Geologia Croatica	63/2	149–154	1 Fig.			Zagreb 2010

Challenges to sustainability in the Caribbean karst

Mick Day

Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin 53201, USA; (mickday@uwm.edu)

doi: 104154/gc.2010.12

Geologia Croatica

ABSTRACT

Karst landscapes in the Caribbean cover nearly 130,000km^2, more than half the total land area of the region. Approximately 90% of the karst is on the Greater Antilles, with other significant areas in the Bahamas, Anguilla, Antigua, the Cayman Islands, the Virgin Islands, Guadeloupe, Barbados, Trinidad and Tobago, and the Netherlands Antilles. There is considerable heterogeneity, but the Caribbean contains many "classic" karst landscapes, including cockpits, towers, dry valleys, dolines (sinkholes), blue holes and caves. The karst has played an important role in Caribbean history, as a focus of resistance to colonial power, and as a basis for subsistence agriculture following emancipation and independence, increasingly incorporating commercial agriculture, urbanization and industrial activities, and tourism. Karst landscape provides a critical physical backdrop for many of the Caribbean's environmental, agricultural, economic and cultural issues, and its sustainability is critical to regional wellbeing.

The Caribbean karstlands are challenging to human habitation, since they possess a broad array of natural hazards, such as drought and flooding, but they are also inherently fragile, at risk of degradation and vulnerable to environmental change. Despite this vulnerability to environmental change, under rational management regimes there is no inherent reason why human use should not be sustainable in the long term. Human impacts, however, have been long-term and severe, particularly through destruction of natural vegetation, contamination of water supplies, urbanization and quarrying.

The Caribbean karst continues to play important roles locally, nationally and regionally in water supply, mining and quarrying, agriculture, tourism and conservation, all of which represent specific and collective challenges to sustainability of the karst environment. Additionally, sustainability is threatened by the consequences of anthropogenic climatic change, which is predicted to lead to increasing air and water temperatures, rising sea levels and changing weather patterns, including decreasing precipitation totals, and the increasing frequency of extreme events, such as droughts and hurricanes, the effects of all of which will be magnified in the karst, particularly with respect to karst hydrology.

Disruption of the karst hydrological cycle may lead to increasing aridity and desertification, with concomitant impacts on ecology and potential land use. Increasing population and economic development will further exacerbate human impacts on the karst landscapes. Climate change and other human impacts will increasingly threaten already at-risk and vulnerable ecosystems and human communities, necessitating integration of climate change parameters and the adoption of appropriate risk management measures. The severity of these impacts may be reduced by appropriate land management and land use planning, which are necessary ingredients for long-term sustainability.

Keywords: Caribbean, karst, sustainability, management

1. INTRODUCTION

The Caribbean, defined broadly as the islands of the Greater and Lesser Antilles, the Bahamas, Trinidad, Tobago, and the Netherlands Antilles, broadly corresponding to the West Indies (WATTS, 1987), is one of the premier karst regions in the world, with a limestone area of nearly 130,000km^2, more than half the total land area of the region (DAY, 1993).

The karst challenges sustained human activities because it possesses a broad array of natural hazards and is inherently fragile and vulnerable to environmental change (DAY, 1993, in press a). The karst is particularly vulnerable because of its unique hydrology, with sporadic surface drainage, limited surface water storage and rapid subterranean flow. Karst landscape ecology is adapted to these hydrologic constraints, the parameters of which can be altered radically by anthropogenic environmental change, which threatens sustainability.

The IUCN World Commission on Protected Areas (WCPA) recognizes karst landscapes, including the Caribbean, as being at risk of degradation and warranting protection (WATSON et al., 1997). Protection and conservation are critical in the Caribbean, and they are central to a consideration of karst sustainability. This paper considers sustainability of the Caribbean karst in relation to past, present and future environmental conditions, particularly those arising from human activities and anthropogenic environmental change (DAY, 1993; DAY & CHENOWETH, 2009). Although impacts have already been severe, and future change threatens to be more so, there is no inherent reason why human use should not be sustainable in the long term under rational management regimes that recognize and encourage appropriate activities whilst restricting those that are deleterious.

