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Human impacts quantification on the coastal landforms of Gran Canaria Island (Canary Islands)

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ABSTRACT

The coastal areas of the Canary Islands are particularly sensitive to changes, both from a natural perspective and for their potential socio-economic implications. In this paper, the state of conservation of an insular coast is approached from a geomorphological point of view, considering recent changes induced by urban and tourism development. The analysis is applied to the coast of Gran Canaria, a small Atlantic island of volcanic origin, subject to a high degree of human pressure on its coastal areas, especially in recent decades. Currently, much of the economic activity of Gran Canaria is linked to mass tourism, associated with climatic and geomorphological features of the coast. This work is addressed through detailed mapping of coastal landforms across the island (256 km perimeter), corresponding to the period before the urban and tourism development (late 19th century for the island's capital, mid-20th century for the rest of the island) and today. The comparison between the coastal geomorphology before and after the urban and tourism development was established through four categories of human impacts, related to their conservation state: unaltered, altered, semi-destroyed and extinct. The results indicate that 43% of coastal landforms have been affected by human impacts, while 57% remain unaltered. The most affected are sedimentary landforms, namely coastal dunes, palaeo-dunes, beaches and wetlands. Geodiversity loss was also evaluated by applying two diversity indices. The coastal geodiversity loss by total or partial destruction of landforms is estimated at −15.2%, according to Shannon index (H′), while it increases to −32.1% according to an index proposed in this paper. We conclude that the transformations of the coast of Gran Canaria induced by urban and tourism development have heavily affected the most singular coastal landforms (dunes, palaeo-dunes and wetlands), reducing significantly its geodiversity.

1. Introduction

Coastal areas attract the population of the planet, either for their multiple resources or as places of residence. Throughout history human activity affects the natural conditions of the coastal territories (Nordstrom, 1994). This has been more significant in recent decades (Jackson and Nordstrom, 2011), when the phenomenon of "littoralisation" has occurred (Bajocco et al., 2012). Currently between 50% and 70% of the world population is concentrated on the coasts (Mimura et al., 2007) and nearly 30% of coastal areas are altered by activities related to human development (Martínez et al., 2007). This has led to an accelerated degradation of the natural coastal systems, which are close to extinction in some cases (Santana-Cordero et al., 2016).

In this context, efforts have been made to address the changing trends on the coast, both from an institutional perspective (e.g., U.S. Geological Survey, European Commission) and by the scientific community. With regard to the latter, numerous papers study coastal erosion problems, at different scales, in recognized problematic areas in the US and Europe (Terich and Levenseller, 1986; Dolan et al., 1990; Amin and Davidson-Arnott, 1997; Aubié and Tastet, 2000; White and Wang, 2003; Cui and Li, 2011; Hapke et al., 2013; Lira et al., 2016) and in other parts of the world, mainly focusing on the analysis of the relationship between observed rates of change and human activities, especially changes in coverage and land-use on sedimentary coasts (Smith and Abdel-Kader, 1988; Narayana and Priju, 2006; El Banna and Frihy, 2009).

Sedimentary shores have been more widely studied in the global context (Naylor et al., 2010). Very few studies have analyzed the conflicts between the human occupation and the rocky shore dynamics, although these environments represent 80% of the world coasts (Emery and Kuhn, 1982). Notable examples of this have been developed on the coast of Algarve, south Portugal, where there are serious problems

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related to the urban and tourism development along the coastal stretches characterized by high sea-cliff recession rates (Alveirinho Dias and Neal, 1992; Teixeira, 2006; Nunes et al., 2009).

Tourism development plays an important role in the changes in coastal morphology of many parts of the world. The impacts of this activity can caused by the occupation of the coast by infrastructures, the development of recreational activities and the implementation of an inadequate management (Nordstrom, 1994, 2000; Tzatzanis et al., 2003; Grunewald, 2006). In this context, the islands, especially small islands under great tourist pressure, are even more vulnerable territories, due to their limited and scarce resources (Hay, 2013) and strong dependency on goods and services provided by marine and coastal systems (Mimura et al., 2007). The concentration of infrastructures and activities in these fragile environments generates overexploitation of resources and jeopardizes the natural values that these activities are based on, producing serious conflicts (García-Romero et al., 2016).

The effects of changes in island coasts have been addressed through some qualitative and mapping approaches. A study about the Canary Islands by Morales Matos and Santana Santana (1993) and Pérez-Chacón et al. (2007) suggest human coastal development, especially tourism, has produced geomorphological and functional changes in certain ecosystems; García-Romero et al. (2016) relate the rates of changes in aeolian sedimentary systems to urban-tourism development. Other authors relate the development of this activity to direct or indirect changes in aeolian sedimentary landforms, such as the alteration of the wind or the vegetation (Hernández-Cordero et al., 2012; Hernández-Calvento et al., 2014). However, there are few studies that analyze the impacts of human activity on coastal geodiversity (Ruban, 2010), and none of them have been applied to island shores.

