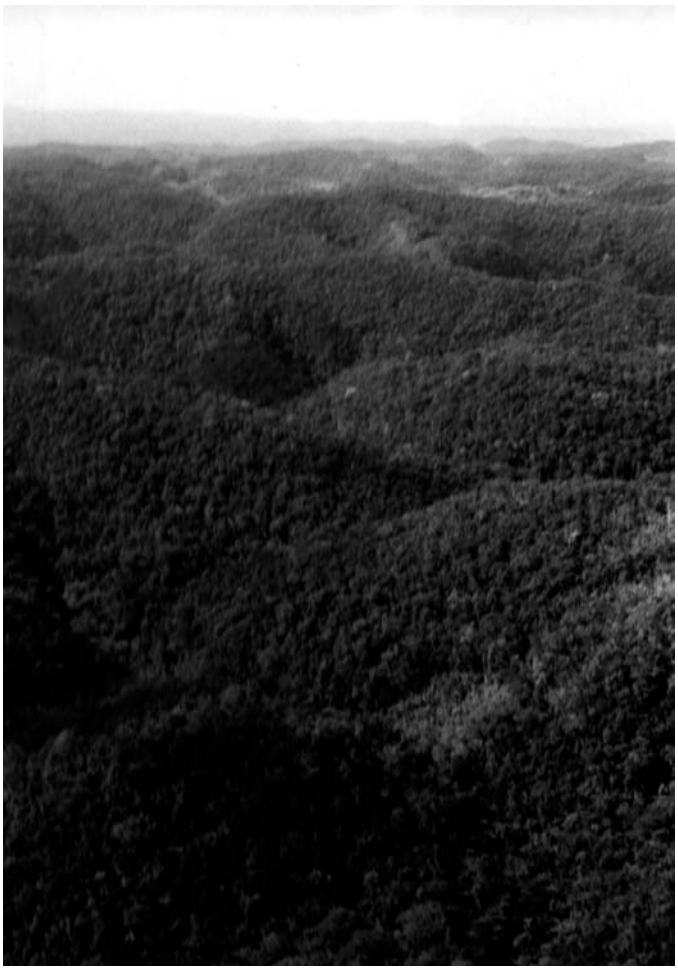

Figure 4. Polygonal (cockpit) karst, Peten, Guatemala.

Table 3. Protected karst in Central America

Country	Karst Area km²	Protected Karst Area km²	% Karst Protected	Number Protected
Belize	5000	3400	68	18
Costa Rica	2000	68	3	5
El Salvador	300	0	0	0
Guatemala	15000	1517	10	7
Honduras	10000	3500	35	7
Mexico:				
Campeche	45000	7232	16	1
Quintana Roo	35000	7712	22	3
Yucatan	35000	4407	13	3
Nicaragua	5000	0	0	0
Panama	2000	80	4	1
TOTALS	154300	27916	18	45

Source: Kueny 2000

developed in Cretaceous and Tertiary carbonates, extends through the Peten of eastern Guatemala into Belize (Figs. 4-8), covering nearly 15,000 km², with other karst areas in the Alta Verapaz and Huehuetenango Departments of Guatemala (Fig. 1).

Honduras has three major karst areas covering ~10,000 km²: the Montana Santa Barbara in the northwest, the Cordillera Agalta in central Honduras, and the Sierra de Colon and Cordillera Entre Rios in the southeast bordering Nicaragua. The karst in both Montana Santa Barbara and

Figure 5. Polygonal karst depression hillslope, Peten, Guatemala.

Figure 6. Karst tower, Gracy Rock, Belize.

Cordillera Agalta have received only moderate scientific attention and that on the Sierra de Colon has received even less due

Figure 7. Dry valley, Hummingbird karst, Belize.

to its remoteness and dense vegetation (Middleton & Waltham 1986).

There are also significant carbonate karst areas in Nicaragua and throughout Costa Rica (Troester *et al.* 1987; Mora 1992; Peacock & Hempel 1993) (Fig. 1). Karst occurs in Panama in the Archipielego de Bocas del Toro along the northwest border with Costa Rica, in the Maje Mountains of central Panama near the Río Chepo o Bayano, and in the eastern Darien Department (Fig. 1; AID 1967; Reeves 2000). El Salvador has <300 km² of karst, located along the border with Honduras and Guatemala south of Anguiatu (Fig. 1; AID 1966).