2. CARIBBEAN KARST

Caribbean limestones range from Holocene to Jurassic in age (0–200myrs BP). There is a wide range of karst landscapes including dry valleys, dolines (sinkholes), cockpits, residual towers, and extensive cave systems. The karst has been and still is influenced by tectonic, eustatic, and climatic changes (DAY, 1993).

The largest karst areas are on the Greater Antilles (Cuba, Hispaniola, Jamaica, and Puerto Rico) with a total karst area of approximately 115,000 sq. km (Fig. 1). The islands of the Bahamas, the Lesser Antilles, Trinidad, Tobago, and the Netherlands Antilles contain an additional 15,000 km^2 of karst (DAY, 1993, 2009). Karst topography is variable, although including three distinct styles: doline, cockpit, and tower (DAY, 1993). Doline karst occurs throughout the Caribbean whereas cockpit and tower karst occur particularly in the Greater Antilles (Cuba, Hispaniola, Puerto Rico and Jamaica). Caves are numerous.

The karst is heterogeneous with respect to geologic and geomorphic factors, and climate, soils and biota also vary, producing a wide range of specific karst environments. Karst elevations range from sea level up to 3000m including mountains and plains. Some karsts are autogenic, others much influenced by allogenic inputs. Climate varies considerably,

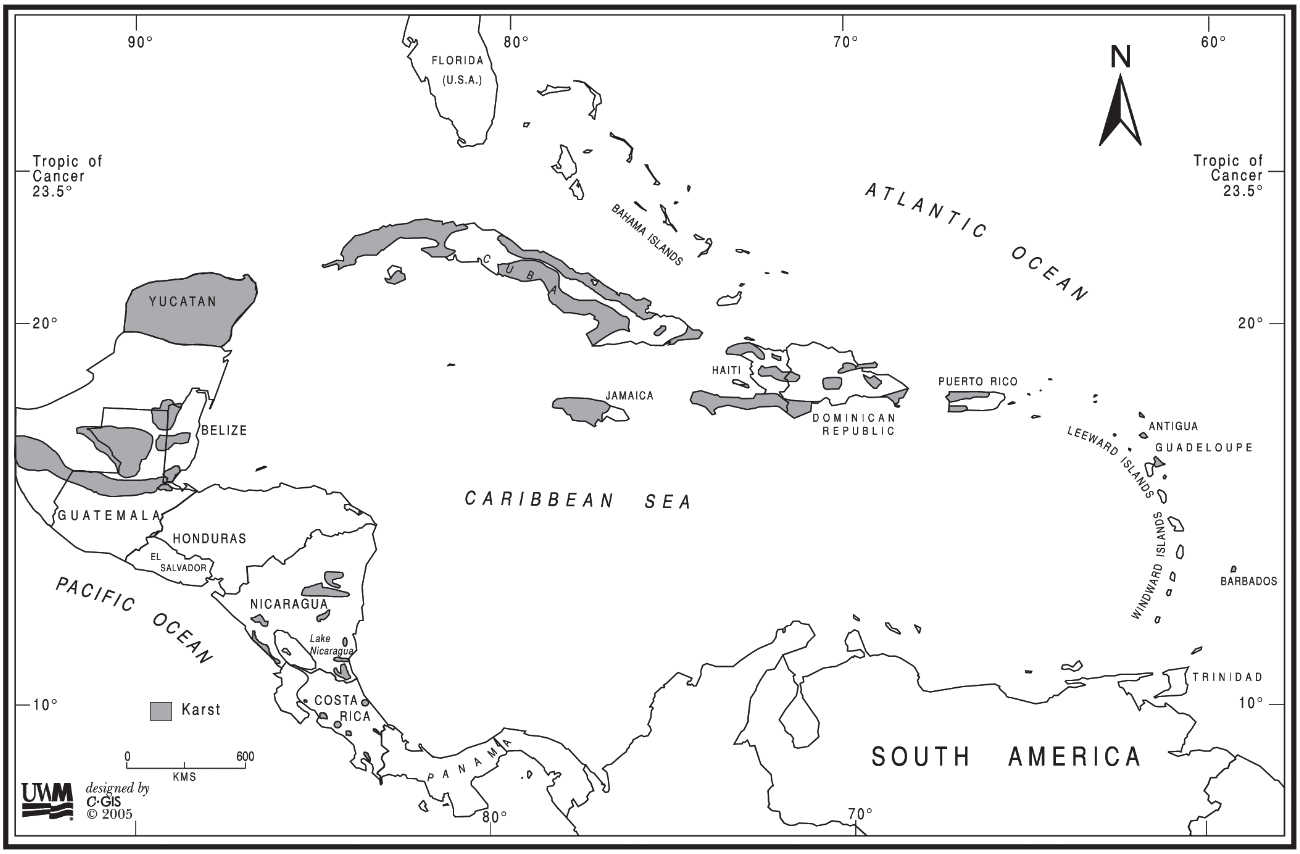

Figure 1: Major locations of Caribbean karst.

with mean annual precipitation ranging from less than 1000 to over 3000mm, and with marked orographic influences. There are distinct winter dry periods of differing onset, intensity and duration and brief midsummer droughts. Summer rainfall is spatially uneven and hurricanes and tropical depressions can cause severe flooding, particularly in valleys and depressions.

Karst soils are extremely variable. Steep slopes may be bare, while thicker soils in depressions and valley bases are often associated with bauxitic infills. Vegetation varies from xerophytic scrub to wet tropical deciduous and coniferous forest, with many endemic species. Most of the original forest has been cleared, with only fragments remaining in remote karst areas.

3. MAJOR SUSTAINABILITY ISSUES IN THE KARST

