

Coastal erosion monitoring in Colombia: overview and study cases on Caribbean and Pacific coasts

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Abstract

Tourism is one of the fastest growing activities in Colombia; the coast represents the favourite destination for both national and foreign visitors. However, coastal erosion is an actual problem, with high erosive rates in some areas. This chapter shows a general overview of the coastal erosion problem in Colombia and emphasizes the institutional framework used in monitoring. Four study cases are included to present a wide diagnosis of relevant erosive processes, both on Caribbean and Pacific coasts. Findings show erosive rates due to human interventions in all coastal departments on the Caribbean Sea; highest values were recorded in Cordoba (3.3 m/yr), Magdalena (5.3 m/yr) and La Guajira (3.2 m/yr). In addition, monitoring of barrier islands indicated that erosive processes on the Pacific coast are essentially due to natural phenomena, i.e. tsunami and El Niño events. In conclusion, long-term coastal erosion monitoring is urgently required in order to make adequate decisions and assess their effectiveness, with special concern to the correct location of coastal infrastructure and the management of coastal risks.

Introduction

Human occupation along the world's coastlines has been increasing in the past decades especially due to coastal tourism-related activities, which emerged as one of the largest industries in the world (Jones and Phillips, 2011).

Spain plus Italy, France, Greece and Turkey account for 'the most significant flow of tourists... a sun, sea and sand (3S) market' (Dodds and Kelman 2008); tourism is expected to grow at a rate of 4.0 % per year over the next ten years.

In the Caribbean countries, tourist arrivals have increased fivefold, from 166 million in 1970 to 935 million in 2010. Cruise arrivals grew more rapidly over the same period increasing from 1.3 in 1970 to 20 million in 2010 (CTO, 2011). Barbados beaches are an example, where cruises contributed to the local economy with more than US\$13 million in 2010 (Dharmaratne & Braithwaite, 1998).

On the other hand, despite the fact that Colombia has been affected by a number of social, political and security problems that have limited coastal tourism development, it currently record an average revenue per arrival of 1,500 US\$/per tourist (UNWTO, 2008).

Hence, due to the actual degree of coastal tourism development and its continuous growth, all environmental impacts on coastal areas are very important and may acquire further significance in future years especially when associated to climatic change processes, e.g. increase in storminess and sea level rise (Jones and Phillips, 2011). Despite causes of coastal erosion, littoral retreat always corresponds to flooding and/or beach and dune erosion. Such processes do not only affect or threaten beaches, which are worth billions of tourist dollars (Clark, 1996), but also human activities and infrastructure, becoming in this sense natural hazards.

Characterising natural coastal dynamics, behaviour and trend are a basic preliminary step in order to minimise beach erosion. Shoreline position fluctuates in a variety of time scales, a behaviour that introduces many difficulties when reconstructing medium-term coastal trends. In fact, variability in coastline position may be the response to a single factor or to a combination of factors. Main causes of coastal erosion or accretion include individual large storm events or tsunamis, seasonal variability in wave energy, multiyear to decadal-scale variations in storminess, wave energy and coastal morphodynamics, and long-term variations in the relationship between climate and sediment supply (Forbes et al., 2004; Zhang et al., 2002; Orford et al., 2002).

In this sense, coastal studies and particularly monitoring programmes acquire the utmost importance. Specifically, coastal changes are surveyed using a wide variety of methods and datasets according to the time spans of the study. Studies on short-term shoreline dynamics are usually carried out at small spatial scales, in a time span less of than 10 years (Crowell et al. 1993). The most common technique used is beach topographical profiling or 3D survey, repeated at regular intervals, in order to measure daily to annual variations in shoreline position and beach volume. Most used tools are the theodolite, total station, DGPS and terrestrial LIDAR ("Light Detection and Ranging").

Vertical aerial photographs, satellite imageries, maps and charts all represent a very useful tool to reconstruct coastline changes at long (>60 years) and medium (between 60 and 10 years) temporal scales (Crowell et al., 1993), and large and medium spatial scales; in addition, they also display coastal type distribution, land uses and dune field evolution. The precision and accuracy of aerial photogrammetric measurements depend on their own characteristics (Moore, 2000) and on the difficulties of locating shoreline position, typically taken as the high water line or identified in mesotidal environments as being the seaward vegetation limit, dune toe or cliff top. Over the last two decades, airborne laser ("LIDAR") surveys have been largely developed and used in coastal morphological studies (Robertson et al., 2007). This remote sensing technique, usually carried out from a small aeroplane, allows detailed 3D surveys to be undertaken, but its application is limited due to rather expensive costs.

