Selection of Appropriate Coastal Protection Strategies for Caribbean Coastlines

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ABSTRACT

The coastlines of the Caribbean are unique in many ways. Their warm waters and sandy beaches attract millions of visitors to their shores and these attributes provide an essential economic opportunity. Coastal hazards affecting the region include hurricanes, tsunami, and coastal erosion. For islands with mountainous interiors, development is often concentrated along the coastlines. This paper draws on more than 20 years of experience designing and evaluating coastal protection schemes in the region, and the related issues, constraints and opportunities are discussed. Projects in The Bahamas, St. Vincent, Guyana, Jamaica and Barbados are cited and the reasons for their appropriateness to the region and specific locations are highlighted. The paper highlights the importance of multi-criteria analyses for coastal project selection and the need for funding agencies to insist on a thorough evaluation of options at the design stage. The unique nature of both the local and regional issues must be recognized and, as such, the design parameters used must have a Caribbean focus. Stakeholder consultation is an essential component of the design process and projects should be treated as an opportunity for socio-economic enhancement as much as possible. Eco-system based approaches should also be given due consideration. Experience has shown that the regulations and codes that govern coastal development need to be updated in most cases. Further, proper enforcement of these regulations will be key if Caribbean coastlines are to survive the next century of anticipated sea level rise.

BACKGROUND

The coastlines of the Caribbean are unique in many ways and include both volcanic and raised limestone terrace-type landforms. In addition, there is often significant contrast in landscape between the leeward and the windward sides of an island, especially in the eastern Caribbean. The leeward side typically has sandy pocket beaches with gentle waves from the Caribbean Sea, while the windward side is aggressive in both its steep terrain and pounding wave action. The sandy beaches of islands such as Jamaica, The Bahamas and Barbados attract millions of visitors to their shores. The beaches therefore represent an essential economic opportunity. In small islands such as St. Vincent and Dominica, with very hilly interiors, development has been concentrated along the coastline. The coast therefore represents more than just tourism. It houses communities, facilitates local livelihoods and provides a critical lifeline between adjacent communities.

Under existing climatic conditions, tropical cyclones already pose several hazards for coastal zones in the Caribbean, including storm surge flooding, extreme

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wave forces and coastal erosion. The gently sloping beaches are relatively narrow and there is often little horizontal or vertical setback to the intensely developed coastal zone, which accommodates human settlements and infrastructure such as hotels, roads and other critical facilities. In the island of Martinique, for example, just under 80% of the country's population is situated along the coast below the 20 meter contour line (Schleupner, 2008). Projected increases in sea level will therefore encroach into this intensely developed area, and act to exacerbate erosion and flooding conditions. For the Caribbean region, the Fifth IPCC report predicts from 0.5 to 0.6 meters of sea level rise for the year 2100 (Nurse et al., 2014). Additionally, it is likely that tropical cyclones will become more intense with increased maximum wind speeds and precipitation rates (Christensen et al., 2013). It is therefore critical that island nations in the region consider how, when and which sections of their coastlines will need to be protected from this increasing risk.

INTRODUCTION

When considering coastal zone management and developing coastal protection for the Caribbean context, there are many factors that must be taken into account, including:

- The use of beach nourishment - Sand nourishment is often a preferred "soft en gineering" approach to coastal enhancement. However, sand supply can be limited or expensive. In addition, as a stand-alone activity, beach nourishment requires ongoing maintenance, and governments and developers are often hesitant to commit to activities with such recurring costs.
- Logistics of construction material - The extreme waves from hurricanes often d ictate the need for either large rock armour or concrete armour units for coastal defense. Large boulders sometimes cannot be transported on the small r oadways, and concrete can be an expensive material for the usually limited construction budgets. Access from the sea is in many cases not practical due to the unprotected coastal zones on the Atlantic side of these islands.
- The applicability of sand mining - While sand mining from rivers starves the coastlines of sediments and contributes to coastal erosion, this is activity provides a basic material required for many different construction activities.
- The applicability of retreat - Relocation and the enforcement of sound setback regulations is a means of reducing coastal vulnerability. However, relocation has the potential to introduce undesired social impacts. Local residents can be dislocated from their livelihoods (e.g. fishing). Development pressures and political interests may also result in problems in enforcing setback regulations.
- Quantification of hazards - With various Caribbean islands having exposure to hazards such as hurricanes, earthquakes, volcanoes, landslides, tsunamis, drought and flooding, coastal protection works must appropriately consider and incorporate disaster risk management strategies. Additionally, changing climatic conditions should be taken into account for climate sensitive hazards.