The major sustainability issues in the Caribbean karst are drought and water supply. The lack of surface drainage is particularly seasonal, and short-term dry season drought may be severe or extend over longer periods, leading to crop and livestock losses, bush fires, and emergency distribution of water supplies (LASHLEY & BANDARA, 2001).

Much progress has been made in the provision of urban water supplies via wells and pumps, but rural water supply still relies largely on rainwater collection in tanks from roofs and gutters. These collection systems, although simple and environmentally-friendly, have their limitations. Storage capacity is limited, and supply is unreliable, characterized by deficit or surplus. Storage may be further compromised by evaporation and leakage, or by accidental contamination.

Springs remain the other major source of rural supply, particularly around karst edges. Major perennial springs are generally reliable, but seasonal and ephemeral springs are less dependable. Drought often requires water to be brought in by trucks from non-karst areas or from remaining sources within the karst.

Conversely, and perversely, flooding is also a great hazard, with serious short-term consequences, including human death, injury and displacement, and damage to homes and other structures (LASHLEY & BANDARA, 2001). Seasonal or intermittent flooding is an integral component of Caribbean karst hydrology, and is particularly hazardous where drainage paths are provided by elongated, compound depressions or dry valleys. Flooding may also occur where allogenic drainage exceeds the capacity of the karst drainage system, particularly in poljes, where such occurrences are sufficiently frequent as to be predictable on a broadly seasonal basis. Flooding may also result from filling and overtopping of the epikarstic reservoir. This is unpredictable and uncommon, but is usually localized and temporary. Flooding on a broader scale may result from elevation of groundwater levels and upwelling of groundwater via estavelles. This may occur on a more-or-less predictable seasonal basis in larger, low-lying depressions, and it is this regional groundwater upwelling that represents the most serious flooding hazard, particularly in more densely populated, low lying areas.