Institutional framework of beach erosion monitoring in Colombia

Competences in Colombia concerning coastal erosion monitoring are not very clearly distributed and there are several institutions in charge of this issue. The main bodies are the Maritime General Direction (DIMAR - its acronym in Spanish), the Colombian Oce-

anic Commission (CCO) and the Ministry of Environment and Sustainable Development (MADS). Despite the existence of these authorities, advances in coastal erosion monitoring started only five years ago and results are still partial, especially considering the magnitude of erosive processes recorded in the Caribbean and Pacific coasts.

The main institution with competences in coastal issues is DIMAR, which was created in 1984 as the national maritime authority, according to Law 2324. In spite of the new challenges in coastal management, administration of common goods in coastal areas is among the DIMAR responsibilities that have not changed during the past 28 years. In fact, several themes as climate change, sea level rise, coastal erosion and beach tourism are not yet among the responsibilities of DIMAR.

With regard to the decision making process DIMAR is supported by two research centres, one on the Pacific coast (CCCP) and one on the Caribbean coast (CIOH). Both of them have research programmes in coastal management and geomorphologic issues but unfortunately most of the results obtained are published only in Spanish or are not accessible at all. Another important effort made by this institution was the use of LIDAR technology to scan all the coastline of Colombia during 2005 to 2007; unfortunately, access to this information is not possible, due to national security restrictions. Finally, DIMAR is part of the Navy and thus a highly centralised organisation; this point favoured the protection of the coast from short-term developments, but on the other hand they often took too much time in decision-making (Avella et al, 2009).

A second institution deeply related to coastal issues is the Colombian Oceanic Commission (CCO). It is composed by 14 ministries and 4 national level institutions, led by the Vice-president of the Republic; it is therefore the highest level arena for decision-making on oceanic and coastal themes. The more remarkable achievement of CCO was the National Oceanic and Coastal Areas Policy, approved in 2008, although its implementation is currently less effective than expected. The highest level of this commission is a consultancy and advisory board and its decisions constitute only guidelines that can be easily disregarded (Avella et al, 2009).

The third institution is the Ministry of Environment and Sustainable Development (MADS) which was created in 1993 and underwent two structural reorganisations (in 2003 and 2011). Since its creation, this ministry has never been a single division or department in charge of oceanic and coastal issues. Only in 2012, after the last reorganisation, a department of marine environment was established in the third hierarchical level. In spite of that, the Integrated Coastal Management Policy was approved in 2000, and was economically supported by a specific budget established by National Government; unfortunately, this Policy is currently much less applied than expected.

Within this institutional framework, the coastal erosion monitoring has been a frequent issue, but no one has legal responsibility for its implementation. The main development has been the National Programme for Research, Prevention, Mitigation and Control of Coastal Erosion in Colombia (Guzman et al., 2008), established for the 2009 – 2019 period and led by INVEMAR, a national research centre in marine issues linked to MADS. In this programme there are five clear goals for coastal erosion monitoring, three of which were to be reached before 2011 - no information is available to check their level of implementation. The importance of coastal erosion monitoring in Colombia relates to four main issues: Tourism, Risk Management, Urban Population and Infrastructures. Tourism is of increasing

interest in Colombia, as the country aims at developing the “3S” market as an engine to local economies. In 2010, the Ministry of Trade, Industry and Tourism created the public position of ‘National Beach Manager’, who should be in charge of developing a National Policy of Beach Tourism; this effort has been joined by several projects financed by the National Tourism Fund (Botero and Sosa, 2011). However, coastal erosion is never mentioned in such initiatives, forgetting that it constitutes the main threat for the “3S” market.

The other three issues have a similar axis: contingency. Unfortunately, initiatives to control coastal erosion in Colombia have been triggered by emergencies, as the well-known “km 19” case in the highway between Barranquilla and Santa Marta, two of the biggest cities on the Caribbean coast. In 2010 storm waves reached a line just a few meters from the highway and a multimillionaire public work was urgently approved to control increasing erosion; concrete blocks were emplaced in front of the highway to reduce wave impact, although public knowledge about the success of this project is still unknown. It is a precise example of coastal erosion management within an institutional framework where nobody is directly in charge of it.

It is also important to underline the existence of a monitoring programme carried out by INVEMAR from April 2009 to April 2011 in the Caribbean and Pacific littorals of Colombia. The main objective was to understand geomorphologic, tectonic and in general terms geologic and climatic characteristics of the littoral in order to review and adjust the existing legal regulations to coastal management. The main achievements have been the realisation of eight workshops, the elaboration of a basic legal regulation document and a conclusive report.

Coastal trend in the Caribbean Sea and in the Pacific Ocean

A total amount of 4.5 million inhabitants (DANE, 2010), e.g. 11% of national population, lives along coastal areas of Colombia. This includes 46 coastal municipalities: 30 along the Caribbean Sea and 16 along the Pacific Ocean, grouped in thirteen territorial units called ‘Departments’ (Figure 1). Such municipalities have significant land resources and natural ecosystems which represent the base of important economic activities. In spite of that, development of many coastal towns was not in accordance to natural resource distribution and coastal processes. This led to high environmental impact of natural processes (coastal erosion, flooding, etc.) on the quality and availability of marine and coastal resources, quality of human life and economic development of coastal areas (CONPES, 2002).