- New technologies - “New” engineered approaches such as coral propagation, artificial reef systems (reef balls, bio-rock, etc.), floating breakwaters, and geotubes have been discussed and applied in some cases but these also have unique challenges for different sites. For example, using these techniques for wave attenuation in shallow water requires proper anchoring to the sea bed, which is sometimes difficult given the seabed substrate or high energy hurricane waves. Floating breakwaters are usually suitable for short wave periods (under 5 seconds) which are frequently exceeded even on the lee side of the islands.
- Ecosystem Based Approaches - Ecosystem-based adaptation (EbA), which focuses on the maintenance and restoration of ecosystems, are increasingly being applied as a strategy to enhance resilience to climate and disaster risks. Coastal ecosystems such as seagrass beds, mangroves, coral reefs and barrier beaches provide some degree of protection from storm surges and other hazards, and approaches that incorporate indigenous knowledge and are community-based can supplement and complement infrastructure interventions.
- Social benefits - Coastal construction should be a source of income for the residents of the local communities who are often unskilled. Coastal development can also be an opportunity to provide long term income generation, boost skills and add social value through additional recreational space. These social issues must not be forgotten in choosing effective coastal protection solutions.

The Caribbean region is therefore faced with the challenge of developing appropriate strategies to deal with coastal erosion in a unique environment, giving consideration to climate change impacts.

STRATEGIES FOR COASTAL PROTECTION

The decision to choose an appropriate strategy to reduce or avert disaster on a particular coastline is quite site specific. In addition to coastal environmental, physical, morphological and biological factors, socioeconomic issues must also be considered. All of these factors must be looked at in the context of vulnerability to the particular hazards and the available budget. In general, these are typically the available strategies:

1. Hazard preparedness measures – early warning systems and evacuation plans;
2. Strategic retreat – relocation of vulnerable communities and infrastructure, imposition of a setback distance for development;
3. Hold the line – shoreline defense with hard protection on existing coastline;
4. Move seawards – moving the protection seaward to facilitate or encourage natural shoreline growth;
5. Ecosystem rehabilitation – recognizing the ecological importance of the ecosystem and using its functional benefits for coastal protection.

Hazard Preparedness Measures. Many coastal communities are located in areas of high hazard exposure, and their vulnerability is exacerbated by various physical and socio-economic factors. For example, access routes might be poorly designed and at risk to sudden collapse. In many of the islands of the mountainous eastern Caribbean islands, the only access to communities is by way of a coastal highway that is vulnerable to significant wave damage in some areas. Therefore effective use of Early Warning Systems (EWS) and Evacuation Plans (EP) are essential to save lives. An effective system requires certain key elements to be in place: i) extensive mapping of vulnerable communities and infrastructure through comprehensive storm surge, coastal erosion and tsunami inundation mapping; ii) timely and regular public awareness campaigns iii) use of reliable forecast models for hurricanes and effective monitoring systems for tsunamis; iv) redundant means of transmitting urgent and accurate information to the communities in a timely manner (both formal and informal methods); v) a coordinated execution of evacuation plans to appropriately prepared shelters; and vi) post-disaster response and recovery efforts to restore normalcy and avoid future repeats. All of this requires that the funding and capacity exist within the disaster management institutions and that there is a legal framework that links the warning systems to the national disaster plan. Similarly, critical importance must be placed on building bottom-up process with local communities to increase awareness, knowledge, and readiness to respond.

