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Urban-touristic impacts on the aeolian sedimentary systems of the Canary Islands: conflict between development and conservation

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ABSTRACT: Aeolian sedimentary systems in the Canary Islands differ from other European and African systems due to climate, vegetation and isolation. In turn, they experience high human pressure from touristic development. This paper analyzes the impact of urban-touristic development in four aeolian sedimentary systems in the Canaries: Maspalomas, Corralejo, Lambra and Jable Sur. Spatial and surface change variables related to vegetation and geomorphology are obtained by photo-interpretation of historical aerial photography and current orthophotos. Results indicate that systems affected by urban-touristic development have witnessed significant environmental change. In contrast, the systems not impacted by building and construction of infrastructure show minor changes.

Keywords: aeolian sedimentary systems, Canary Islands, conservation, Corralejo, environmental changes, GIS, Jable Sur, Lambra, Maspalomas, urban-touristic development

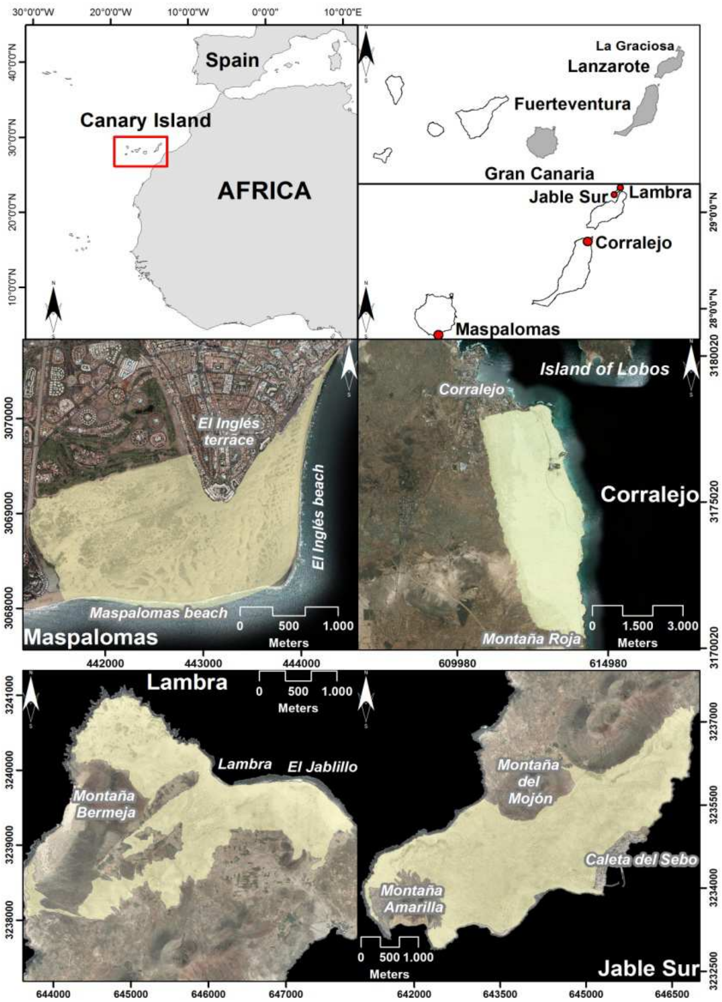
Introduction

The aeolian sedimentary systems of the Canary Islands show significant differences with respect to those in the rest of Europe. First, they have an arid climate, which affects the characteristics of the vegetation: low density, mainly consisting of plant communities and species shared with the northwest coast of Africa (from southern Morocco to Mauritania) and Macaronesia such as *Traganum moquinii*, or endemic species (Santos, 1993; Géhu & Biondi, 1998). *Traganum moquinii* is a shrubby species that generate foredunes with hummock-like morphologies in the Canary Islands. In European temperate areas, foredunes normally consist of continuous ridges due to greater plant cover, and also because the plants of these foredunes are herbaceous species equipped with rhizomes (Hernández-Cordero et al., 2012). Aridity, and the consequent lower vegetation growth together with the existence of constant and intense winds (NE trade winds) ensure that geomorphological processes and landform types of aeolian sedimentary systems also have certain characteristics in the Canaries that are different from those of other European systems. Thus, they are transgressive systems with sediment input areas and, owing to their location on small oceanic islands, are also export areas after the sand has traveled (sometimes losing sediments), from hundreds of meters to several kilometers, across the interior of the islands as free dunes (transversal and barchanoid ridges, barchan dunes and sand sheets). This peculiarity of the island aeolian systems is essential to understanding how coastal domains far from input areas have received sedimentary contributions that create or maintain some beaches (Hernández-Calvento et al., 2009). These characteristics determine the high average rates of advance of the dunes, between 8 m/year (SW trend) (Maspalomas in Gran Canaria) and 5.8 m/year (S trend) (Corralejo in Fuerteventura) (Jiménez et al., 2006; Pérez-Chacón et al., 2007a). Moreover, in some systems such as Corralejo and La Graciosa, as a result of the transgressive nature of the dunes, the sands have been deposited on volcanic rocks, forming unique environments with mixed aeolian-volcanic characteristics. The sediment sources are mainly marine (Hernández-Calvento & Mangas, 2004; Mangas et al., 2012; García-Sanjosé et al., 2014), although not from rivers as in continental areas, so the sands have a high proportion of organic components (forams, shells mollusks, seaweed meshes), in contrast to Europe and Africa where the composition is mainly terrigenous. Terrigenous components are also present and correspond to fragments of volcanic materials supplied by the erosion of ravines and sea cliffs, but in a low proportion.

