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Hard protection structures as a principal coastal erosion management strategy along the Caribbean coast of Colombia. A chronicle of pitfalls

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ABSTRACT

Over the last 50 years, coastal erosion has become a serious problem, rising in magnitude and dominance along the Caribbean coastline of Colombia. *Circa* 50% of this important area for the country is undergoing serious erosion problems related to a multiplicity of factors contrasted by their degree of influence and magnitude, e.g. sedimentary imbalances, extreme waves, ecosystems destruction and sea level rise. Coastal protection related with hard structures has been the first, and in some cases, the only management strategy for these erosion problems. At the beginning of 2016, at least 1484 hard structures (both cross and longshore, such as, groins, seawalls, breakwaters, amongst others) have been built along the Colombian Caribbean coast, the highest concentrations being found in tourist cities. A significant percentage (close to 90%) of these hard structures have not been very successful or have failed in their purpose. These hard structures have altered the natural conditions of the study area, producing impacts such as i) coastal armoring, ii) reduced sediment supplies to downdrift areas, iii) intensification of erosion processes, iv) generation of nearby new erosion hot spots, v) deterioration of coastal scenery quality, among others. This paper describes and evaluates the functionality of coastal protection strategies used up to the present and delves into management aspects of coastal protection in the Caribbean coast of Colombia. It also indicates the current and future coastal protection scene for the region and highlights major trends and challenges faced by users, land owners, and coastal managers.

1. Introduction

Coastal communities around the world face serious problems related to coastal erosion (Pilkey and Cooper, 2014). This process is magnified by the existing conditions of a warming climate that have resulted in constant inundation and an increased risk of flooding during extreme wave events (Donnelly et al., 2004; Aerts et al., 2014; Jin et al., 2015). Coastal erosion issues become more critical because coastal zones are optimal places for population concentration and the development of productive activities, such as, industry, transportation, tourism, etc. (Barragan and Andreis, 2015).

Adger et al. (2005) indicated that close to 20% of the world population (1409 million inhabitants) reside less than 25 km from the coastline, and 40% (2818 million inhabitants) live less than 100 km inside a coastal strip representing approximately 25% of the world total surface. From 1950 to the present, coastlines of the world have experienced rapid development with an annual average urban growth of 2.6% (UN-Habitat, 2009). For the same period the number of coastal cities has multiplied by 4.5 times going from 472 in 1950 to 2129 in 2015. It has been estimated that almost 30% of residences within 200 m along low coasts, may be severely affected by erosion-related property losses over the next 50 years (UN-Habitat, 2009).

One of the prerequisites for sustainable coastal development, on a national, regional or local scale, is adequate zoning and implementation of optimal coastal erosion management strategies (EU, 2004; Boruff et al., 2005; Pranzini and Williams, 2013; Rangel-

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Buitrago and Anfuso, 2015). The different strategies have become an issue of widespread worldwide concern. Unfortunately, most coastal erosion management decisions are conditioned by economic considerations manifested on an action-reaction basis (Rangel-Buitrago et al., 2015a,b) or a cost-benefit analysis approach (Cooper and McKenna, 2007).

Management strategies must include techniques, knowledge, equipment, and institutional instruments designed to minimize or eliminate coastal erosion related impacts. These must have an optimal benefit to reducing society's vulnerability due to coastal erosion hazards. Considering actual, and future climate change scenarios, management strategies must also allow coastal communities to minimize their detrimental impacts while benefitting from any potential positive consequences.

The typology of coastal management strategies approaches was first suggested by IPCC CZMS (1990) and includes four generic options:

- **Protect**: preserve vulnerable areas, especially population centers, economic activities and natural resources using hard structures and/or soft protection measures.
- **Accommodate**: persist in occupying sensitive areas, but accept a greater degree of flooding by changing land use, construction methods and improving preparedness.
- **Planned retreat**: remove structures in currently developed areas, resettle inhabitants and require that new development is set back from the coast, as appropriate.
- **Do nothing: (no actions planned)**.

It is important to note that coastal erosion management consists of more than just implementing one of the four interventions options. Coastal erosion management is a policy and implementation process involving general decision-making and technology application (Zhu, 2010) and the most successful management is integrated within the activities of all planning departments, rather than acted upon in an isolationist way (Tompkins, 2005).