On September 1, 2009 the Caribbean Disaster Emergency Response Agency (CDERA) was transitioned to the Caribbean Disaster Emergency Management Agency (CDEMA) whose mandate is to lead the region in comprehensive disaster risk reduction, rather than just response and relief. Significant economies of scale are gained with this regional effort as the smaller countries would not have the resources to do this effectively. However, with funding constraints and the looming effects of climate change there are many opportunities for improvement: i) insufficient climate, topographic, bathymetric and other relevant data to assess coastal hazards and their changing frequency/severity with climate change; ii) poor understanding of the extent and intensity of coastal hazards, with many coastal communities still lacking hazard maps; iii) critical infrastructure (roads, hospitals, emergency shelters) are still at risk; iv) building and setback regulations in the coastal zone need to be re-visited; and v) institutional capacity bridging local to national to the regional framework needs to be strengthened.

Strategic Retreat. The Caribbean has some unique challenges in applying this strategy. When hazards are intermittent or less obviously apparent, such as storm surge, people living close to coastal hazards are often very unwilling to relocate. In many cases relocation would cause economic hardship, as traditional sources of income, such as fishing or water-taxi services become too difficult to maintain. In cases where the technical justifications for relocation may be sound, decisions to avoid or defer relocation can often be politically motivated. The fishing community of Rose Bank in St. Vincent is one such example. The neighbouring community of Dark View, where people literally lived on the beach, was completely destroyed by Hurricane Lenny in 1999. Today, residents of Rose Bank live on the backshore of the beach at the base of a hillside, all within the mapped hurricane inundation zone. Moving people away from this area, however technically sound, could have grave socioeconomic and political implications. The fishermen live here to protect their boats and wares, which are essential to their livelihood. For them, relocation is not an option without a proper substitute for protection of their livelihood. Moving an entire community can also influence political outcomes given the small population. Relocation means moving votes from a particular constituency and, as such, a technical recommendation may not get the necessary political support to see it happen. The low-lying community of Portland Cottage in Jamaica also highlights these challenges. This area was devastated by Hurricane Ivan in 2004. Six of the seventeen deaths in the island were in this community. Storm surge mapping showed the community is vulnerable to events as frequent as the 25-year hurricane[5] yet despite efforts to relocate people to higher ground following this disaster, people have moved back into the vulnerable area over time. Higher ground means that people are farther away from their source of livelihood, and transportation costs increase for them to access services outside the community. Again, concern for the socioeconomic issues does not encourage rigid enforcement of relocation and evacuation becomes the primary alternative.

Hold the Line. The traditional term used around the Caribbean for hard structures that prevent further retreat of the shoreline is *sea defense* - typically seawalls and rock armour protection (revetments). These types of structures have been widely applied throughout the region to protect coastal roadways. After the damage caused by Hurricane Lenny in 1999 to the lee side of eastern Caribbean islands, for example, the USAID funded a number of projects to repair and protect coastal roadways. These included Soufriere in St. Lucia, Gouyave in Grenada and Cabrits in Dominica. A design that used boulders from local quarries to make a revetment was built in front of a smaller than usual reinforced concrete wall to provide protection. However, site specific challenges vary from island to island and implementing this typical protection is therefore not always straightforward, especially in the smaller Eastern Caribbean states. Some challenges for shoreline protection there include:

- The roadway to be protected sometimes runs along a vertical "cliff" 10 to 20m above sea level. The cliff is exposed to wave undercutting, which may lead to slip failure. The volcanic origin of these islands means that the cliff face is comprised of pyroclastic material that is relatively easily dislodged from the soil matrix. Moving the road inland is not always a feasible option as the steep hillside often elevates even further inland from the road, making construction costs higher.
- Providing heavy equipment access to build a revetment at the base of steep cliffs can be problematic. Barge access from the sea is often just as difficult, given what can be a continuously high-energy environment on the windward side of these islands.

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[5] Coastal Multi-Hazard Mapping and Vulnerability Assessments Towards Integrated Planning and Reduction of Vulnerability for Portland Cottage, Morant Bay and Manchioneal, Jamaica; Smith Warner International Ltd., 2010

- Although good quality rocks exist, in some islands there are no established quarries that can produce the quantity of boulders required for construction. As such, boulders sometimes have to be barged from other territories. Finding an appropriate offloading point for these barges can be a problem and one often has to be built.
- In cases where rocks can be found, another issue may exist: The roadways and bridges often do not have the capacity to accommodate trucks to carry large boulders (over 4 tonnes).
- As cement is an imported item in many of these small islands, concrete armour units that are sometimes necessary can be cost prohibitive.
- In limestone-dominated islands such as Barbados and The Bahamas, rock quality is poor and rarely suitable for coastal construction.