The study and understanding of coastal erosion in order to control, counteract, prevent and mitigate its negative effects on the littoral should have therefore become an imperative issue, of national importance, in Colombia. Specific studies carried out by government authorities and universities have demonstrated that erosion processes have increased significantly in past three decades. Representative cases are observed in the Department of Córdoba and in the Urabá Gulf. At Urabá many square kilometres of land devoted to agricultural and livestock areas were lost at Turbo River mouth (CORPOURABA-UNAL, 1998) and at Arboletes, between the Departments of Córdoba and Antioquia (Correa et al., 2007). Close to Cartagena city, coastal erosion degraded marine seaweeds and coral reefs (CARDIQUE, 1997; INVEMAR, 2005). In the Department of Atlántico, coastal erosion was enhanced by the contraction of a jetty at the mouth of River Magdalena and natural ecosystems were largely damaged at Mallorquin coastal lagoon and in the littoral spit of Galerazamba (Correa et al., 2005; INVEMAR, 2006).

In the Valle del Cauca, the most important tourist centres such as Juan Chaco and Ladrilleros have been affected by coastal erosion, especially along sectors characterised by cliffs consisting of very vulnerable sedimentary rocks. Furthermore, sea level rise linked to El Niño phenomenon caused the disappearance of large extensions of land in barrier islands and beaches; it also caused eroded sediments to be deposited in the nearshore area, forming sand bars that constitute a problem to fishing activities and navigation (INVEMAR, 2006). Coastal erosion also affected Colombian islands: threatened areas can be observed at San Andres and Providencia islands (Posada and Guzmán, 2007). Four study cases will be presented, three on the Caribbean Coast (A) and one on the Pacific shores (B). Finally, erosion processes reduced beach width and induced the construction of different structures. Examples can be seen at Santa Marta, Cartagena de Indias, Tolú and Turbo, where high erosion rates were counteracted in the past decades by the progressive and disorganised emplacement of numerous groins and, secondarily, seawalls and rip-rap re-ventments (Rangel et al., 2011; Stancheva et al., 2011).

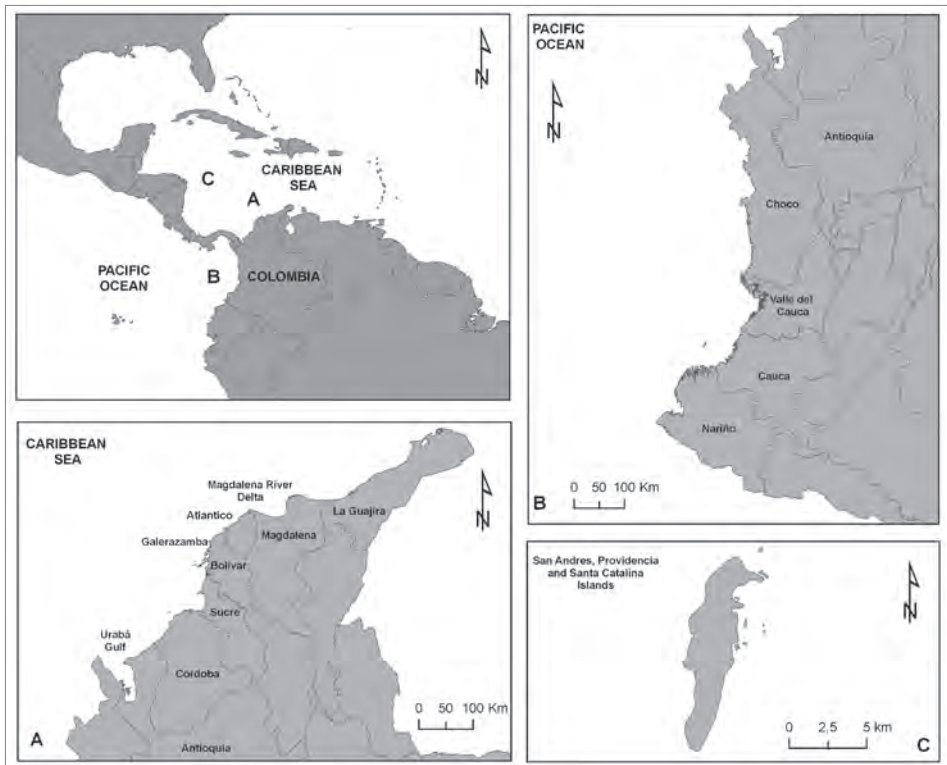


Figure 1 - Study area with the Caribbean (A), Pacific (B) coast of Colombia and Islands of San Andres, Providencia and Santa Catalina (C).