Considerable topographic variation characterizes the karst of Central America as a whole, although three distinct karst terrain styles–doline, polygonal (cockpit/cone), and tower–are recognized by Day (1979, 1993). Dry or underdrained valleys and subdued depressions or dolines (Figs. 2 & 7) occur throughout the region but have received little scientific attention. Cockpit, cone, and tower karst occurs in Belize, Guatemala, Honduras, and Nicaragua (Table 2; Figs. 4-6). Variations of these types occur throughout Central America and are not restricted to the areas described above. Caves, formed by the underground dissolution of carbonate rock, are also abundant (Middleton & Waltham 1986).

Widely published scientific research has been conducted in some Central American karst areas, notably in Belize (Miller 1996, 2000; Veni *et al*. 1996) and Costa Rica (Troester *et al* 1987; Mora 1992; Peacock & Hempel 1993), but overall the regional karst offers considerable scope for future research (Day & Kueny in press). The karst areas of Honduras and Nicaragua, in particular, warrant further study, although this may be hindered by problems of accessibility.

KARST ENVIRONMENTS

The Central America karstlands are far from homogeneous with respect to geologic and geomorphic factors. Moreover, climate, soils, and biota are also variable, leading to a wide

Figure 8. Tikal, Peten, Guatemala

range of specific karst environments.

The karst rocks themselves range from pure, dense, hard, fractured, crystalline limestones, some much altered from their original state, to impure, powdery, soft, porous, amorphous carbonates (Day 1979; Troester *et al.* 1987; Mora 1992; Miller 1996). Some are covered by volcanic ash, some are brecciated, and others have been folded and faulted. Karst landscape elevations range from sea level up to 2000 m msl; some are mountainous, others planar; some are hydrologically isolated, others receive surface drainage from higher, adjacent non-karst terrains.

Climate varies too, with mean annual precipitation ranging from <1000 mm to >3000 mm. Precipitation is influenced by shifting atmospheric pressure belts, prevailing winds, and orographic effects (Clawson 1997). Rainfall generally increases with elevation, and leeward locations experience higher temperatures and lower precipitation than karst areas to the windward. As a result of shifting atmospheric pressure belts, there are distinct winter dry periods of differing intensity and duration, with prevailing winds and elevated landmasses also accounting for spatially uneven rainfall distribution (Clawson 1997). Late summer hurricanes and tropical depressions can cause severe flooding in normally dry karst areas. Temperatures are influenced mainly by altitude and ocean currents, generally decreasing with increasing altitude and with increasing distance from the coast (Clawson 1997).

The predominant soil types in the Central American karst are calcimorphic mollisols and vertisols, although complex associations of other orders also occur (Furley & Newey 1983; Whitmore & Prance 1987; Blouet & Blouet 1997). Karstland soils are extremely variable, but generally tend to be clay-rich, heavily leached, patchy and thin, except in depressions and valley bases, where they are deeper. Steep slopes may have no soil cover except in joints and solutional pockets. Differences in climate, vegetation, age, and relief account for major differences in karst soil types throughout Central America, and many soils have been altered by agricultural practices (Blouet & Blouet 1997).

The natural karstland vegetation varies from xerophytic scrub to wet tropical broadleaf forest, including both deciduous and evergreen trees, although much of the original forest has been cleared, with only fragments remaining in remote karst areas. For general overviews of karst landscape ecology, see Gillieson (1997) and Vermeulen and Whitten (1999), and for a Central American perspective see Day (in press). Central America also supports one of the world's most diverse wildlife assemblages (Iremonger & Sayre 1994), and specifics of the regional karstland ecology warrant additional studies. Biological significance is a major factor in designation of protected areas within the Central American karst, as elsewhere (Hamilton-Smith 1999).

Human impact on Central American karst landscapes has been long-term and severe, in particular through forest clearance, species introduction, agriculture, degradation of water resources, and industrial activities, including mining and quarrying (Watts 1987; Day 1993). Important archaeological sites, both surface and subterranean, are significant facets of karstlands throughout Central America (Hartshorn *et al*. 1984; Day 1993; Fig. 8).

Particular threats to the Yucatan karst include hotel expansion along the coast, illegal quarrying activities, and the potential impacts of inappropriate attempts to restore quarried areas (Hamilton-Smith 1999). In Belize, adverse impacts range from agricultural expansion to increasing tourism (Day 1996). Forest reserves continue to be logged despite local opposition and quarrying of limestone for construction projects is ongoing. In Guatemala and Honduras, the World Conservation Monitoring Centre (1992) lists major threats as including the exploitation of floral and faunal resources, the establishment of settlements within protected areas, and unclear or ineffective legislation.