Since the mid-1960s, the Canary Island economy has been based primarily on the service sector, especially tourism. The predominant type of tourism is that of 'sun, and beach', so most of the infrastructure is coastal, usually associated with sandy areas such as beaches and dune systems. The construction of large tourist complexes and facilities since the 1970s has led to the environmental disturbance of the dune systems of Maspalomas (Gran Canaria), Corralejo (Fuerteventura) and El Jable, Lanzarote (Hernández-Calvento et al., 2005; Hernández-Calvento, 2006; Pérez-Chacón et al., 2007b; Alonso et al., 2011; Fernández-Cabrera et al., 2011; Cabrera et al., 2013; Malvárez et al., 2013; Hernández-Calvento et al., 2014). These sandy systems endure constant tourist occupation throughout the year (Cabrera-Vega et al., 2013), such that there are no rest periods in which the system can recover from the impacts of this human activity. As a result of their geological, geomorphological, floral and faunal value, the dune systems of the Canary Islands are protected as Biosphere Reserves, Special Areas of Conservation (SAC), Special Protection Areas (SPAs), National Parks and Nature Reserves by international (UNESCO, European Union), national and regional bodies.

The aim of this paper is to analyze the impact of urban-touristic development on four dune fields of the Canary Islands: Maspalomas (Gran Canaria), Corralejo (Fuerteventura), Lambra and Jable Sur (both on the island of La Graciosa) (Figure 1).

Figure 1: The four arid aeolian sedimentary systems in the Canary Islands.



Areas of study

Geomorphological diversity and degree of tourist pressure experienced by these systems in recent decades has been taken into account for the selection of the four dune fields. Thus, we intend to assess the relationship between the degree of human impact on these systems and changes in their geomorphology and vegetation. We now describe the most significant features of the four systems.

Maspalomas

With an area of 360.9 ha, this dune field is located in the south of the island of Gran Canaria. According to the classification of Hesp and Walker (2013), Maspalomas is a transgressive dune field. Sediments enter the system via El Inglés beach in the east, move inland as free dunes driven by the trade winds from E-NE, and finally return to the sea at Maspalomas beach (in the south) (Hernández-Calvento, 2006). Maspalomas has three different zones according to the aeolian sedimentary activity associated with specific landforms that are conditioned by the surrounding terrain as well as touristic development (Hernández-Cordero et al., 2015a): the *active area*, where free dunes up to 14 meters high predominate (from the coast inland, the following landforms are present: beach, foredune, barchan dunes and sand sheets, deflation surfaces, barchanoid ridges and interdune depressions); *the semi-stabilized area* formed by erosional landforms such as deflation surfaces, and depositional landforms such as barchan dunes, sand sheets and hummock dunes; *the stabilized area*, consisting of dunes stabilized by vegetation and interdune depressions. Vegetation consists of 19 plant communities, with the communities of *Cyperus capitatus-Ononis serrata*, *Tamarix canariensis*, *Launaea arborescens*, *Suaeda mollis* and *Traganum moquinii* (Hernández-Cordero *et al*., 2015a) standing out for their surface and ecological importance.

Corralejo

Located in the north of the island of Fuerteventura, it has an area of 1812.4 ha. According to the classification of Hesp and Walker (2013) this system, like Maspalomas, constitutes a transgressive dune field. Depending on the age of its materials, there are three zones (Fernández-Galván *et al*., 1982): *the old jable*, *the clay jable* and *the current jable*. The first two areas are characterized by stabilized dunes, whereas the current jable features mobile dunes (Criado, 1987). The old jable consists of cemented sands (organic) with calcium carbonate. The intermediate-age clay jable, consists of a mixture of clay, volcanic rocks and aeolian uncemented sands, with the stabilized dunes predominating. The current jable can be divided into three areas: sand input areas, the dune field, and areas of export of sand to the sea (Criado, 1987). Free dunes, such as sand sheets, barchanoid ridges and barchan dunes, predominate in mobile dunes, plus hummock dunes formed by plant species (Criado et al., 2007; Gutiérrez-Elorza et al., 2013; Malvárez et al., 2013). Sands access the land in the north and northeast of the island and are mobilized southward by the trade winds, which come from the north due to the effect of the Lobos island (Criado, 1987). Some of the sediments reach the sea along the southeast coast while others move south, and eventually reach the southern boundary of the system at the Montaña Roja volcanic cone. The main plant communities are: the *Traganum moquinii* community found in foredunes and output dunes (which lead to the sea); communities of *Euphorbia paralias*, of *Ononis hesperia*, and of *Launaea arborescens* in mobile dunes; and communities of *Salsola vermiculata* and *Launaea arborescens* in the stabilized dunes (Fernández-Galvan et al., 1982; Fernández-Cabrera et al., 2011).