Coastal erosion overview in the Department of Cordoba

The Department of Cordoba is located in the SW part of the Colombian Caribbean littoral. The coastline is composed by sandy beaches and cliff sectors developed along numerous

“log spiral” bays formed downdrift of rocky headlands linked to structural faults and/or diapiric volcanoes (Correa et al., 2007).

The analysis of shoreline changes clearly evidenced severe erosive processes (Figure 2).

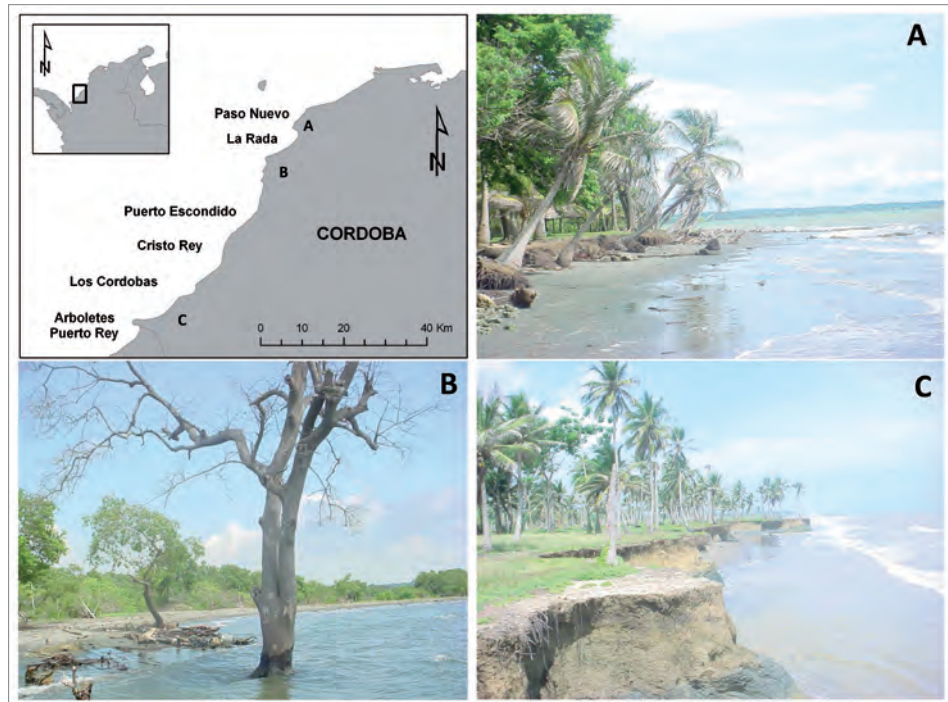


Figure 2 - Erosion examples at Cordoba department (Caribbean coast). Vegetation destruction at Paso Nuevo and La Rada villages (A and B). Cliff erosion at Los Cordobas (C).

In the southern part, e.g. the Arboletes-Puerto Rey sector, land loss recorded average retreat values of 60-100 m during the past 80 yrs, with peak values of 1.5 km at Puerto Rey where the morphological point of Arboletes totally disappeared (INVEMAR, 2003; Mazorra, 2004; Correa et al., 2007).

Mazorra (2004) and Correa et al., (2007) identified high erosion rates between Puerto Rey and Punta Brava linked to retreat values of 93 m (for the period 1938 – 2005), at the Los Cordobas river mouth and values of 220 m (for the 1938-2005 period) close to Punta Brava, e.g. retreat rates of 1.4 m/yr and 3.3 m/yr respectively. In the central sector of the Department, between the coastal villages of Puerto Escondido and Cristo Rey, retreat values of 63 m between 1938 and 2005 (e.g. 0.97 m/yr) were observed. Similar values were observed by Mazorra (2004), Correa et al., (2007) and Gonzáles (2007) at Puerto Escondido (0.62 m/yr). In the northern part of the Department, between the coastal villages of La Rada and Paso Nuevo, along a sector of circa 8.5 km long, about 138 m of land (2.12 m/yr) were lost between 1938 and 2003 (Rangel & Posada, 2005)

Coastal erosion overview in the Department of Magdalena

The coastline of the Department of Magdalena is essentially formed by cliffs located at the base of the *Sierra Nevada de Santa Marta* (SNSM), a mountain chain limited northward by the Oca fault and composed by different geological units ranging in age from the Precambrian to the Neocene.