PROTECTION OF KARST LANDSCAPES

With a restricted land area of 679,435 km² (Europa 1999) and a dense population approaching 126 million (CIA 1999),

pressures on natural resources in Central America are severe, although most nations now recognize the importance of resource protection for environmental, economic, and social reasons. Particular stress on karstlands results from forest clearance, agriculture, degradation of water resources, and industrial activities, including mining and quarrying (Watts 1987; Day 1993; Vermeulen & Whitten 1999). Throughout the region, efforts to conserve natural resources have involved the establishment of protected areas in which human activities and impacts are restricted.

The importance of karst landscape protection was highlighted in 1997 by the International Union for the Conservation of Nature and Natural Resources (IUCN) Working Group on Cave and Karst Protection, which published guidelines for the design and maintenance of protected karst areas. Rationales for the protection of karst areas as significant landscapes include the following: habitats for endangered species of flora and fauna; areas possessing rare minerals and/or unique landscape features; important historic and prehistoric areas with cultural importance; important areas for scientific study across a variety of disciplines; religious and spiritual areas; areas of specialized agriculture and industry; important areas to the understanding of regional hydrology; and as recreation and tourism areas with important economic and aesthetic value (Watson *et al*. 1997). These rationales notwithstanding, very few karst areas are designated for protection because of their intrinsic overall value as karst landscapes. Rather, they are selected for protection in recognition of the specific biological or cultural traits associated with, and inextricably linked to the karst.

REGIONAL PROTECTED AREAS LEGISLATION

Protected areas legislation throughout Central America is highly variable as a result of the multiplicity of sovereign nations, government agencies, and non-government organizations. The Central American Commission on Development and the Environment (CCAD) is one regional arbiter of conservation strategies, but the levels of participation by the countries considered here are variable. All have adopted both the UN Convention for the Protection of World Natural and Cultural Heritage and the UNESCO Man and the Biosphere Program (MAB). Some of the legislation relevant to karst landscapes is summarized in Table 4, and additional details are provided by the World Conservation Monitoring Centre (1992).

Several countries have cooperated in establishing protected areas that traverse political boundaries. For example, in 1982 Costa Rica and Panama signed the Basic Convention for Creation of the Park (Convenio Básico de Creación del Parque), a binational agreement for the establishment of the La Amistad Transfrontier Park. Costa Rica and Nicaragua have also cooperated to create a protected areas system between their countries (WCMC 1992), yet establishment of a protected area is incomplete. Costa Rica, Guatemala, Honduras, and Mexico participate in the UN Food and Agriculture Organisation's Latin American Network Program, which "aims to coordinate the activities of participating countries, to assist in the implementation and functioning of a coherent and

Table 4. Protected area legislation in Central America.

Belize	Forest Ordinance (1927, revised in 1958)
	The Crown Land Ordinance (1924, revised in 1958)
	National Parks System Act No. 5 (1981)
	Wildlife Protection Act No. 4 (1981)
Costa Rica	Forestry Law No. 4465 (1969)
	National Parks Service Law No. 6084 (1977)
	Wildlife Conservation Law No. 6919 (1984)
	Reformation of the Forestry Law No. 7174 (1990)
	Ministry of Natural Resources, Energy And Mines established under Law No. 7152 (1986)
El Salvador	Forestry Law (1973)
	Ministerial Decree No. 236 National Parks and Wildlife Section (1981)
	Basic Land Reform Law (1981)
Guatemala	Forestry Law (1921)
	Forestry Law Decree No. 7089 (1989)
	National Environment Commission established under Law for the Protection and Improvement of the Environment Decree No. 6886 (1986)
	Law of Protected Areas Decree No. 4 89 (1989)
	Department of Petén Biosphere Reserve Decree No.590 (1990)
	Eastern Lowlands Biosphere Reserve Decree No. 4990 (1990)
Honduras	1982 Constitution declares all natural resources to be state property
	Forestry Law Decree 85 (1971)
	Decree Law No. 103 (1974) established the Honduran Forest Development Corporation
	Decree No. 123 (1974) established General Directorate for Forest Resources and Wildlife
	General Forestry Regulation, Resolution No. 634 (1984)
	Cloud Forest Law, Decree No.87 (1987)
Mexico	1st protected area created in 1876
	Forestry Law (1926)
	Forestry Law (1942)
	Forestry Law (1948)
	General Law for Ecological Equilibrium and Environmental Protection (1988)
Nicaragua	Law for the Creation of the Nicaraguan Institute of Natural Resources and the Environment (1979)
	Law for the Establishment of the National Parks Service, Decree No. 340 (1979)
	Decree No. 1194 (1983) established a national parks act
	Decree No. 1294 (1983) created a wildlife refuge act
	Decree No. 1320 (1983) declared 14 protected areas as nature reserves
	Decree No. 527 (1990) created
	Decree No. 42 91 (1991) declared protected remnant montane ecosystems in the central part of the coun try, pine forests of the Caribbean coast, and vol canic craters of the Pacific slope mountains
Panama	General Forestry Law No. 39(1966)
	National Institute of Natural Renewable Resources (1986)
	National Plan for Environmental Protection and Rehabilitation (1989)
	Forestry Action Plan for Panama (1990)

