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Biogeomorphological processes in an arid transgressive dunefield as indicators of human impact by urbanization

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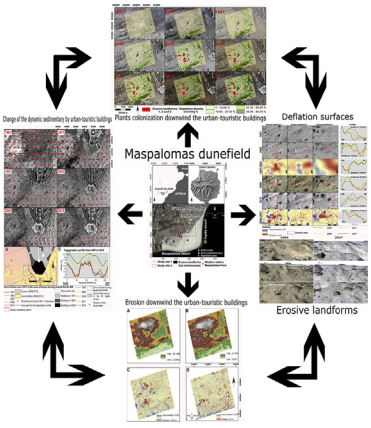
HIGHLIGHTS

- This research analyzes factors that induce an aeolian shadow zone in a dunefield.
- The aeolian shadow zone downwind of urban-touristic buildings is studied.
- The main change in the sedimentary dynamics is due to urban-touristic development.
- Dune trends and morphology change, plant colonization occurs.
- Spatio-temporal changes in biogeomorphological processes are examined.

GRAPHICAL ABSTRACT



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ABSTRACT

Urban and tourist developments can have long-lasting impacts on coastal environments and fundamentally alter the evolution of coastal dune systems. This is the case of the Maspalomas dunefield (Gran Canaria, Canary Islands), hosting one of the largest tourist resorts in Spain. The resort was built on top of a sedimentary terrace at 25 m above sea level (El Inglés) in the 1960s, and has subsequently affected local winds and therefore aeolian sediment transport patterns. Buildings on the terrace deflect the winds to the south of the dunefield, where the rate of sediment transport accelerated. A shadow zone appeared to the lee side of the resort with a consequent decrease in wind speed and aeolian sediment transport and an increase in vegetation cover. In this paper, first we characterize the environmental changes around El Inglés terrace in recent decades, and describe the changes in the shadow zone through an analysis of the evolution of sedimentary volumes and vegetation characteristics (density, spatial patterns, and plants communities). A series of historical aerial photographs, recent orthophotos and digital elevation models obtained by digital photogrammetry and LiDAR, as well as fieldwork were used to characterize plant communities and spatial-temporal changes in erosive landforms. Results show changes in the pattern and migration rates of dunes located at the southern edge of the urbanization, as well as the

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formation of blowouts and large deflation areas, where the vegetation increases in density and number of plant communities. We discuss eco-anthropogenic factors that have produced these environmental changes.
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1. Introduction

The coast has a great diversity of environments and resources, making it a particularly attractive area for human settlements, both as a place of residence and as an ideal location for multiple recreational and economic activities (Cendrero et al., 2005). The last few decades have seen an accelerated *littoralisation* process (accelerated rate of human occupation at the coast) (Cerdá, 2002), with a significant increase in human pressure, which alters natural processes due to human developments, therefore increasing the vulnerability of coastal environments, especially sandy coasts (Brown and McLachlan, 2002; Martinez et al., 2006). This process has accelerated on some arid coastlines, especially those with beach-dune systems, with good climate conditions during the winter driving the development of both tourist and residential urbanization (Hernández-Calvento et al., 2014). The poor, or incorrect location of buildings and infrastructure can generate serious impacts, partial to total destruction of coastal dunes and their vegetation, including building on top of the dunes and interfering with natural beach-dune dynamics (Cooper and McKenna, 2009; Nordstrom, 2004). This has significant implications for both society and management of dunefields, decreasing the ecosystem services and the ability of beach-dune systems to act as a natural coastal defense against storms (Everard et al., 2010; Liquete et al., 2013). It also creates a paradox, where the impacts of anthropogenic activities are directed towards natural resources that are in turn the base of these anthropogenic activities (Cooper and McKenna, 2008; Cabrera-Vega et al., 2013).

Much research has focused on human impacts on beaches and coastal dunes (Bauer, 2009; Jackson and Nordstrom, 2011; Curr et al., 2000; Martínez et al., 2013a,b) especially in temperate zones. However, studies on the direct impacts of urbanization on coastal dune fields landwards from the foredune are scarce (Jackson and Nordstrom, 2011; Hernández-Calvento et al., 2014; Smith et al., 2017). Buildings located near or inside dune fields act as rigid and impermeable structures that intrude and modify the Internal Boundary Layer (IBL) and alter aeolian sediment dynamics (Nordstrom and McCluskey, 1984; Gundlach and Siah, 1987; Nordstrom and Jackson, 1998; Tsoar and Blumberg, 2002; Wiedemann and Pickart, 2004).