Shoreline variations were obtained by means of aerial photographs from different years (1954, 1978, 1991, 1995 and 2004). At the city of Santa Marta, retreat recorded maximum values of 23 m, e.g. 1.7 m/yr (between 1991 and 2004). Maximum retreat values (61 m, 2.53 m/yr) were recorded between 1954 and 1978; during the 1978-1991 period, maximum retreat was recorded south of Punta Gloria, with values of 77 m, or 5.3 m/yr (Figure 3). There are no data available for the sector between San Juan and Punta Betin, but erosion, particularly affected rocky headlands along the coastline of Tayrona Natural National Park (Figure 3). The Guachaca - Cabo San Juan sector recorded, during the 1958-2004 period, maximum erosion of 10 m (0.4 m/yr) at the Piedra River mouth (Rangel & Anfuso, 2009a). Coastal changes along the sector between Los Muchachitos and Palomino were investigated through the use of 1958, 1979 and 2004 aerial photographs. Maximum erosion (3.2 m/yr) was recorded east of Palomino, at San Salvador, and maximum accretion (0.16 m/yr) was observed west of San Agustin headland. Specifically, in the 1958-1979 period, maximum retreat occurred at San Salvador (almost 100 m coastal retreat, e.g. c. 4.6 m/yr). In the 1979-2004 period, maximum erosion was 73 m at Palomino coastal village. No quantitative data are available for the Los Muchachitos cliff sector but there is plenty of evidence of a severe coastal retreat process (Figure 3).

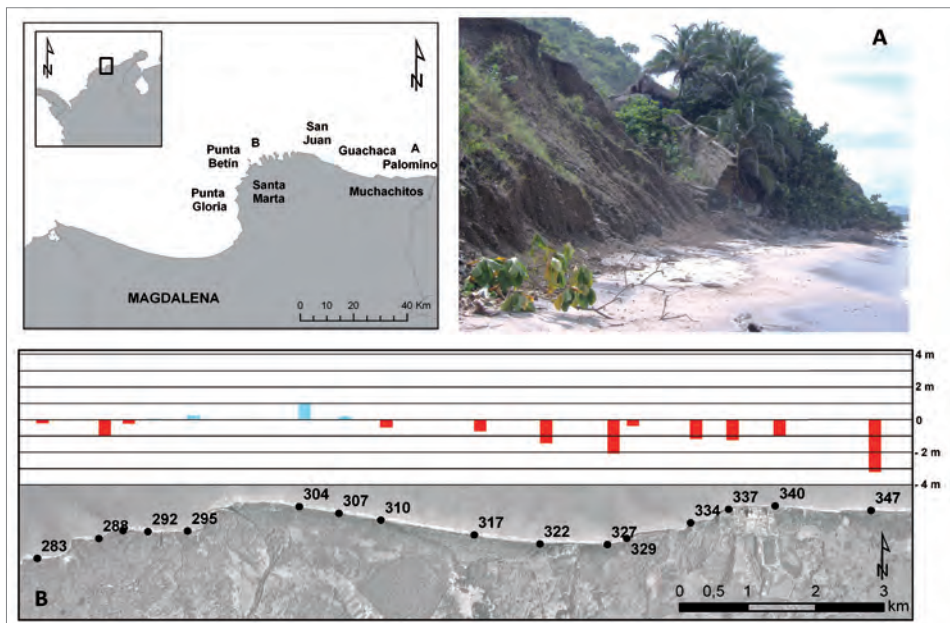


Figure 3 - Coastal erosion at Magdalena department (Caribbean coast). Cliff erosion and house collapsing at Los Muchachitos area (A) and erosion rates at Palomino (B).

Coastal erosion overview in the Department of La Guajira

This Department is located in the northeastern part of Colombia; it consists mainly of a peninsula with beaches, dunes, cliffs and coastal lagoons at sites used for salt harvesting. From an administrative perspective, it includes the coastal municipalities of Dibulla, Riohacha, Manaure and Uribia.

Maximum erosion and accretion rates were respectively recorded west of Dibulla (3.23 m/yr) and at Ancho River (1 m/yr). Considering the 1958-1979 period, 65 and 13 m of coastal erosion were respectively observed. For the 1979-2004 period, maximum erosion was near 40 m, with erosion rates of 1.5 m/yr (Rangel & Anfuso, 2009b).

At Riohacha municipality, which includes a deltaic system and coastal lagoons, erosive rate of 1.85 m/yr were recorded, e.g. c. 105 m in 57 years (Figure 4).