Lambra

This system is located in the north of the island of La Graciosa with a surface area of 401.1 ha. Following the classification of Hesp and Walker (2013), Lambra is a transgressive sand sheet. Five geomorphological units can be observed (Pérez-Chacón et al., 2010): coastal environment-input of sediments, mobile environment, transportation environment, detrital environment and mixed environment. Stabilized dunes and hummock dunes predominate and, to a lesser extent, sand sheets also appear. In this system nine plant communities are identified (Pérez-Chacón et al., 2010; Hernández-Cordero et al., 2015b): the *Salsola vermiculata* community, *Traganum moquinii* community, *Launaea arborescens* community, *Suaeda vera* community, *Polycarpaea nivea* community, *Frankenia ericifolia* community, *Chenoloides tomentosa* community, *Astydamia latifolia* community, and the *Mesembryanthemum nodiflorum* community.

Jable Sur

Jable Sur covers the south of the island of La Graciosa with an area of 868.7 ha. Based on the classification of Hesp and Walker (2013), this system is also a transgressive sand sheet. Fifteen geomorphological units can be observed (Pérez-Chacón et al., 2010): coastal environment-input of sediment, high-hillside accumulation environment, mid-hillside accumulation environment, low-hillside accumulation environment, mobile environment, climbing dune environment, heterogeneous environment, transportation environment, mixed environment, endorreic environment, aeolian terminal environment, coastal environment-output of sediment, tidal environment, accumulative environment, and high beach environment. Stabilized dunes and hummock dunes predominate. Eleven plant communities have been identified (Pérez-Chacón et al., 2010; Hernández-Cordero et al., 2015b): the *Salsola vermiculata* community, *Traganum moquinii* community, *Launaea arborescens* community, *Ononis serrata* community, *Euphorbia paralias* community, *Ononis hesperia* community, *Cakile maritima* community, *Plantago coronopus* community, *Euphorbia regis-jubae* community, *Mesembryanthemum crystallinum* community, and the *Mesembryanthemum nodiflorum* community.

Methodology

Information sources

The sources of information used in this study were historical aerial photos and digital orthophotos. To gather information about Lambra, Jable Sur (La Graciosa) and Corralejo (Fuerteventura) in the 1950s and 1960s (before urban-touristic development began), the photos were scanned at high resolution and subsequently georeferenced through a geographic information system (GIS). In the case of Maspalomas, the WMS service by IDECanarias was used (Table 1).

To collect contemporary information about these aeolian sedimentary systems, recent orthophotos were used. In the case of Maspalomas, a panchromatic orthophoto with a spatial resolution of 15 cm was used. For the other three systems, color orthophotos with 10 cm spatial resolution were used (Table 2).

The geo-referencing system for these data is UTM (28-N) with the WGS84 datum. The delineation error was calculated according to Robinson et al. (1987).

Table 1. Historical information sources.

System	Date	Scale	Spatial resolution (m)	RMS (m)	Error delineation (m)
Lambra	1954	1:5,000	1	1.05- 2.01	1
Jable Sur	1954	1:5,000	1	1.05- 2.01	1
Corralejo	1969	1:7,000	1.5	0.5- 1.01	1.45
Maspalomas	1961	WMS service by IDECanarias	0.12	*	1.2

* = missing data

Table 2: Contemporary information sources.

System	Date	Scale	Spatial resolution (m)	RMS (m)	Error delineation (m)
Lambra	2009	*	0.1	*	0.1
Jable Sur	2009	*	0.1	*	0.1
Corralejo	2009	*	0.1	*	0.1
Maspalomas	2003	*	0.15	*	0.15

* = missing data

Data analysis

Landforms, vegetation surfaces, bare sand surfaces, buildings and other human infrastructure were digitized within a GIS environment. The changes in landforms, vegetation surfaces and bare sand surfaces were used as indicators of environmental change induced by urban-touristic development. To determine the impact of urban-touristic development, these environmental changes were related to the evolution of buildings and infrastructure in systems affected by urban-touristic development to different degrees (Maspalomas, Corralejo and Jable Sur), and were also assessed in other unaffected systems (Lambra).

Results

Environmental changes in aeolian sedimentary systems

Maspalomas (1961-2003)

In the dune field of Maspalomas, landforms that have suffered a greater reduction, and even complete disappearance, are those associated with topographic obstacles: clifftop dunes, echo dunes, climbing dunes and falling dunes (Table 3; Figure 2). Other landforms that have suffered significant reductions are the hummock dunes, barchanoid ridges, barchan dunes and sand sheets, and the foredune. In contrast, other landforms, such as the stabilized dunes and deflation surfaces, have increased their reach. There are also new landforms associated with human disturbance, including those characterized by the presence of anthropogenic deposits

(Table 3). Changes in vegetation are significant: its surface area has increased by 38.8%, while the bare sand surfaces have fallen radically by 61.3% in 42 year (Table 3).

Table 3: Environmental changes in Maspalomas (1961-2003).