Coastal erosion is a common problem affecting about 75% of the world's shorelines (Bird, 1985; Zhang et al., 2004; Pilkey and Cooper, 2014). This process has changed the Colombian Caribbean coast during the last 50 years bringing significant ecological impacts, high economic losses and socio-political problems (Rangel-Buitrago et al., 2015a,b). At least 50% (1182 km) of the Colombian Caribbean coast is facing severe coastal erosion (more than 1.5 m yr^{-1}), 32% (812.6 km) can be considered as stable, and only 18% (450.5 km) is accreting. Currently, coastal erosion produces not only beach loss but also a deterioration of scenic quality, that is becoming a problem that hinders economic growth of the country.

Recent history suggests that developed coastal management strategies for Colombia are designed to control and mitigate coastal erosion. This is achieved by protection based upon the construction of hard defense structures, a process known as coastline armoring (Griggs, 2005; Charlier et al., 2005). This is founded principally on an action-reaction, or post-disaster basis, entailing that initiatives are usually triggered by emergencies, not by prevention.

Over the last decade, the expanded level of coastal armouring and its negative influence has been seen as a critical problem along this coastline. Management strategies have involved traditional onshore structures that generate some adverse effects, such as:

- Accelerated bottom erosion in front of the hardstructures and downdrift scouring.
- Disturbance of sediment supply and beach reduction.
- Restricted public access.
- Potential risks for bathers.
- Aesthetic visual effects on the seaside landscape.

There are many examples where millions of dollars of public investment were urgently approved to mitigate erosion (Rodriguez-Ramírez et al., 2008; Botero et al., 2013a,b; Flor-Blanco et al., 2015; Rangel-Buitrago et al., 2015a). In most cases, these "coastal erosion solutions" were poorly designed and hurriedly constructed in order to reduce the erosion process impact generating an "express" coastal defense structure that was not fit for purpose. Despite the adverse effects, implementation of hard structures as protection measures against coastal erosion prevails. The above demands correct application of adequate management policies to preserve ecosystems as well as socio-economic activities.

This paper assesses the coastal erosion management strategies used along the Caribbean coast of Colombia by analysing the distribution, characteristics, and effects of hard protection structures, which seemingly are the only management strategy for erosion problems along the Caribbean coast.

Attempts to illustrate the role of national politicies and priorities represents a choice of existing and future coastal stabilization techniques. Results presented in this work are useful to local and national coastal managers and planners, who need coastal inventories based on ascertained facts in order to adopt sound management decisions.

1.1. The Caribbean coast of Colombia: regional setting

The Colombian Caribbean coast extends for 2445 km, between the E boundary with Venezuela and the W boundary with Panama (Fig. 1). Its general, orientation is NE − SW with some sectors oriented W-E so that long linear segments alternate with bays. This coastline is a complex region where tectonic processes have defined the actual topography with landscape units that include medium - high relief mountain areas and low relief deltaic plains (Correa and Morton, 2011; Rangel-Buitrago et al., 2013).

Quaternary interactions among tropical climate, oceanographic processes, and tectonic activity make a varied unstable littoral geomorphology characterized by beaches along the flat coastal plains, spits, and cliffed coastlines (commonly terraced) along the coastal rock areas (Martínez et al., 2010).

Seasonal precipitation shows two rain periods, i.e. April−May and October−November and two dry periods, i.e. November−April and July−September. Maximum annual precipitation values are *circa* 2500 mm, while mean monthly temperatures of <28° C, makes coastal environments attractive for tourism development (Rangel-Buitrago et al., 2013).

Tides are mixed semi-diurnal, with maximum amplitudes of 65 cm (Andrade, 2008). Average significant wave height fluctuates between 1 and 2 m and peak period average values vary between 6 and 10 s. From November to July, the wave system is dominated by NE swells; for the remainder of the time, waves from NW, WSW and even SW occur. This wave direction seasonal variation corresponds with a decrease in significant wave height, with the lowest values occurring between August and October (≤1.5 m); whereas highest energy conditions occur from November to July where wave heights can exceed 2 m (Restrepo et al., 2012).

Longshore sand drift has a dominant south-westward component, but minor reversals to the northeast occurs during rain periods when southerly winds become dominant in some sectors and set up short, high-frequency waves able to cause significant shore erosion along cliffed and mud coastlines (Correa and Morton, 2011).

2. Methodology

Mapping or indicating human modifications of the coast (coast-protection structures) is a vital element of identifying areas most

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