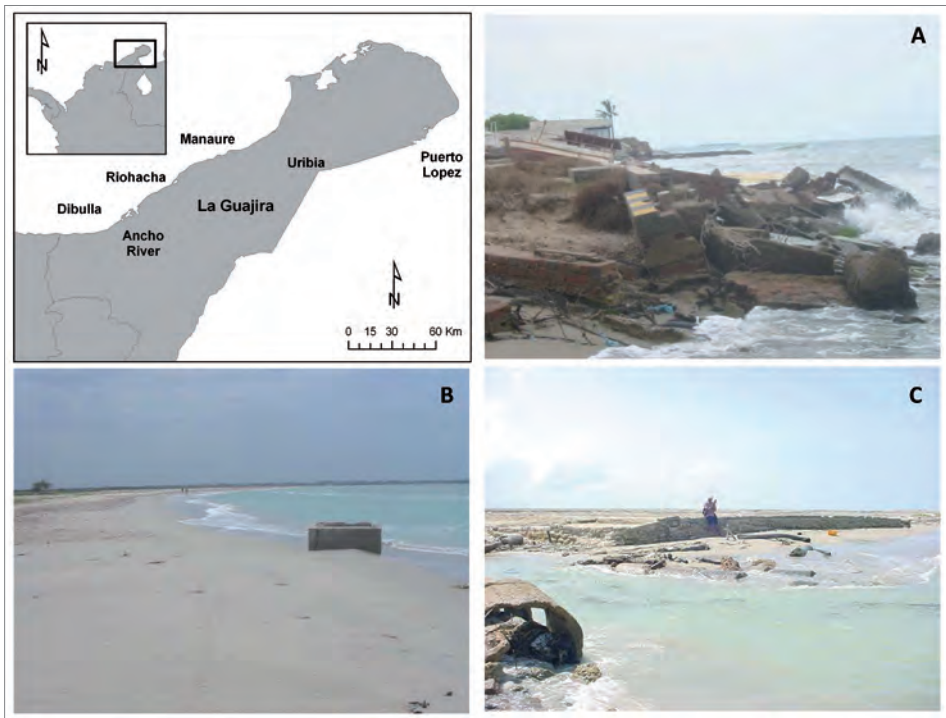


Figure 4 - Erosion at La Guajira department (Caribbean coast). Collapsing of human structures (A) and erosion of a natural beach (B) at Riohacha. Collapsed structure at Manaure (C).

In the municipality of Manaure, the beach accreted 34 m in 32 years (e.g. c. 1.5 m/yr) and a similar trend (c. 95 m in 32 years, e.g. 2 m/yr) was recorded at Puerto Lopez village (Rangel & Anfuso, 2009b).

Coastal erosion monitoring of barrier islands along the Pacific coast

Located just eastwards of the subduction zone of the Nazca plate under the South American plate, the Pacific coast of Colombia is a humid tropical region with mean temperatures

about 27°C and annual rainfalls between 3 and 10 m/yr (West, 1957; Velez et al., 2001; Correa and Restrepo, 2002; Correa and Morton, 2011a, 2011b). It is a tectonically active, high-seismic risk region with a present coastline of circa 1300 km, between Punta Arditá (Colombia-Panama border) and Cabo Manglares (at the Ecuadorian border) (Duque-Caro, 1990; Paris et. al, 2000; Cediél et al., 2003). The Pacific coast is mostly a low-developed, difficult access and relatively pristine region, proverbial for its luxuriant vegetation and natural beauties, and with a high potential for future development, including touristic activities. High water discharges and sediment supplies derived from the adjacent Andes of Colombia combined with meso- to macro-tidal ranges and medium wave energy in the late Holocene caused the formation of numerous, extensive fluvio-deltaic plains dominated by sandy barrier islands and ebb tidal deltas, funnel-shaped coastal lagoons/estuaries and wide muddy tidal flats vegetated by species of mangrove ecosystem penetrating in some places up to 30 km landward from the present coastlines (Martínez et al., 1995, 2000; Correa and Morton 2011a, 2011b).

Detailed studies of the geomorphology and historical evolution of the Pacific coast of Colombia began in the past two decades and were driven in part by the urgency of assessing the medium term morphological response of the littoral zone to the effects of shallow-depth, historical high magnitude seisms. – from which the most famous were the 31 January 1906 (M 8.8) and the 12 December 1979 (M 6.5) Tumaco earthquakes (West, 1957; Herd et al., 1981, González and Correa, 2001).

The 31 January 1906 event is considered as one of the six strongest seisms in the world (M 8.8) and affected around 300.000 km² of the (at the time) almost undeveloped coastal zones of northeast Ecuador and southern Colombia; there were approximately 400 human casualties related to the impact of a 5 m high wave tsunami that barred the littoral zone and penetrated the coastal land as a wave bore, reaching further than 15 km inland, through the interconnected tidal channels and creeks (Ramírez, 2004). The 12 December 1979 earthquake (M 6.5) had its epicentre 50 km northwest of Tumaco and generated at least 3 tsunami waves that hit the southern Colombian Pacific coast killing approximately 150 persons at San Juan de la Costa Village, a developing centre located on a frontal barrier island 60 km north of the Tumaco bay (Herd et al., 1981). Coseismic subsidence values estimated along the littoral zone for above seisms range between 20 and 160 cm, well enough for accelerating pre-existing erosion trends or triggering erosion in new sites, along the southern Pacific coast of Colombia. Tumaco city (at the southern tip of the Tumaco bay) has had double fortune: it is fronted by extensive offshore sandy barriers that caused tsunamis waves to break some hundreds of meters offshore and these waves arrived during low tide, in a zone where a tidal range is 3.5 m.

