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HYPERANNUAL MORPHODYNAMIC CHANGES (1951-2007) OF THE SHORELINE BETWEEN DIAMANTE HEADLAND AND PAPAGAYO RIVER, ACAPULCO, MEXICO

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Coastal morphological changes are of increasing concern today. Among the studied aspects are the effects of climate change and sea level trends (IPCC, 2013); coastal variability (Morton *et al*., 2005); coastal hazards (Froede, 2006; Márquez *et al*., 2010); coastal vulnerability (Boruff *et al*., 2005; Thomas-Bohorquez, 2013); beach regeneration (Hernandez and Reyes, 2002); municipal coastal management (Moreno *et al*., 2005); morphodynamic changes at the national, regional and local levels (Juanes-Martí, 1996), and the management of the coastal areas (Barragán, 2003). In Mexico there are studies on the dynamics of the coastline in relation to sediments, and the extent of the morphodynamic variations along both the Gulf of Mexico and the Pacific coastlines (Ortiz and Mendez, 2000; Hernández-Santana *et al*, 2008).

This work deals with the historical morphodynamic changes of beaches on the southern Mexican Pacific coastline, along the eastern side of the municipality of Acapulco. Through the analysis of aerial photography and maps spanning 56 years, from 1951 to 2007, the environmental and socioeconomic processes leading to their present morphological conditions, and the extent of human agency are assessed.

The study area is a 26-km long cumulative coastline extending south-southeast from Punta Diamante to the Papagayo River mouth (16° 41' 03'' and 16 ° 47' 2'' N; 99° 36' 33'' and 99° 49' 32'' W). Its geology consists of gneisses and schists, interrupted by granites and granodiorites (Consejo de Recursos Minerales, 1999) with an overlapping of Quaternary deposits. Its geomorphology is a series of polygenic cumulative flat plains, all severely altered by human settlements, tourist resorts and agricultural plots.

The climate is warm subhumid with low humidity and an average annual rainfall of 2,033.2 mm during summer (García, 2004). Prevailing winds are from the West and North with an average speed of less than 10 m/s. The main watershed and source of sediments for the local beaches is the Papagayo River basin, with an area of 7,410 km^2 and a mean annual runoff of 3,926 m^3 907.1 (SEPLAP, 1985; Conagua, 2011).

This coastal area stands out for its high waves (between 2 and 3 m high) with wavelength periods of between 12 and 15 seconds (Flamand, 1991). The tide is of the semidiurnal mixed type, with an interval range of less than 2 meters (SMN, 2013). The main streams run towards the NW, reaching speeds of up to 0.5 m/s (Pacheco, 1991; Vázquez *et al*., 1998).

The demography of the municipality of Acapulco has changed significantly since the second half of the Twentieth century, mostly as a result of the development of tourism. This is especially true at the municipal capital, the port of Acapulco, which concentrates about 85% of the total municipal population (789,971 inhabitants) (INEGI, 2011). It is estimated that 51.6% of the population of Acapulco live in poverty.

Although the tourism industry remains the main factor attracting immigrants from the rural areas, it cannot provide sufficient jobs for a steadily growing population. According to INEGI (2011), the total economically active population is 323,429 people, of which 55.2% work in the tourism sector, including accommodation, transportation and other services. In 2010, there were 245 hotels, which housed 4'890,456 tourists, 97% of which were nationals or residents in the country, and the rest came from abroad. This made Acapulco the second most visited tourist destination in Mexico (INEGI, 2011).

This study features a threefold methodological approach: 1) morphogenetic classification of the coastal landforms; 2) identification of trends through historical analysis of the behavior of the coastline through time, and 3) an assessment of current beach conditions. Morphogenetic classification was based on Digital Terrain Models with data obtained from LiDAR (INEGI, 2008), with a spatial resolution of 5 meters and a vertical resolution of 1 meter, having as a reference the Acapulco map sheet 1:250,000 (Servicio Geológico Mexicano, 2000). Coastline changes through time were determined using aerial photographs 1:30,000 with a pixel resolution of 10 m (ICA, 1951), as well as orthophotos 1:20,000, with a resolution of 2 m (INEGI, 1995), and orthophotos at a scale of 1:10,000, with resolution of 1 m (INEGI, 2007).

A detailed morphogenetic and geomorphological survey of the area under study was carried out based on the methodological criteria followed by Hernández-Santana *et al*. (2015) in their study of the coastal areas of Veracruz: 1) Morphometric interpretation of land forms; 2) Identification of morphogenetic types; 3) Comparison of geomorphologic with geologic data; 4) Analysis of terraces and other land forms characteristic of the plains system, including fragments; 5) Review of the existing literature and cartography; 6) Fieldwork method.

Fieldwork and sampling were carried out at Stations 1 to 12, from Punta Diamante to the mouth of Río Papagayo, including multiple transversal transects. Also, a morphometric analysis of landforms and of the local environmental characteristics was undertaken.