Source: World Conservation Monitoring Centre, 1992.

effective national system of protected areas in each country" (WCMC 1992).

Conservation in Central America began before European contact, with the implementation of protective measures in sensitive areas (Gómez-Pompa & Kaus 1990), planting of trees, and creation of botanical gardens and zoological parks (WCMC 1992). Some Central American countries inherited colonial legislation restricting certain activities in designated areas, although this was largely intended to protect economic rather than environmental interests, particularly those in timber production and mining.

Most protected-areas legislation is of more recent, post-independence vintage, with the majority of Central American countries adopting late 20th century constitutional provisions for the designation of protected areas (Table 4). Throughout the region, significant karst landscapes are variously encompassed within national parks (e.g., Tikal in Guatemala, Cocos Island in Costa Rica, and Santa Barbara in Honduras), forest reserves (e.g., the Vaca and Chiquibul Forest Reserves in Belize), wildlife reserves, refuges and sanctuaries (e.g., Machaquila-Cuevas de San Miguel Wildlife Refuge in Guatemala) and other conservation areas (e.g., the Río Bravo Conservation and Management Area in Belize). Karstlands are present in at least 5 UNESCO World Heritage Sites: Tikal, Cocos Island, Darien, La Amistad, and Sian Ka'an, the last 3 of which are also Man and the Biosphere Reserves. Much of the Guatemalan Peten karst is incorporated in the Maya Biosphere Reserve.

Regionally, the pattern of protected-areas legislation is inequitable, with levels of protection reflecting population, economic, and political pressures and with application and enforcement minimal. There is considerable scope regionally for the continued development and implementation of effective protected areas policy and enforcement (Margules & Pressey 2000).

International non-governmental and inter-governmental organizations also play a role in the proposal, identification, establishment, and management of protected areas. Organizations involved nationally and regionally include the International Union for the Conservation of Nature and Natural Resources (IUCN), the World Wide Fund for Nature (WWF), Conservation International (CI), the Nature Conservancy (TNC) and the International Council for Bird Preservation (ICBP).

PROTECTED KARSTLANDS: THE REGIONAL SITUATION

About 23% of the total Central American land area, ~154,300 km², is karst landscape. Protected karst areas for individual countries and the region as a whole are shown in Table 3. Regionally, there are 45 protected karst areas, collectively encompassing 27,916 km², ~18% of the regional karst total. Considering individual countries, the greatest number of protected karst areas (18) is in Belize, where 68% of the karst is protected, with the largest total area of protected karst (19,351 km²) in the Mexican Yucatan states, where ~18% of the total karst is protected.

It is interesting to compare the karstland situation with overall national levels of protected area designation (Table 5), although it is important to note that the UN/WCMC data are constrained by criteria of size and legal status, so that the protected area totals in Tables 3 and 5 are not directly comparable. Belize and the Yucatan states have relatively high levels of protected-area designation both for karst and non-karst landscapes; in contrast protected-area designation in El Salvador is minimal in both cases. Honduras has designated only 10% of its total landscape as protected, but it affords protection to seven karst areas, representing 35% of its total karst. By contrast, Guatemala has designated 20% of its total landscape as protected, but its seven protected karst areas represent only 10% of the national karst total. Karst protected areas in Costa

Table 5. 1997 total protected areas and population density in Central America (km²).