Given these issues, it is often difficult to find a solution that provides the necessary coastal protection and is also financially feasible. Further, a Caribbean-appropriate solution should preferably also provide socioeconomic benefits to the community and fit within the Caribbean landscape. The environmental impacts must also be reasonably minimized and mitigatable.

One example of an appropriate solution is the proposed protection for a low-income rural community in St. Vincent. Figure 1[6] provides a plan and section. The solution will provide wave and coastal erosion protection to the coastal roadway from the aggressive hurricane wave climate. A masonry stone wall is proposed to be built along the road up to the anticipated storm surge level, but seaward of that a 30m wide buffer zone will be reclaimed to create a recreational area for the community. This green area will host community events (concerts, meetings, festivals, etc.) and be the starting point of tours to the nearby La Soufriere volcano. A reinforced concrete wall and boulder revetment will provide the primary protection from wave damage. This solution was developed to add recreational space to an area that currently has little, while creating the opportunity for economic gains to members of the community during and after implementation of the project. Using two types of wall construction (reinforced concrete and stone masonry) is deliberate so that the skill sets of a wider range of local community members can be used during construction. Implementation issues such as the inability to supply all the boulders from a local source are being solved by the construction of a jetty to allow barge access. This jetty is to be left in place to facilitate emergency evacuation in the event of an eruption of the La Soufriere volcano.

[6] Final Coastal Study Report - Smith Warner International Ltd; 2014

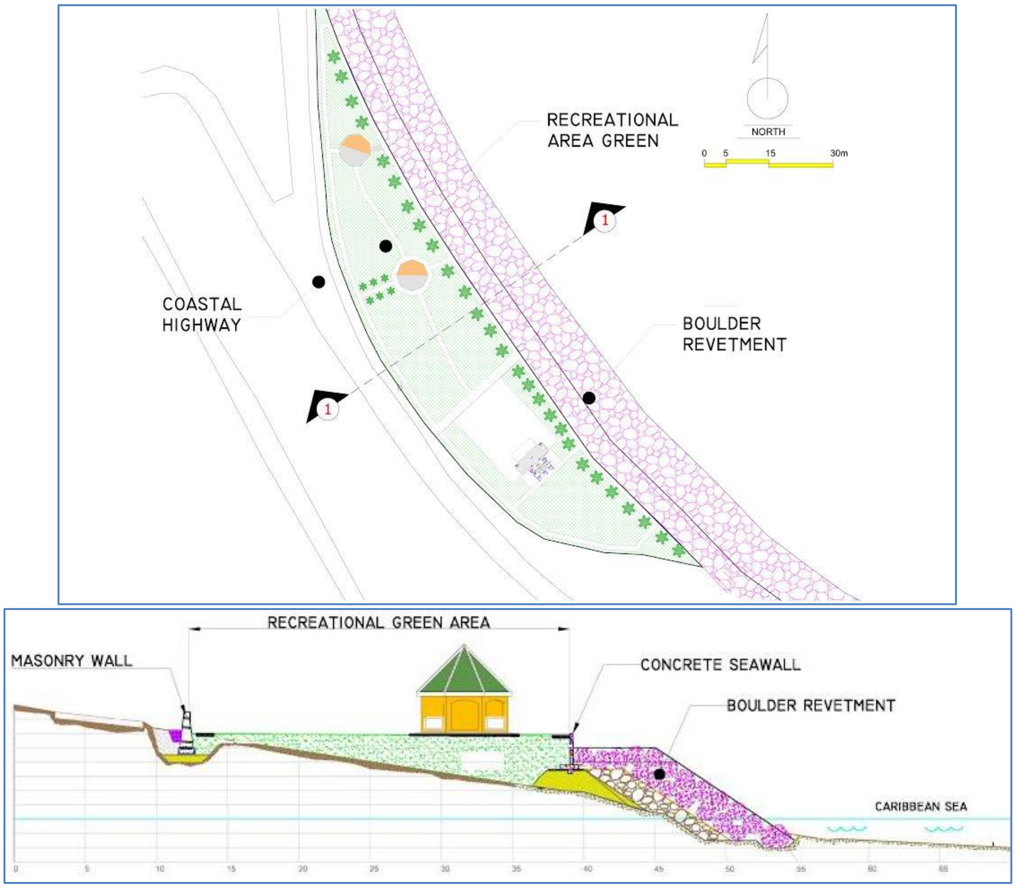

Figure 1: Plan and Section of the proposed green area and coastal protection for St. Vincent community