Landform	Surface in 1961 (ha)	% in the system in 1961	Surface in 2003 (ha)	% in the system in 2003	Variation (ha)	Variation (%)
Barchanoid ridges	225.2	47.4	115.1	31.9	-110.1	-48.9
Barchan dunes and sand sheets	102.9	21.7	56.1	15.5	-46.8	-45.5
Cliff-top dunes	14.1	3.0	0.0	0.0	-14.1	-100.0
Foredune	13.2	2.8	9.5	2.6	-3.7	-28.0
Echo dunes	8.4	1.8	0.0	0.0	-8.4	-100.0
Falling dunes	6.7	1.4	0.0	0.0	-6.7	-100.0
Climbing dunes	3.3	0.7	0.0	0.0	-3.3	-100.0
Beach	18.5	3.9	32.3	8.9	13.8	74.6
Hummock dunes	44.8	9.4	11.8	3.3	-33.0	-73.7
Stabilized dunes	22.4	4.7	90.9	25.2	68.5	305.8
Deflation surfaces	10.1	2.1	32.2	8.9	22.1	218.8
Anthropogenic deposits	0.0	0.0	5.4	1.5	5.4	100.0
Sand mining	5.3	1.1	3.2	0.9	2.1	39.6
Anthropogenic deposits with sand	0.0	0.0	2.7	0.7	2.7	100.0
Slope with anthropogenic deposits	0.0	0.0	1.7	0.5	1.7	100.0
Total	474.9	100.0	360.9	100.0	-114.0	-24.0
Vegetation	90.1	19.0	125.1	34.7	35.0	38.8
Bare sand	384.9	81.04	235.8	65.3	-149.1	-61.3

Accumulation	Stabilization	Erosion	Anthropization

Corralejo (1969-2009)

Changes in landforms in Corralejo are similar to those that occurred in Maspalomas. It is noted that landforms with higher aeolian sedimentary activity have reduced surface areas (barchanoid ridges, foredune, barchan dunes and sand sheets). The foredunes in some sectors have been replaced by buildings. However, landforms with less aeolian sedimentary activity, such as hummock dunes and stabilized dunes, have increased their surface areas (Table 4, Figure 3). Finally, in recent decades a landform that did not appear in 1969 is detected; these deflation surfaces correspond to erosive areas in the dune system. Vegetation has also changed significantly with an increase in its area of 8.9%. The opposite has occurred with the bare sand surfaces that decreased by 32.0% (Table 4).

Figure 2: Landform changes in Maspalomas (1961- 2003).

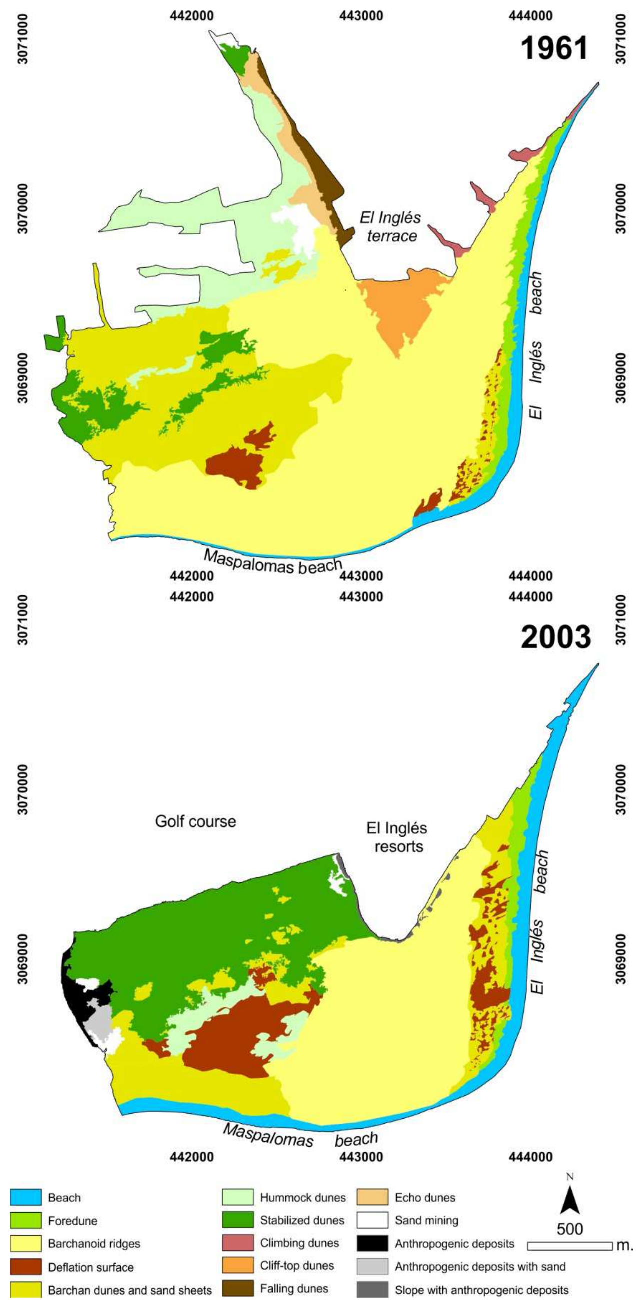


Table 4: Environmental changes in Corralejo (1969-2009).