Recent research on this topic demonstrated the effects of buildings on modifying the airflow regime and aeolian sediment transport patterns reducing the wind speed by 50% in some places at the dune system of Maspalomas, Gran Canaria, Spain (Hernández-Calvento et al., 2014; Smith et al., 2017), an excellent example of the conflict between urban-tourist development and conservation (García-Romero et al., 2016). At this location, three different geomorphological areas can be identified based on regional disturbances of the wind patterns: an area of air flow acceleration to the south of a terrace upon which much of the tourist infrastructure has been developed; and two 'shadow' areas in the lee-side of the urbanized area, characterized by airflow deceleration, with different degrees of sedimentary stabilization and vegetation growth. All these areas have been described by Hernández-Calvento et al. (2014) and Hernández-Cordero et al. (2017). It has also been shown that these environmental changes have not been produced by a regional climate change: according to Smith et al. (2017), the mobility index (Lancaster, 1988) has been maintained since the 1960s with a value > 200, indicating a fully active mobile dunefield or aeolian processes.

While airflow patterns in shadow zones within a dunefield have been described in general (Hernández-Calvento et al., 2014; Smith et al., 2017), little is known about the evolution and temporal dynamics of these aeolian zones, which are determined by a combination of several variables including feedbacks between topographic change, vegetation growth and aeolian processes. Previous research including the combination of geomorphology and biota has aided in the understanding of such dune systems (Stallins, 2006; Corenblit et al., 2011) and can improve our knowledge of, for example, the operation of barrier-island dunes (Stallins, 2001, 2002; Stallins and Parker, 2003). Vegetation type and density becomes in these cases a good indicator of environmental changes (Moreno-Casasola, 1986; Hesp, 1988; Arens, 1996; Lancaster and Baas, 1998; Martinez et al., 2001; Hernández Calvento, 2006; Miot da Silva et al., 2008; Hernández-Cordero et al., 2017). Similarly, comprehensive analyses of the combined evolution of vegetation cover and density, plant communities and topographic changes within the shadow zone can provide valuable information on how these previously active areas adapt to new environmental conditions as a result of building and developing infrastructure.

This paper analyses the evolution of a shadow zone within an arid transgressive dune field where sediment supply was cut off following the construction of a large resort. First, we quantify volumetric changes and vegetation patterns using a set of orthophotos, historical aerial photographs and digital elevation models (DEMs) since the 1960s. Second, we then focus on the relationship between these parameters, as well as the impact of urbanization on the overall biogeomorphological evolution of this area.

2. Study area

The arid transgressive dunefield of Maspalomas (360.9 ha), is located on the fan-delta of the Fataga ravine at the south of Gran Canaria, in Canary Islands (Fig. 1). Sediment input to the dune system comes primarily from its eastern beach (El Inglés), where the foredune is located. Above threshold, effective winds are >5.1 m/s according to Pérez-Chacón et al. (2007) and the aeolian sediment transport is predominantly ENE-WSW (Máyer-Suárez et al., 2012), with the sand eventually returning to the sea at the southern end section of the dune system (Maspalomas beach; Fig. 1). One of its most foremost geomorphological features is the existence of a high Pleistocene wedge-shaped terrace on its north-eastern boundary. Building of one of the largest tourist resorts in Spain started in the 1960s on this terrace (Domínguez-Mujica et al., 2011), with the consequent alteration of local winds and aeolian sediment transport patterns, and the generation of the shadow zone studied here (Hernández-Calvento et al., 2014; Smith et al., 2017). A few erosive landforms have been detected in this area at a similar distance from the resort (García-Romero et al., 2017). A *trough blowout* according to the classification of Hesp (2002) has also been identified within these landforms (Mir-Gual et al., 2015). However, the origin and evolution of these landforms have not been studied in detail.

3. Methodology

Analyses were conducted at two spatial scales and at two study sites. First, a regional scale is used to evaluate if the aeolian shadow zone could be related to disturbances of the sedimentary dynamics induced by the presence of the urban-touristic buildings, or related to a regional climate change (study site 1). Second, a local scale is used to analyze the biogeomorphological processes in the aeolian shadow zone (study site 2).

The cartographic documents (aerial photographs, orthophotos and DEMs) which were used in this study are listed in Table 1.

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