Events like the above mentioned (and more recent coseismic subsidence related to non tsunamigenic, modern seisms) have strongly influenced the progressive erosion and rapid thinning of the longest barrier islands of the Pacific Coast of Colombia considered appropriate for future coastal and tourism development.

The largest barrier islands on the Pacific coast are typically multiple beach ridge sandy-muddy deposits, currently 12-14 km long and 4-5 km wide, whose formation began around 500 yr B.P. according to radiocarbon dates obtained at the El Choncho barrier island, San Juan River delta (González and Correa, 2001; Correa and Restrepo, 2002) (Figure 5). Both this barrier spit and the spit of San Juan de la Costa (Patia River delta, Figure 6a) were

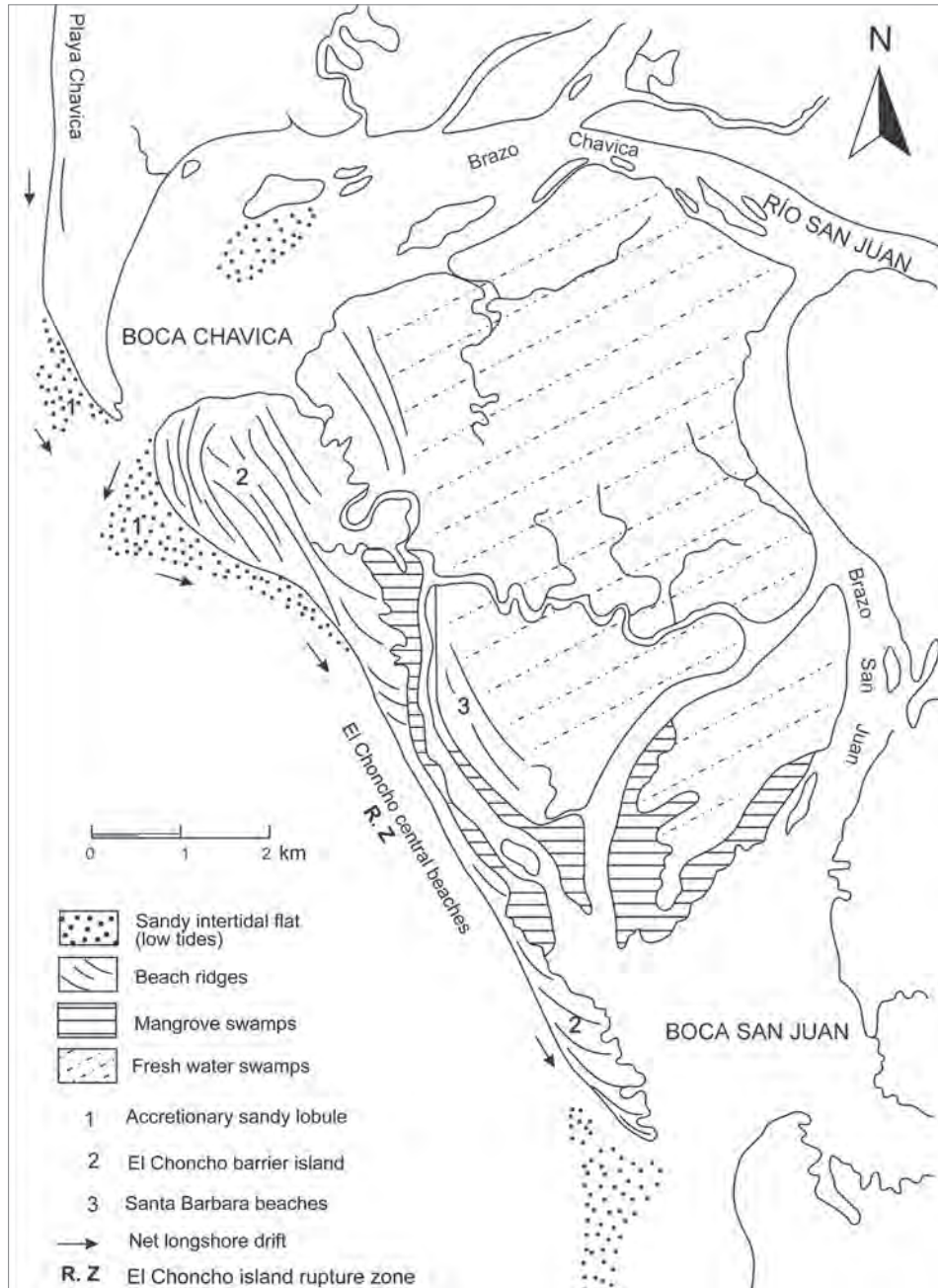


Figure 5 - Geomorphological map of the southern lobule of the San Juan River delta and location of El Choncho barrier island.