Landform	Surface area in 1969 (ha)	% in the system in 1969	Surface area in 2009 (ha)	% in the system in 2009	Variation (ha)	Variation (%)
Barchanoid ridges and barchan dunes	782.1	37.5	369.7	20.4	-412.4	-52.7
Foredune	28.0	1.3	12.1	0.7	-15.9	-56.7
Sand sheets	167.8	8.1	10.6	0.6	-157.2	-93.7
Hummock dunes	623.7	30.0	780.8	43.1	157.1	25.2
Stabilized dunes	479.5	23.0	633.6	35.0	154.1	32.1
Deflation surfaces	0.0	0.0	5.6	0.3	5.6	100.0
Total	2081.3	100.0	1812.4	100.0	-269.0	-12.9
Vegetation	926.9	44.5	1009.8	55.7	82.9	8.9
Bare sand	1149.4	55.2	781.3	43.1	-368.5	-32.0

Accumulation Stabilization Erosion

Lambra (1954-2009)

The changes in Lambra are less significant than those detected in Maspalomas and Corralejo, but their trend is similar. The landforms with higher aeolian sedimentary activity, such as sand sheets, reduced their surface areas by 74.7%. In contrast, the hummock dunes, a landform associated with individual plants and indicative of the start of system stabilization, increased their reach by 1.8%. Finally, rocky outcrops remained virtually unchanged (Table 5; Figure 4). As for vegetation surfaces, their areas also increased by 12.1%, while the bare sand areas decreased by 47.1% (Table 5).

<u>Figure 3</u>: Landform changes in Corralejo (1969-2009).

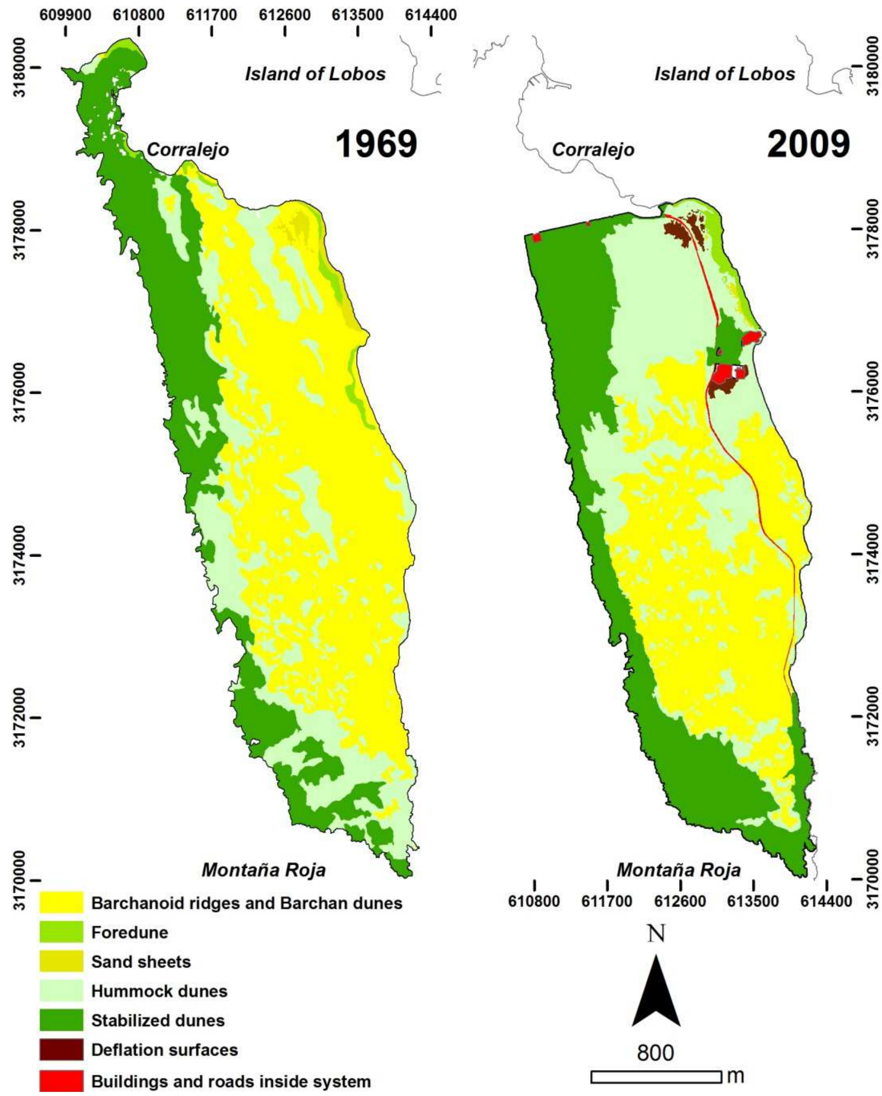
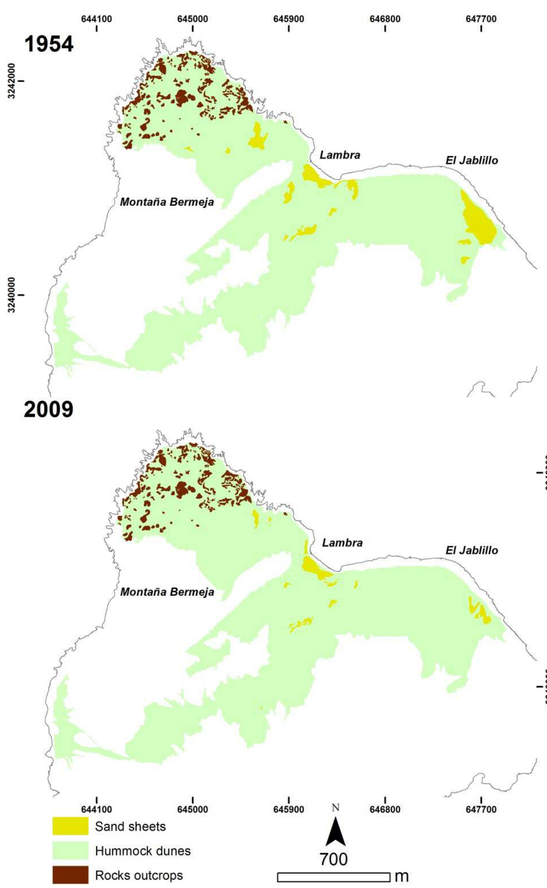