This paper aims to develop a methodology to measure the influence of the historical urban and tourism development on the geomorphological transformations on the coast, studying the intensity of human impacts on its natural morphology and geodiversity. The whole coast of Gran Canaria (256 km) is studied as a pilot area. The proposed methodology is applied as a test, to be later implemented in other areas with similar characteristics.

2. Regional setting

Gran Canaria is an Atlantic volcanic island, which has a roughly circular shape with 50 km of average diameter, located 200 km off northwest Africa (Fig. 1). It has an area of 1560.10 km^2 and a coastline of 256 km (ISTAC, 2009).

It is part of the Canary Islands (Spain), whose origin corresponds to a typical intraplate hot spot archipelago (Carracedo et al., 1998). The displacement of the African plate over the hot spot determines that the geological age increases towards the easternmost islands, whose development phase is called post-erosional volcanism. In this scheme, Gran Canaria (14.5 million years) is the third oldest island of the archipelago (Carracedo et al., 1998).

The geological diversity of Gran Canaria, well represented on the coast, is one of the highest in the archipelago (Araña and Carracedo, 1980). The island consists mainly of basic rocks (basalts, basanites), and to a lesser extent, by salic emissions (phonolites, trachytes, rhyolites), extruded in various eruptive processes (flows, pyroclasts, tuffs, ignimbrites). The island formed a single huge stratovolcano, which has intensively been eroded since Mio-Pliocene times. As a result, currently it reaches a maximum altitude of 1949 m above sea level at its center (Pico de las Nieves) and it has an abrupt relief in which the erosive landforms, such as deeply incised ravines and eroded massifs, predominate in the inland, and rocky shores, such as marine cliffs and shore platforms, predominate along the coast.

Gran Canaria has experienced an intense population and urban growth, particularly throughout the last decades, related to changes in the economic base of the island. Before the 1960s, the economy was organized around the agricultural sector and the population mostly distributed in the interior. Since the 1960s, the economy gave way to a model based on the service sector, mainly tourism, construction and trade. The transformations of the second half of the 20th century triggered an urban growth process mainly in the northern, southern and eastern coasts, leading to the expansion of residential, industrial, commercial, transport fabrics and, above all, tourism infrastructures along the coasts. Previously, during the first half of the 20th century, the urban expansion of the island's capital (Las Palmas de Gran Canaria) was already taking place along the Guanarteme isthmus, in the northeast coast, driven by the implementation and development of the seaport.

Nowadays, the population, urbanization and infrastructures are heavily concentrated on the coast of the island, particularly in the northeast, east and south (Fig. 1). Gran Canaria has currently 829,597 inhabitants and high population density (532 inhabitants/km^2) (ISTAC, 2009). This combined with the large number of tourists visiting the island, 1,681,743 in 2008 (ISTAC, 2009), have recently led to the occupation and degradation of a significant part of the coastal areas (Morales Matos and Santana Santana, 1993).

3. Material and methods

3.1. Sources

The geomorphological mapping is based on the integration of photographic and topographic sources in a Geographic Information System (GIS) and field work. In areas affected by urbanization processes, we proceeded to georeference historical sources in order to reconstruct the situation before the urban and tourism development. For the island's capital, Las Palmas de Gran Canaria (5% of the island perimeter), cartography from late 19th century, before the beginning of its expansion to the north, was used. For the rest of the island (95% of the perimeter) we used aerial photographs from the 1960s of the last century, before the widespread urban and tourism development. For undisturbed areas, the geomorphological interpretation was based on a modern series (2002–2015) of 10 digital orthophotos from the Spatial Data Infrastructure (SDI) of the Canary Islands (IDECanarias, GRAFCAN, S.A., Government of the Canary Islands).

In addition to photographic sources, the geomorphological recognition was also based on the use of Topographic Maps at 1:1000 and 1:5000 scales (GRAFCAN, SA, Canary Islands Government) and LiDAR clouds points from 2009, with a density of 0.5 points/m^2 (National Geographic Institute).

3.2. Coastal geomorphic classification and mapping

The quantification of the urban and tourism impacts on the coasts of Gran Canaria was made comparing the geomorphological map before the urban and tourism development and the currently observed state of the coast.

The classification system used for the geomorphological mapping was based on the individual identification of the main landforms that comprise the shoreline (McGill, 1958; Alexander, 1966; Finkl, 2004; Biolchi et al., 2016), considering only simple first-order landforms, i.e., those that who cannot be grouped into larger landforms, from the Maximum Low Tide Observed (MLTO). Then, 9 first-order landforms, which, in our criterion, represent the entire spectrum of mesoscale coastal geodiversity in Gran Canaria, were selected (summarized in the Table 1). Note that “geodiversity” is a conceptually broader term, but in this paper it is used as a synonym for “geomorphological diversity”.

The cartographic method consisted in transposing the identified landforms into the historical reconstructed coastal perimeter by shore-normal projection. Projecting a set of multiple superficial landforms (dunes, beaches, platforms, etc.) on the coastline, allowed us, for analytical purposes, to simplify and integrate a heterogeneous spatial data set in a simple and shared longitudinal dimension. The