Perhaps one of the most Caribbean-appropriate projects in recent time is the construction of 1.6km of boardwalk along the southeast coast of Barbados. The coastline had been subject to extensive beach erosion and waterfront properties had become vulnerable to further attack from hurricane waves. The area is an important part of the tourism product of Barbados and, as such, it was necessary to develop a solution that holds the line, but at the same time enhances the shoreline. The Government of Barbados and the IADB funded the design of a boardwalk and a headland and beach system (Figure 2)[7]. The project provides nourished beaches to replace the eroded shorelines, improves access to businesses and is a great recreational corridor for locals and tourists. The boardwalk is now a popular jogging track and tourists use it as a pedestrian link between shops, bars and hotels. The re-establishment of the beaches means that turtle nesting will continue along this section of the shoreline. The beaches, headlands and the boardwalk provide a buffer and physical protection against potential hurricane wave damage. This is an example of a project that achieves not only the necessary coastal protection, but offers significant social and economic benefits while at the same time fitting the Caribbean landscape.

[7] http://www.baird.com/what-we-do/project/beach-restoration-and-boardwalk

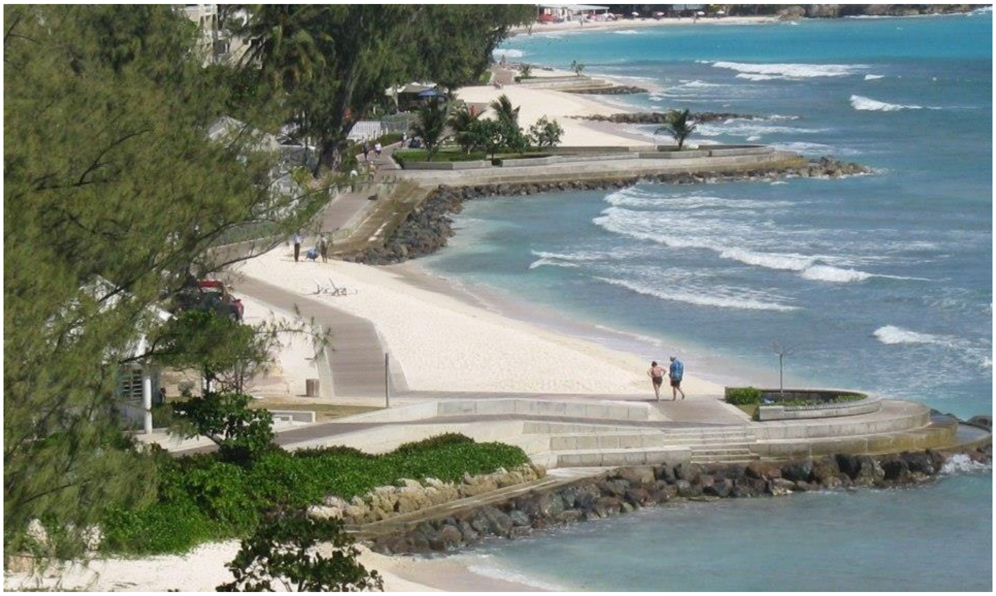

Figure 2: Boardwalk, beach and headland protection on the south east coast of Barbados

Move Seawards. The importance of engineering solutions that will be functional after a direct hit from a tropical cyclone, and the extreme nature of these hurricanes, leads to the frequent adoption of hard engineering, such as armour stone revetments and breakwaters. This is good for traditionally significant infrastructure, such as ports, airports, and road networks, but as tourism becomes a larger proportion of the regional economy, coastal protection must increasingly be designed to include soft engineering components. Beach nourishment, submerged breakwaters, and buried revetments are some of the strategies that have a place in the Caribbean, where tourism interests are strong.