Table 5: Environmental changes in Lambra (1954-2009).

Landform	Surface area in 1954 (ha)	% in the system in 1954	Surface area in 2009 (ha)	% in the system in 2009	Variation (ha)	Variation (%)
Sand sheets	16.2	4.0	4.1	1.0	-12.1	-74.7
Hummock dunes	364.6	118.4	371.0	119.9	6.4	1.8
Rocks outcrops	16.4	4.0	16.5	4.1	0.1	0.6
Total	401.2	100.0	401.1	100.0	-0.1	0.0
Vegetation	319.2	79.6	357.7	89.2	38.5	12.1
Bare sand	82.0	20.4	43.4	10.8	-38.6	-47.1

Accumulation Stabilization Erosion

Figure 4: Landform changes in Lambra (1954- 2009)



Jable Sur (1954-2009)

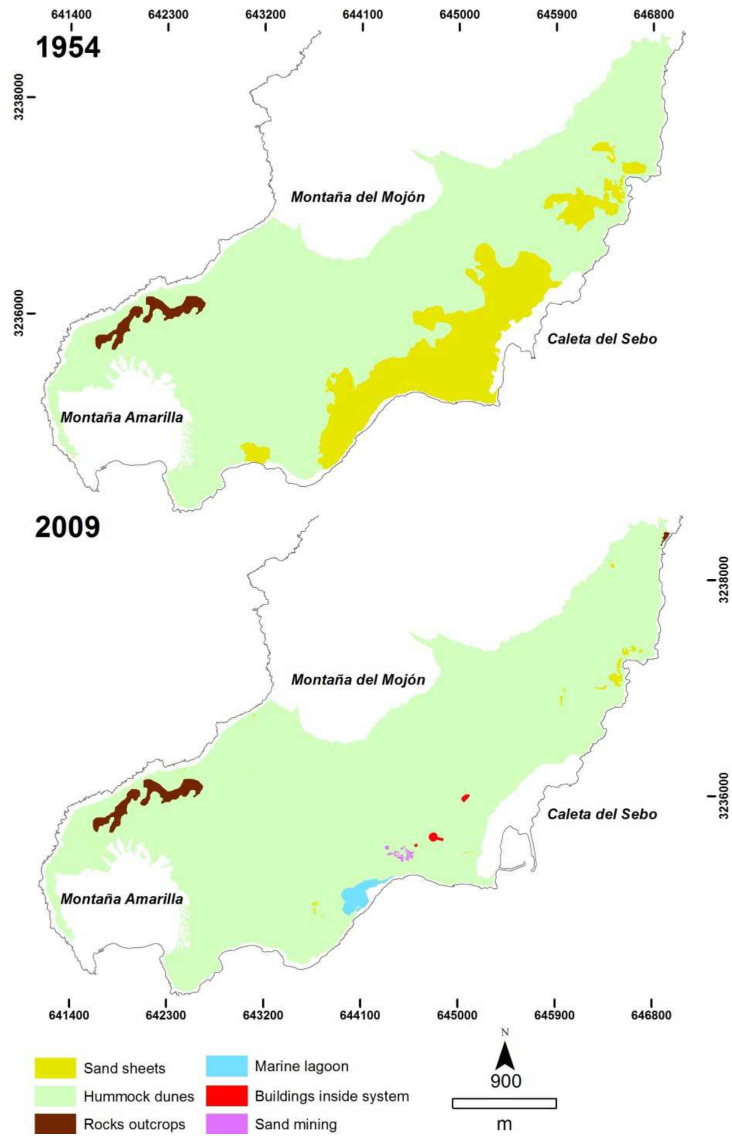
In the south of La Graciosa, the landforms that experienced major changes are those related to higher aeolian sedimentary activity, such as sand sheets, which have been reduced by 98.1% (this means their virtual disappearance). However, the rest of the landforms, related to processes involving stabilization and erosion, show increased surface areas, as in the case of the hummock dunes, the same that in other systems. The marine lagoon landform, undetected until the 1950s, is a new emergence that suggests a sedimentary deficit in the system because the level of the sand decreased causing the sea level to rise (Table 6; Figure 5). The sand mining activities are also detected in this last fifty-five years. The vegetation surface area has increased significantly, with a variation of 60.9%; however, the bare sand surface areas decreased by 77.5%, suggesting an additional sedimentary deficit in the system (Table 6). These latest results indicate a plant colonization process to be underway in the aeolian sedimentary system.