Country	Area km²	Population Density/km²	Total Protected Area km²		Number Protected
Belize	22965	10	9118	(40%)	36
Costa Rica	51100	67.8	11972	(23%)	88
El Salvador	21041	243.3	52	(0.25%)	2
Guatemala	108889	100.4	21649	(20%)	34
Honduras	112492	56.3	11298	(10%)	51
Mexico:					
Campeche	56798	11.3	14282	(25%)	2
Quintana Roo	39376	17.9	7730	(20%)	5
Yucatan	43257	36	4407	(10%)	3
Nicaragua	148000	26	16334	(11%)	60
Panama	75517	36	15464	(21%)	23

Sources: Europa World Year Book 1999; World Conservation Monitoring Centre 1997.

Rica and Panama are comparatively small, both in area and proportion, and El Salvador and Nicaragua have yet to designate any karst areas as protected. Nicaragua has designated 11% of its total land area as protected, but so far this includes no karst. Costa Rica (23%) and Panama (21%) both have reasonable national protected areas systems, but neither includes much karst.

PROTECTED KARST AREAS: SELECTED EXAMPLES

The 18% of the Central American karst landscape afforded protected area status includes some individual karstlands that are extensive and significant in terms of scientific, cultural, and recreational criteria. The majority of the 45 protected karst areas are so designated because of their biological, archaeological, or recreational significance, rather than on the basis of geomorphic criteria.

The Yucatan Peninsula is the largest karst area, with the most protected karst in Central America (Table 3; Fig. 1). The largest single protected area is the 7232 km² Calakmul Biological Reserve in Campeche, established in 1989, which adjoins the Maya Biosphere Reserve in Guatemala. Quintana Roo has three protected karst areas: Sian Ka'an Biological Reserve (5281 km²), Yum-Balam Flora and Fauna Protection Area (1540 km²), and Uaymil Flora and Fauna Protection Area (891 km²). Yucatan also has three protected karst areas: Arrecife Alacranes National Park (3338 km²), Rio Celestun Special Biosphere Reserve (591 km²), and Rio Lagartos Special Biosphere Reserve (478 km²).

Belize has the highest level of karst protection in the region (Day 1996; Table 3). The largest area is the Chiquibul National Park, established in 1991, which encompasses 1865 km² in the western Cayo District. The park contains the Caracol Archaeological Reserve, as well as portions of the Chiquibul Cave System, the longest known cave system in Central America, presently surveyed to 55 km (Miller 1996, 2000). The Rio Bravo Conservation and Management Area (1010 km²) in the Orange Walk District is managed by the Programme for Belize, a non-government organization established in 1988 to promote conservation of natural heritage and wise use of natural resources. Other significant protected karst areas include the Vaca Forest Reserve (210 km²) and parts of the Bladen Branch Nature Reserve and the Columbia River Forest Reserve (Day 1996).

Two small karst areas in Belize that are protected, at least in part, for their intrinsic karst value, are the Blue Hole National Park and Five Blues Lake National Park in the Cayo District. Blue Hole National Park, established in 1986, is 2.3 km² in area and is managed by the Belize Audubon Society, receiving about 6000 visitors annually (Rath 2000). Five Blues Lake National Park is focused around a large sinkhole lake and is 4 km² in area.

A proposed agreement between Belize and Mexico is designed to protect the border areas between the two countries. An international protected area in the Gran Petén, encompassing parts of Mexico, Guatemala, and Belize, is also under consideration and would include the Rio Bravo area. A third proposed binational agreement includes the Chiquibul/Mayan Mountain project between Guatemala and Belize (WCMC 1992).

Guatemala has 1517 km² of protected karst contained in seven protected areas (Table 3). The karst of Guatemala has "major significance due to its profusion and diversity." (Middleton & Waltham 1986: 95). The Río Chiquibul-Montanas Mayas Biosphere Reserve (619 km²) is the largest contiguous protected karst area in Guatemala. Located in the Petén Department, the Reserve adjoins the Vaca Forest Reserve in Belize. The Machaquila-Cuevas de San Miguel Wildlife Refuge contains 148 km² of karst in south-central Petén. Laguna Lachua National Park (150 km²), in the Alta Verapaz Department, is one of the most important karst areas in Guatemala, characterized by towers, cones, dolines, and poljes (Middleton & Waltham 1986). The largest protected area in Guatemala is the Maya Biosphere Reserve (18,449 km²) established in 1990 (Sundberg 1997), located in the Department of Petén. The reserve contains many important archaeological sites, including El Mirador, El Zotz, Piedras Negras, Tikal, and Uaxactun. The protected karst is contained in 2 areas: Tikal National Park (576 km²) and the Mario Dary Biotope for the Conservation of the Quetzal (12 km²). Despite its protected status, the Maya Biosphere Reserve loses an estimated 485 km² of forested land to unauthorized agricultural clearance each year (Aburto 1995).