Many beaches in the Caribbean have been suffering erosion for various reasons: damage and destruction of protective reefs; building too close to the shoreline; cyclic shoreline change; hurricane activity; destruction of coastal ecosystems (coral reefs, seagrass, and mangroves) and rising sea levels. One of the most well-known beaches suffering this fate is Jamaica's Negril Beach at the western end of the island. The beach has suffered more than 1m of erosion per year since 1980[8]. Proposals have been put forward to replenish the beach with sand and build reef-type breakwaters offshore, as part of an umbrella solution to repair the damaged ecosystem and reduce ongoing erosion. The beach is to be replenished with sand to regain the lost 30m of beach and the breakwaters are intended to minimize retreat of this new shoreline through the reduction of storm wave energy. Such a project, which has major national importance, requires significant capital funding and stakeholder consultation that can lead to implementation delays. In the meantime, hotels also suffer property-specific beach erosion, which could benefit from more immediate action. However, the nourishment carried out on these small beaches across the region suffers from several issues: i)

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[8] Preliminary Engineering Report for Beach Restoration Works at Negril by Smith warner International Ltd.

limited availability of offshore sources of sand, ii) small grainsize of imported sand leads to flattening of the beach and eventual increased erosion of the beach crest; and iii) imported beach sand is usually cost-prohibitive. This points to the need for the implementation of area-wide solutions.

An example of unobtrusive reef-like breakwaters used in conjunction with beach nourishment is at Bahamar, The Bahamas. In the 1980's, groynes were built to create a lagoon dissecting Cable Beach, a premier local beach. Since then, the down drift (eastern) side of the beach continually suffered up to 30m of erosion[9] while the western side accreted. When the area was being redeveloped into the Bahamar Resort, the challenge was to remove the groynes and recreate the original straight shoreline while maintaining the accreted beach on the western side. This was achieved with a series of submerged breakwaters and beach nourishment. The breakwaters are intended to encourage the formation of salients that slow alongshore transport (Figure 3 below). The solution recaptures the scenery that tourists expect of the Caribbean; the natural vista of the Caribbean Sea and an uninterrupted white sand beach.

Figure 3: Submerged breakwater and sand nourishment on the new Bahamar beach in The Bahamas

Ecosystem Rehabilitation. The coastal ecosystems of the Caribbean contribute to reducing negative impacts of climate variability and change. They act as defenses against wave action and storm surge, protecting coastal populations and infrastructure. They also support numerous livelihood activities such as fishing and tourism. Ecosystems are of particular relevance for climate change adaptation, especially with respect to reduced coastal erosion and to enhanced climate-resilient livelihoods.

The primary coastal ecosystems are seagrass, mangroves and coral reefs. Stressors prevalent in the Caribbean include sea level rise and increasing sea surface temperatures, coral bleaching, hurricane activity, ocean acidification, pollution,

[9] Bahamar Final Engineering Report, Smith Warner International Ltd, 2012

boating and overfishing, and construction practices such as dredging and land reclamation (Chatenoux and Wolf, 2014). Ecosystem based adaptation (EbA) is increasingly promoted as a community-centered approach to not only help people adapt to climate change, but also maintain and enhance ecosystem services crucial for livelihoods and human well-being. With the value of coral reefs in the Caribbean estimated at between US$3.1 and 4.6 billion for services such as fisheries, tourism and coastal protection, preserving such ecosystems is of critical importance (Burke et al., 2004). Measured rates of storm surge reduction through mangroves range from 5 to 50 centimetres per kilometre of mangrove width. In addition, surface wind waves are expected to be reduced by more than 75% over one kilometre of mangroves (McIvor et al., 2012). Coral reefs protect coastlines from the damaging effects of wave action especially during tropical storms. The reefs are a natural buffer against high waves, breaking them and absorbing wave energy. They also act as a sediment trap, sustaining beaches and counteracting the effects of erosion.