Rapid surface failure is not common within the Caribbean karst, but both ground surface collapse and subsidence represent an increasing threat to developing infrastructure, such as highways and public service facilities, plus a minor hazard to rural dwellings and livestock. Slope failure also poses a minor to moderate hazard to buildings, roads and other structures, although one that is rarely recognized.

4. HUMAN IMPACTS ON THE KARST

Human impacts on the Caribbean karst have been long-term and severe (DAY, 1993), in particular through forest clearing, species introduction, agriculture, utilization of water resources, urbanization and industrial activities, including mining. Disturbance extends back to pre-colonial times.

With a land area of 233,927 km^2 (WATTS, 1987) and a population approaching 40 million people (UNEP, 2005), pressures on the Caribbean karst are already severe. Future prospects threaten further exacerbation, through clearing of remaining natural vegetation, species extinction or introduction, expanding agriculture, increasing utilization and contamination of water resources, tourism, urbanization and industrial activities, including quarrying and mining.

Human impact on the karst may be schematized by reference to a broad, landscape-wide impact-process-consequence model involving human activity, landscape process change and response, and problems for human occupancy and activity. This can be illustrated by reference to the karst hydrologic system, in which forest clearance, agriculture, groundwater abstraction and modification of surface drainage courses has resulted in increased runoff, decreased infiltration, increased surface sediment transport, and decreased spring discharge. This has impacted sustainability through increased flood susceptibility, desiccation of springs and accelerated soil erosion (DAY, 1993).

Forest clearance and agriculture have had profound effects on the Caribbean karst, and agriculture remains the dominant regional karst land use. Although agricultural activities are increasing steadily, they are potentially sustainable in the long-term if subject to rigorous control over soil erosion, water use and contamination and maintenance of protected areas. Small-scale agriculture is most suited to much of the Caribbean karst, although larger-scale operations are locally feasible if tied to stringent conservation measures.

Limestone quarrying has had pronounced impacts on the Caribbean karst, most significantly for cement production. Annual production of limestone and cement are each about 10m Mt (DAY & CHENOWETH, 2009). There is also a limited amount of marble, gypsum and aragonite mining, plus some small-scale mining of phosphate rock and of bat guano from caves. Petroleum reserves are associated with karst in Cuba, Trinidad, Aruba and Barbados. Commercial bauxite production began in the Caribbean in the1950s, and Jamaica is the World's third largest bauxite producer. About 100,000 ha of northern Jamaican karst, particularly in the Dry Harbour Mountains, have been exploited for bauxite and alumina by surface mining, with similar areas affected in the southcentral karst. By 2004, bauxite and alumina production amounted to 13.3 m Mt and 4.08 m Mt respectively (USGS, 2006). Beyond the physical devastation of the karst by bauxite mining, the operations have caused the displacement of thousands of local residents and serious ground and surface water contamination.

5. FUTURE ENVIRONMENTAL CHANGE IN THE KARST

Predictions for the Caribbean are that anthropogenic climatic change will lead to increasing air and water temperatures, rising sea levels and changing weather patterns, including decreasing precipitation totals, and the increasing frequency of extreme events, such as droughts and hurricanes (NURSE & SEM, 2001; PELLING & UITTO, 2001; SIMMS & REID, 2006). The most significant and immediate changes will be related to rising sea levels and to changes in rainfall regimes, soil moisture budgets, prevailing wind speeds and directions, and patterns of wave action (NURSE & SEM, 2001). Coastal locations, where socioeconomic activities, infrastructure and population are concentrated, will be particularly vulnerable, and the effects of all these changes will be magnified in the karst.

Atmospheric carbon dioxide levels are increasing by about 1.0 percent per annum compounded, and sea level has been rising by nearly 2 mm per year. Atmospheric carbon dioxide levels are predicted to reach 550 ppm by the mid 21st century (HULME & VINER, 1998) and sea level may rise by as much as 5 mm per year over the next 100 years. This will have serious sustainability implications throughout the Caribbean karst, both for natural biological systems and for social and economic development (NURSE & SEM, 2001). It is unclear what impact these changes might have upon karst processes, but changes in soil CO_2 levels have clear implications for dissolution rates as the soil is the primary source of CO_2 dissolved by percolating rainwater.