studied in detail to establish the possible causes of their definitive rupture (breaching) that took place between June and September of 1996 (Morton et al., 2000). Based on the



Figure 6a - Aerial photograph showing the rupture zone of El Choncho barrier island (August 1998).

inventory of coastline changes, elaborated further to aerial photographs, radar images and planimetric surveys dated 1968 – 2004, we conclude that breaching and segmentation of these barrier islands result from the combined actions of three different natural processes that included, in sequential order:

- the progressive starvation of sand in the central shores of both barriers islands due to the formation of extensive sandy intertidal deltas along updrift areas, which reduced significantly the longshore transport of sand to the distal parts of the islands and consequently triggered net erosional trends of approximately 1m/yr in these shores.
- the coseismic subsidence of the islands, associated to the December 12 earthquake in the San Juan de la Costa barrier island (1.5 m subsidence) and to the November 12, 1998 earthquake in the El Choncho barrier island (estimates subsidence of 0.3 m at the central part of the island). Coastal subsidence of both islands caused a sharp increase in the number of yearly inundations of its central segments (coinciding with the highest annual tidal amplitudes in March and October) that rose from 2 to 14 (approximately one flooding per month) at the El Choncho barrier island. A rapid increase in the already existing shoreline erosion trends was also observed.
- positive mean sea level anomalies of 20-30 cm along the Pacific coast of Colombia caused by temperature anomalies of 3 to 4°C during the El Niño 1997-1998 event. High water and wave levels during the highest tides of this period caused extensive overwash events along the central parts of the islands and determined their definitive segmentation by widening the pre-existing small channel formed in June 1996 which rapidly evolved to a conspicuous tidal channel tens of meters wide and over 5 m depth.

Further observations and research based on comparisons of historical remote sensing materials have evidenced similar rupture patterns for other barrier islands of the Pacific coast

of Colombia, namely several islands located between the border with Ecuador and Tumaco



Figure 6b - The New Choncho village, relocated inland of his former location, on the Santa Barbara beaches, an ancient barrier.

bay. New elements related to littoral hazards and vulnerability have thus emerged and enhanced the importance of considering medium to long term evolution of barrier islands, particularly when future sea level rise is considered. Of special interest has been the positive response of barrier island inhabitants to the relocation of coastal villages landward from the actual beaches and promoting their adaptability to changes by constructing their houses entirely in wood materials (Figure 6b).

Conclusions

According to the findings of this study, it is evident that Colombian beaches are being widely impacted by coastal dynamics and in many cases locally by the inadequate development of different kinds of human structures constructed in the past decades. However, coastal tourism is currently one of the fastest growth economic activities in Colombia, as this is the fifth country in Latin America with the maximum average revenue per arrival.

The four study cases shown in this document give a clear overview of the intense erosive processes that occur along the Caribbean and Pacific littorals of Colombia. Nevertheless, the causes of coastal erosion on each coast are different. On the Caribbean coast, several studies carried out by universities and research institutes evidence coastal retreats of 1.5 km in the last 50 years in points as Punta Rey (Department of Cordoba), with maximum erosion rates ranging from 3.2 m/yr to 5.3 m/yr. Human interventions, such as jetties, breakwaters and groins, become the main reasons for current erosive processes.

On the Pacific coast erosion processes are essentially caused by natural reasons. In spite of environmental impacts due to Buenaventura and Tumaco cities (which sum together almost half million inhabitants), human impacts along the Pacific littoral are not important because of the small human pressure. The main causes of coastal erosion are due to natural progressive sand starvation, coseismic subsidence and sea level anomalies.

Concerning the response of policy-makers and managers in Colombia to coastal erosion, short-term and punctual human interests prevailed on long-term strategic goals despite the fact that ICZM general principles should prevail over local ones. Many examples on the Caribbean coast prove that coastal infrastructures have been more of a problem than a solution. Furthermore, the relationship between scientists and managers is very weak in Colombia; The National Program for Research, Prevention, Mitigation and Control of Coastal Erosion is hardly in its first stages of implementation.

Stable and long-term coastal erosion monitoring does not exist and for this reason is not possible to evaluate the consequences of the decisions adopted. Nowadays, some improvement can be seen due to the development of environmental studies, collaborations with research entities and the elaboration of general ICZM guidelines at a regional and national level. Information already obtained with 'LIDAR' technology could be a crucial input

for future monitoring, but first a harmonic institutional framework should be developed to support data acquisition and analysis.

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