Examples of ongoing and planned initiatives that focus on coastal communities in the Caribbean include i) enhancing the viability and health of the Mesoamerican Reef in Belize (World Wildlife Foundation), ii) building resilience of urban systems through EbA in pilot cities across Jamaica, El Salvador and Mexico (UNEP), iii) At the Water's Edge program in Grenada and St. Vincent (The Nature Conservancy), and iv) reducing vulnerability to coastal flooding through EbA in Artemisa and Mayabeque provinces of Cuba (UNDP). Mercer et al. (2012) provided an extensive review of ongoing EbA activities in the Caribbean and found that initiatives were generally ad hoc, lacked coordination and learning from existing approaches and did not sufficiently integrate local knowledge. Similarly, while traditional engineering solutions currently have simulation models to effectively predict safety and sustainability, similar modeling expertise still remains to be developed to predict the impact of events on ecosystem species (Borsje et al., 2011). It is clear that ecological coastal protection offers a new and complementary approach to traditional engineering methods; however such solutions still require standard protocols for predicting and monitoring their effectiveness.

An example of a national effort to rehabilitate an ecosystem is the Mangrove Restoration Project in Guyana. The overall objective of this project is to: [10]*respond to climate change and to mitigate its effects through the protection, rehabilitation and wise use of Guyana's mangrove ecosystems through processes that maintain their protective function, values and biodiversity while meeting the socio-economic development and environmental protection needs in estuarine and coastal areas.* Funded by a partnership between the Government of Guyana and the European Union, it was recognized that the success of the project will be determined by the level of involvement, support for and ownership of the project. As such there has been a strategic and sustained approach to community development and public awareness. In a replanting initiative, community involvement included community members being given mangrove seedlings to plant within in a designated area (see Figure 4 below). The planters are compensated if and when the seedling reaches a certain height. This

[10] http://www.mangrovesgy.org/.

not only provides economic benefit to the community members but gives them a sense of ownership, which translates to longer term preservation and protection from damage related to human activity.

Figure 4: Mangrove replanting by community members in Guyana

"New Technologies" such as Reef Balls[11] and WAD™[12] have been used across the Caribbean to recreate fish habitats and for coastal protection. Geotube®[13] and other geo-synthetic bags have also been used on beaches to hold dunes in place to prevent shoreline erosion. Coral ecosystem renewal has been done through creation of coral gardens by propagating certain coral species that respond very well to nursery culture[14].These applications are suitable for many applications but are threatened by aggressive swell and hurricane waves. In many cases, when wave attenuation is the key requirement these applications can form part of the overall solution for coastal erosion.

DISCUSSION AND RECOMMENDATIONS

In developing a coastal protection solution a holistic approach is essential that first looks at the various possible options and then narrows down to the most appropriate. Table 1 captures the typical discussion points for the first-step overview assessment. This stage of the assessment, through stakeholder consultation, should provide meaningful direction to reduce the number of appropriate strategies.

In many instances, a combination of strategies will be required. The next step of the analysis should evaluate the options more carefully in a quantitative manner. A Multi-Criteria Decision Analysis is recommended for this stage. Table 2 presents a list of criteria for inclusion in this analysis.

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[11] http://www.reefball.org/
[12] http://www.livingshorelinesolutions.com/
[13] http://www.tencate.com/
[14] http://www.seascapecarib.com/

Table 1. Typical Coastal Protection Strategies and the associated pros and cons

Coastal Protection Strategies				
Hazard preparedness measures	Strategic retreat	"Hold-the-line"	Advance shoreline	Ecosystem enhancement
Description				
Use emergency management tools to safeguard lives	Retreat inland and allow nature to run its course	Halt erosion using engineered structures or systems	Move shoreline seaward to provide hazard buffer	Support ecosystems that may be under stress to provide "services"
Essential Components				
Map areas at risk Ensure public education and awareness Improved warning and forecast systems Communication systems, including redundancy Evacuation plans shelter facilities Post-disaster response and recovery	Purchase or acquire land Relocate roads, utilities, and facilities Relocate residents Compensate land and business owners	Examples include: • vertical walls • revetments (buried or exposed) • boardwalks • short groynes	Examples include: • armoured land fill • beach nourishment	Examples may include: • mangrove planting • coral reef habitat creation Integrated coastal zone management
Pros				
Focusses resources on saving lives Generally not capital intensive	Creates a natural hazard buffer area Often used in combination with ecosystem enhancement	Well-established design methods Stakeholders recognise as an accepted method Local job-creation during construction Immediate protection	Provides buffer area from hazards Provides additonal space for recreation Buffer guards against future erosion and climate change Local job-creation during construction	Works with "nature" Can be done using low-skilled labour and equipment May improve marine conditions; fishing and recreation Local job-creation during construction
Cons				
Infrastructure and property remains "at risk" Evacuations are disruptive to stakeholders Repair and replacement costs may be significant	Local topography may preclude it Stakeholders reluctance, e.g.: • heritage • socio-economic • political Valuable land is "sacraficed"	Short project lifespan if climate change projections are underestimated Fewer tangential benefits Capitally intensive May occupy coastal space	Potential impact to alongshore sediment balance Capitally intensive Potential impact on nearshore benthic community	Only partial protection from coastal hazards Requires on-going maintenance Requires existing functioning eco-systems Potential long time to see benefits
Risks				
Not all stakeholder comply Relies on effective emergency management system	Land acquisition challenges Full retreat not achieved	Design conditions may be exceeded and systems fail	Downdrift erosion	Ecosystem may degrade in the future