Table 6: Environmental changes in Jable Sur (1954-2009).

Landform	Surface in 1954 (ha)	% in the system in 1954	Surface in 2009 (ha)	% in the system in 2009	Variation (ha)	Variation (%)
Sand sheets	159.3	18.0	3.1	0.4	-156.2	-98.1
Hummock dunes	710.8	80.6	846.05	97.4	135.3	19.03
Rocks outcrops	11.6	1.4	12.2	1.4	0.6	5.2
Marine lagoon	0.0	0.0	6.3	0.7	6.3	100.0
Sand mining	0.0	0.0	1.05	0.12	1.05	100.0
Total	881.7	100.0	868.7	100.0	-13.0	-1.5
Vegetation	484.3	54.9	779.4	89.7	295.1	60.9
Bare sand	397.4	45.1	89.3	10.3	-308.1	-77.5

Accumulation	Stabilization	Erosion	Anthropization

<u>Figure 5</u>: Landform changes in Jable Sur (1954- 2009).



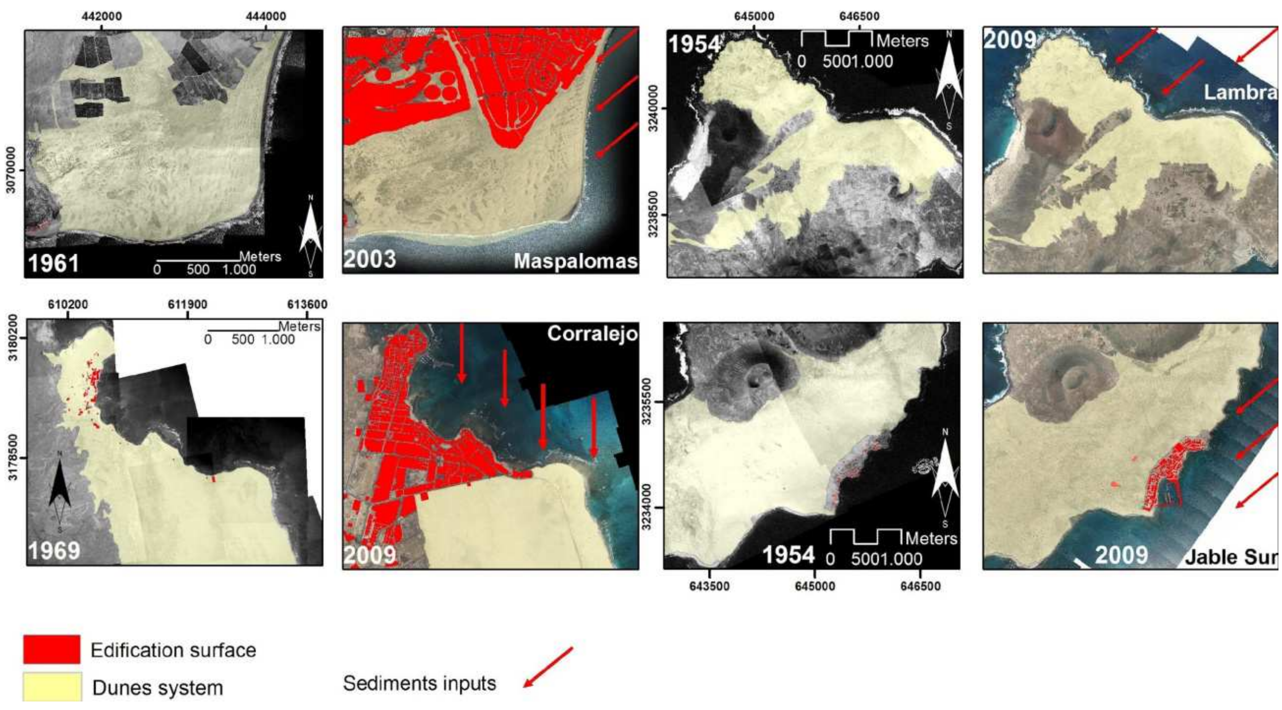
Changes in built surface area

The built surface area produced by urban-touristic development has increased very significantly in Maspalomas, Corralejo and Jable Sur (<u>Table 7</u>). This phenomenon has been the cause of the reducion in the surface areas of these aeolian sedimentary systems by 114 ha, 269 ha and 13 ha, respectively (<u>Tables 3, 4 and 6</u>). In Corralejo and Jable Sur, this development is primarily located in sediment input areas (<u>Figure 6</u>). Only Lambra is not affected by the urban-touristic development, and its surface area has not reduced significantly.

Table 7: Changes in the surface area occupied by buildings in aeolian sedimentary systems.

Dune Systems	Surface area on 1st date (ha)	% in the system on 1st date	Surface area on 2nd date (ha)	% in the system on 2nd date	Variation (ha)	Variation (ratio)
Maspalomas (1961-2003)	6.3	1.3	121.3	33.6	115.0	19.2
Corralejo (1969-2009)	4.6	0.2	233.4	12.8	228.8	50.7
Lambra (1954-2009)	0.0	0.0	0.0	0.0	0.0	0.0
Jable Sur de La Graciosa (1954-2009)	1.4	0.1	14.3	1.6	12.9	10.2

Figure 6: Evolution of the surface area occupied by buildings in aeolian sedimentary systems. Sediment input areas are indicated.