The largest protected karst area in Honduras covers 2400 km² within the Patuca National Park and Tawahka Anthropological Reserve, in the Cordillera Entre Ríos and the Montañas de Colon in southeastern Honduras. Patuca National Park contains ~1600 km² of karst and Tawahka Anthropological Reserve ~800 km² of karst. The area is considered threatened by immigration and is the last homeland of the Tawahka (Sumo) culture, one the most threatened indigenous groups in Honduras (Instituto Hondureno de Turismo, 1998).

The second largest protected karst area is Sierra de Agalta National Park (655 km²) in central Honduras. Karst is also designated as protected within the Pico Pijol National Park (160 km²), the Cerro Azul Copan National Park (155 km²), the Santa Barbara National Park (130 km²) and the Cuevas de Taulabe National Monument.

Costa Rica has ~2000 km² of karst landscape distributed in small areas throughout the country (Mora 1992). The largest protected karst area is the Isla del Coco National Park (24 km²) in the Pacific Ocean off the Peninsula de Nicoya. On the Peninsula de Nicoya, karst is protected within the Barra Honda National Park (23 km²) and the 3 relatively small protected karst areas of Cabo Blanco Nature Reserve (12 km²), Ostional National Park (8 km²) and Curu National Park (1 km²).

SUMMARY AND CONCLUSIONS

Approximately 18% of Central America's karst landscape is afforded at least nominal protection through its designation as protected areas. Its 45 protected karst areas total ~28,000 km², with the single largest area (19,351 km²) in the Yucatan peninsular states, representing 18% of the total karst area. There are also extensive protected karst areas in Honduras, Belize, and Guatemala, with smaller areas in Costa Rica and Panama (Table 3). El Salvador and Nicaragua have yet to designate any karstlands as protected areas. Panama, Costa Rica, and El Salvador have only limited karstlands, with relatively low levels of protection. Combined with Nicaragua, their protected karstlands constitute only 148 km², or <1% of the regional total (Table 3).

We accept that some of the data sources upon which these conclusions are based are not as reliable as we would wish, but we regard them as the best sources available at the regional scale. More detailed field surveys of the extent of karstlands and protected areas in individual countries are warranted, particularly if the effectiveness of protection "on paper" is to be ascertained. This is particularly true in Nicaragua and Honduras, where there is considerable uncertainty about both the extent of the national karst and the status of the protected areas.

Regionally, Belize has the highest percentage of karst protection, with 68% of the total karst incorporated within 18 protected areas. Half of all the protected areas in Belize incorporate karstlands (Tables 3 & 5), although few of the protected areas are so designated primarily because of their karst landscape. The high level of karst protection in Belize reflects the overall national commitment to protected area establishment, which results in some 40% of the country being designated as protected (Table 5). Another important factor is Belize's low population density, which stands in marked contrast to that of other Central American countries (Table 5). Although detailed analysis of the factors influencing the differing levels of karstland protection has not yet been undertaken, population pressure would appear to be an important factor (Table 5).

Conferral of protected area status does not necessarily result in effective protection from such threats as forest clearance, agricultural incursion, water contamination, and the looting of archaeological materials. Because of limited finances and manpower, management and policing of Central America's protected karst areas are of variable effectiveness and, in some instances, non-existent. Some of the largest and most significant of the reserves are the most vulnerable.

It is difficult to assess the Central American situation by comparison with other parts of the world, since few comparable studies have yet been undertaken. Parallel studies of protected karst areas in the Caribbean and Southeast Asia (Kueny & Day 1998; Day & Urich 2000) suggest that approximately 14% and 12% respectively of the karst in those regions is designated as protected.

In the broader conservation context, the protected karst area percentage exceeds the figure of 10-12% that is sometimes suggested as the near-term land area protection target for nations and ecosystems (Noss 1996). The relevance of such low numerical targets is, however, questionable (Soule & Sanjayan 1998).

The protected-areas situation in Central America is volatile, with reserves being created and disestablished on a regular basis. Even within the duration of this study the numbers, sizes, and status of many countries' protected karst areas have changed, in some cases dramatically. The numbers presented here will almost certainly be outdated by the time of publication. The contemporary regional attitude towards conservation is not always encouraging, and it will be interesting to follow the future trend in the status of the protected karst areas. The current modest levels of protection may increase in terms of area, proportion, and efficacy, or they may decrease as other pressures on natural resources increase.

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