Table 2. Components for Multi-Criteria Analysis

Effectiveness
- Protection against coastal erosion
- Stability to hurricane impacts
- Predictability of coastal response to protection measure
- Level of protection to property and infrastructure

Technical Viability
- Ease of construction
- Maintenance requirements
- Flexibility for implementation changes
- Sustainability
- Availability of construction material

Economic Viability
- Cost-Benefit Score including maintenance cost
- Opportunities for local employment
- Opportunities for future spatial development
- Avoided cost for damage to property and infrastructure
- Avoided costs for disaster evacuation and response

Social Influence
- Recreational value
- Commercial value
- Stakeholder acceptance
- Flexibility for use by multiple user groups (locals, tourists for example)

Contribution to ecosystem resilience
- Protection of existing coastal ecosystem
- Improvement to functionality of coastal ecosystem

Environmental Impact
- Impact to local ecosystem
- Use of resources that are naturally present locally
- Aesthetics and fit to local landscape

Climate Change Adaptation
- Stability under current projections of climate change impacts
- Future adaptability to accommodate greater than expected climate change impacts

Disaster Management
- Risk reduction for effective execution of disaster response strategies

A point system that assigns weights to the various issues based on the project-specific objectives should be used for this evaluation. The over-riding consideration in developing any solution for the Caribbean should be that solutions are not simply copied from elsewhere in the world. The region is unique and therefore deserves its own Caribbean-appropriate solutions.

REFERENCES

Borsje, B. W., van Wesenbeeck, B. K., Dekker, F., Paalvast, P., Bouma, T. J., & van Katwijk, Marieke M., de Vries, M. B. (2011). How ecological engineering can serve in coastal protection. *Ecological Engineering*, *37*(2), 113–122.

Burke, L., Maidens, J., Spalding, M., Kramer, P., Green, E., Greenhalgh, S., … Kool, J. (2004). Reefs at Risk in the Caribbean. Washington DC: World Resources Institute (WRI).

Chatenoux, B., & Wolf, A. (2013). Ecosystem based approaches for climate change adaptation in Caribbean SIDS. Geneva and ZMT Leibniz Center for Tropical Marine Biology: UNEP/GRID.

Christensen, J. H., Kanikicharla, K. K., Aldrian, E., An, S.-I., Cavalcanti, I. F. A., de Castro, M., … Zhou, T. (2013). Chapter 14: Climate Phenomena and their Relevance for Future Regional Climate Change. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Mercer, J., Kelman, I., Alfthan, B., & Kurvits, T. (2012). Ecosystem-Based Adaptation to Climate Change in Caribbean Small Island Developing States: Integrating Local and External Knowledge. Sustainability, 4(8), 1908–1932.

Nurse, L. A., McLean, R. F., Agard, J., Briguglio, L. P., Duvat-Magnan, V., Pelesikoti, N., … Webb, A. (2014). Small Islands. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, … L.

L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1613–1654). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Schleupner, C. (2008). Evaluation of coastal squeeze and its consequences for the Caribbean island Martinique. *Ocean & Coastal Management, 51*(5), 383–390. doi:10.1016/j.ocecoaman.2008.01.008