Temperatures across the Caribbean have increased by 0.6 °C over the past 150 years, and are currently increasing by as much as 0.1 °C per decade, with a projected increase of 2.0 °C by 2100 (NURSE & SEM, 2001; PETERSON et al., 2002). Precipitation trends and predictions are more variable, in part because of the inherent variability in Caribbean rainfall. Circulation models suggest enhanced climate change throughout the region, with increases in surface air temperature, decreases in diurnal temperature ranges, and a marginal decrease in rainfall of about 0.1–0.3 percent (NURSE & SEM, 2001). Predictions also suggest increasing summer thermal stress, with more frequent dry season droughts and wet season floods.

Potential loss of biodiversity is another important element of environmental change in the Caribbean, and the 2006 Global Biodiversity Outlook (GBO) identifies climate change as a primary "driver" of biodiversity loss (SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, 2006). Projections suggest that climate change and sea-level rise will cause unfavourable shifts in biotic composition (NURSE & SEM, 2001; SCBD, 2006).

In the karst, the most damaging results of climate change will be those arising from changes in the karst hydrology as a result of more frequent dry season droughts and wet season floods. Overall, the impact will be to exacerbate and magnify the existing situation, with increasing frequency of high magnitude events and greater extremes of drought and flooding. Water resources are already limiting, and disruption of the karst hydrological cycle may lead to increasing aridity and desertification, with concomitant impacts on future sustainability. Increasing drought will further limit human access to rainwater and will also result in a diminution of recharge to the groundwater, placing an increased burden upon water resources in general (DACUNHA, 1989). In addition, floodwaters may contribute relatively little to groundwater resources, as well as potentially increasing contaminant loads. The availability of water resources will become increasingly critical in the karst, where water already is in short supply and reliant upon rainwater from small catchments or limited freshwater lenses. Rising sea levels will also increase the risks of saline water intrusion into the restricted fresh water lenses, especially in smaller islands.

Related to water supply issues, arable land for crop agriculture is limited throughout the Caribbean karst, and the prospect of land loss and increased aridity as a consequence of climate change and sea-level rise will threaten the sustainability of both subsistence and commercial agriculture. Because water resources and agriculture are so climate sensitive, it is expected that these sectors will be adversely affected by future climate and sea-level change (DACUNHA, 1989; NURSE & SEM, 2001; FISCHER et al., 2002; PARRY et al., 2004).

The other major impact of projected climate change will be an increase in flooding within the karstlands. Floods will increasingly produce more serious short-term consequences, including human death, injury and displacement, and damage to homes and other structures. Flooding may still be expected on a similar seasonal or intermittent basis, but it will remain problematic to predict its geographical distribution accurately. Flooding will continue via distinct, but often complementary mechanisms, and will affect increased areas of the karst landscape. Heavy and/or prolonged rains, associated with more intense tropical storms, will produce increased overland flow when surface and epikarstic infiltration capacities are exceeded, particularly in elongated, compound depressions and dry valleys.

There will also be increased flooding by allogenic drainage from non-karst terrains, particularly in poljes, which may be inundated for longer periods seasonally, if not permanently. Such flooding may affect the function of estavelles and other discharge/recharge features. Flooding as a result of filling and overtopping of the epikarstic reservoir will also become more common and extensive but will remain unpredictable and temporary. Widespread flooding may result from elevation of groundwater levels and upwelling of groundwater via estavelles. This may still occur on a more-or-less predictable seasonal basis in larger, low-lying depressions, and it will remain the most serious flooding hazard, particularly in densely-populated, low-lying areas. Increased groundwater levels and volumes may also lead to temporary increases in spring discharge, which may in turn lead to stream flooding on the downstream sides of the karst. Coastal flooding will also increase as sea level rises.