Morphodynamic shoreline rates were obtained using the Digital Shoreline Analysis System (DSAS) version 3.0, with ArcGIS software v. 9.3 (Thieler, 2005), which simplified the calculating process. Cartographic materials were then organized into three time frames:

1951, 1995 and 2007, so as to have two periods for comparison: A 44-year period from 1951 to 1995, and a 12-year period from 1995 to 2007.

Calculation of coastal erosion and progradation rates was undertaken as per the End Point Rate (EPR) method, so as to obtain an annual average rate. This method consists in selecting two representative shorelines for comparison, one older and one recent. The distance between them is then divided into the number of years separating them in time. In order to obtain detailed local trends, transects were placed at every 10 meters.

Initially, the measurement stations for the morphometric and morphological beach profiles had been placed at equal distance from each other, but as some of them fell into private property and were therefore inaccessible, they had to be relocated to beach areas with unrestricted access. The profiles contain information on slopes, surface inclination angles and distances between morphological elements. To calculate these values, a clinometer SUUNTO TANDEM, a 50-m long measuring tape, a level staff and a Garmin GPS III+ with a 5 m precision were used. At each station the current state of the dunes was evaluated.

Beach limits were defined using the high tide line as their lower end, and the crown of a dune or the existing constructions on the beach as their upper end. The degree of human impact and its effects were evaluated at each station.

Given the variations in the occupation of the beaches, as well as in the extent of their modification by human agency, the coast was divided into two sectors: A North-Northwestern Sector, from Punta Diamante to the 'Three Lives' Golf Club (Stations 1 through 6), and a South-Southeastern Sector, from the golf course to the mouth of the Papagayo River (Stations 7 to 12). This allowed for a more detailed analysis, in which the differences in the spatial patterns of erosion/progradation became evident.

The results showed an average total progradation of beaches of +74.46 m during the 44-year long period (1951-1995), a largely homogeneous trend along most of the coast, with values ranging between +50 and +120 m. However, at the Papagayo River delta frontline it totaled +360 m as a result of constant sediment supply from the same river. Drift rates for this period range from a minimum of +1.05 to a maximum of +7.94 m/year. These values mean that for the first period of analysis, the coast maintained a relatively high and stable progradation rate, with maximum values at the extremes of the study area.

However, approximately 70% of the transects showed negative shifting values during the more recent 12-year period (1995-2007), ranging from -72.61 m to +45.79 m, with an average value of -13.16 m. It is significant that the maximum value of this more recent period equals the minimum value of the first period of analysis. Erosive trends dominate much of the beaches with maximum and critical values at the northern portion, with maximum displacement rates of +3.7 m/year in areas of progradation and -6.0 m/year in areas of erosion, yielding a mean value of -1.06 m/year.

Conclusively, the lack of proper land planning and integrated management of the coastal area of so-called Acapulco Diamante has led to a disorganized and oversized tourism and urban development, totally at odds with the structure, functioning and dynamic processes of the surrounding natural systems. This lack of vision is evident in the deterioration of beach profiles along much of the coastline, resulting from severe human modification of coastal ecosystems.

The degradation of coastal natural landscapes is also linked to the intensive urbanization that has spread along the coast. In the North-Northwestern Sector of the study area, urban

expansion operates more rapidly and greedily, in the form of large hotel complexes and residential areas, while in the South-Southeastern Sector, human settlements tend to be rustic and there are even areas still devoid of them.

The morphodynamic analysis of the beaches at different time intervals led to average annual variation values of coastal erosion and progradation during the past 56 years. The zoning of the coastal area in a north-northwestern and a south-southeastern portions allowed for the comparison of these variations (1951-2007) under different conditions of socioeconomic pressure, revealing the close correspondence between morphological and environmental changes in beaches, and trends of erosion and/or progradation of the coastline.

This was confirmed by some of the profiles obtained at the selected stations, where current coastal erosion trends were found at sites with significant changes in the beach-dune-eolic-marine plain system. Negative environmental trends and beach erosion are a recent phenomenon, with higher losses and irreversible changes occurring in the last 12 years (1995-2007), in coincidence with the splendor of the urban and tourist growth.

Three zones of maximum erosion have been identified: a) At Punta Diamante, south-southeast of Station 4, beaches show the greatest loss in recent years due to the expansion and unlimited exploitation of large hotel complexes and their remoteness from the Papagayo River, their main source of sediment; b) At the Golf Club 'Three Lives' construction of the sports infrastructure has led to the loss of beaches, dunes showing a completely modified profile and remaining now exposed to sustained erosive action; c) At The Papagayo River mouth progradation has been reversed in the last decade, possibly as a result of the reduction in the river's sediment load due to the construction upstream of the hydroelectric 'General Ambrosio Figueroa'.

Except for the Papagayo River environment, the greatest coastal erosion has taken place at those beaches where tourism-related activities have brought about significant morphological changes resulting in the loss of land, and rendering beaches more vulnerable to damages by extreme hydro meteorological events such as storms, tropical cyclones, hurricanes, surging waves and others. This may contribute to rising sea levels in the short or longer term, in relation to climate change. It is therefore urgent to protect coastal natural environments and reserve these areas for sustainable tourism based on optimal planning and an appropriate integrated management.