6. SUSTAINABILITY WITHIN THE KARST

Sustainability "....meets the needs of the present without compromising the ability of future generations to meet their own needs" (WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT, 1987). In practice, sustainability is a complex issue and one which is difficult to define in a specific operational sense (CLARK, 2007). It is usually employed with an anthropocentric focus, although it can be argued that this is not necessarily appropriate, and that a broader environmental, rather than social or economic framework may be more appropriate (SERAGELDIN & STEER, 1994). A detailed consideration of the sustainability concept is beyond the remit of this paper.

Broadly, current human use of the Caribbean karst is unsustainable, although some aspects, such as urban expansion, quarrying and industrialization, are clearly more pernicious than others, such as small-scale organic agriculture and ecotourism. Sustainability in the karst may be illusory, particularly in light of contemporary and future environmental changes (DAY & CHENOWETH, 2009).

Sustainability, broad-scale environmental change and land use and land cover modifications within the Caribbean karst must be understood in tandem (DALE, 1997) and responses must be integrated to address the entire panoply of sustainability issues (HAMILTON-SMITH, 2006; UNEP, 2005, SIMMS & REID, 2006). Climate change will have environmental impacts at a variety of spatial and temporal scales, but more direct human impacts will override these in many instances. Climate change and other human impacts on the Caribbean karst will result in combinations of vulnerabilities, necessitating integration of environmental change parameters and the adoption of appropriate sustainability measures (CHALLENGER, 2002).

There is an immediate need for comprehensive regional and national surveys of environmental conditions within the Caribbean karst. Recognition of the inherent characteristics of the karst needs to be at the forefront of such surveys, and the region's karst sustainability issues need to be clearly identified. It is paramount to recognize the karst drought and flooding hazards. A varietry of stakeholders – government agencies, NGOs and communities should be involved. Local and indigenous knowledge about conditions is paramount. Scale issues also warrant attention, since impacts and responses will occur at a variety of spatial and temporal scales. Proactive steps are required from regional bodies and national governments, but local community actions may ultimately prove more important.

Once the contemporary situation is understood, then strategies for mitigating future environmental change and promoting sustainability can be developed rationally and with specific reference to the karst. Appropriate strategies may include the development and implementation of comprehensive land use policies and programs.

Provision of adequate water resources within the karstlands will involve measures such as improved rainfall retention, improved storage and distribution systems, development of alternative water sources, better management of supply and infrastructure, increased conservation, and application of improved technology, including desalinization. Agricultural strategies may include growing more drought-resistant crops, and increased attention to maintenance of soil and water resources. The potential effects of climate change and anthropogenic pressures also need to be integrated into broader community planning and into tourism development.

In a broad sense, the severity of both climatic and other anthropogenic impacts within the karst can best be reduced by appropriate land management and sustainable land use planning, including the expansion and maintenance of protected areas. All elements of natural and human-modified ecosystems within the karst need to be taken into account. Increased monitoring is required, and priority should be allocated to the maintenance and protection of natural "buffers" within the karst, such as natural vegetation, surface watersheds, caves and groundwater aquifers.

Although most Caribbean nations now recognize the importance of resource protection for environmental, economic and social reasons, the ramifications of climate change and other human impacts increasingly require this to be a priority, particularly within the karst, where the potential risks to nature and human wellbeing are magnified and accentuated. Changing environmental conditions within the Caribbean karst may well be a portent for the overall environmental health of the region, and the karst thus represents a potential barometer of human ability to respond to the very real challenges to environmental sustainability.

ACKNOWLEDGEMENT

Research on Caribbean karst has been supported by grants from UWM's Center for Latin American and Caribbean Studies, and the Mary Jo Read Bequest to the UWM Geography Department.

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Manuscript received November 18, 2009
Revised manuscript accepted March 19, 2010
Available online May 31, 2010