Sources: Maspalomas (Canary Islands Government´s IDE Canarias, Grafcan S.A.); Corralejo (Cartography and Photography Center, CECAF - Air Force; Grupo de Geografía Física y Medio Ambiente, IOCAG, ULPGC); Jable Sur, Lambra and La Graciosa (Cartography and Photography Center, CECAF - Air Force); Organismo Autónomo Parques Nacionales, Spanish National Ministry for Agriculture, Food and the Environment).

Relationship between environmental changes and urban development

These results suggest that environmental changes are associated with the urban-touristic development that has occurred in the Canary Islands during recent decades. Virtually all landforms with active aeolian sedimentary activity (foredune, sand sheets, barchanoid ridges and barchan dunes) have experienced a reduction in all the sandy systems studied. Even in some cases, for example Maspalomas, four types of landforms have completely disappeared and have been replaced by buildings. In contrast, those landforms with less aeolian sedimentary activity or anthropogenic landforms have seen increases in their area, or are newly emerging.

The area occupied by vegetation has increased in all systems; this explains the increase in hummock dunes and stabilized dunes because they involve the presence of vegetation. This plant colonization is mainly due to a decrease in aeolian sedimentary activity, which promotes the growth of vegetation after reduction through burial by sand.

In the Maspalomas dune field, most tourist resorts have been built on a high terrace, located NE of the system. This has reduced the wind speed downwind of the terrace and accelerating it to the south of the terrace, inducing changes in significant parts of the system (Hernández-Calvento et al., 2014): free dunes located downwind of the terrace have been stabilized while, in the central part of the system and leeward of the foredune, deflation surface areas have increased. These geomorphological changes have also affected plant colonization, given the stabilization of the dunes in the inner areas of the system and to the outcropping of wet sands and alluvial deposits at the deflation surfaces. Some construction has taken place on parts of the foredune, affecting the sediment input area.

In the dune field of Corralejo, the tourist resorts have been built on the northern coast, in the theoretical sediment input area (Alonso et al., 2006; Malvárez et al., 2013) (Figure 6). This sedimentary blockage has caused changes in the aeolian sedimentary dynamics, which in turn results in significant geomorphological changes such as decrease of the free dunes, the appearance of deflation surfaces, and the increase of stabilized and hummock dunes.

The Lambra system is unaffected by urban-touristic development. The sediment input area is free of any human construction. There have been impacts from human activities such as farming or vegetation removal for fuel (Santana-Cordero et al., 2015); but, since being declared a Natural Park in 1987 (via Law 12/1987, of July 19), these activities have stopped. In any case, the sand sheets have shrunk, probably by a sedimentary deficit or because their existence was linked to traditional activities (Grazing and cutting of plants for firewood); they have been replaced by hummock dunes, indicating an increase of vegetation cover. Finally, rocky outcrops increased in some areas, perhaps because of the sedimentary deficit.

Jable Sur, unlike Lambra, has been affected by urban-touristic development. This is due to the increase in size of the village of Caleta de Sebo, where residential and tourist development has been permitted. Building construction and port infrastructure has occurred in the sediment input area (Figure 6). Thus, some sand sheets that existed in 1954 have been replaced by buildings; others have been stabilized by an increasing vegetation cover, resulting in a predominance of hummock dunes. The rocky outcrops also showed a slight increase, probably due to the sedimentary deficit. The same change has prompted the emergence of a marine lagoon that was previously covered by sand that blocked the entry of sea water inland.

Discussion

In general, morphological and ecological changes in aeolian sedimentary systems have been a consequence of the development of traditional activities such as agriculture, grazing or deforestation (Ratas and Puurmann, 1995; Doody, 2004; Kutiel et al., 2004; Levin and Ben-Dor, 2004; Provoost et al., 2011; Sciandrello et al., 2015), a phenomenon that has also been identified in the Canary Islands (Santana-Cordero et al., 2015). However, since the mid-twentieth century, major environmental changes in these ecosystems have been linked to urban-touristic development (Gormsen, 1997; Nordstrom and Arens, 1998; El Banna and Frihy, 2009; Kiss et al., 2009; Bochev-van der Burgh et al., 2011; Miccadei et al., 2011; Jackson and Nordstrom, 2011; Malavasi et al., 2013). Similarly, tourism-induced changes are also identified in the Canary Islands (Alonso et al., 2002; Cabrera-Vega et al., 2013; Hernández-Calvento et al., 2014).

Aeolian sedimentary systems in the Canary Islands have undergone significant environmental changes. These changes include increases in vegetation surface areas, stabilized dunes, and erosional processes. These are manifested in the formation of deflation surfaces and decline of the free dune characteristics of these transgressive systems (barchanoid ridges, barchan dunes and sand sheets), while buildings and infrastructure surface area have increased. The systems that showed the most significant changes are Maspalomas, Corralejo and Jable Sur. This is because buildings and infrastructures have been placed over sediment input areas, leading to blocking of sediment sources, such as occurred at Jable Sur and Corralejo (Malvárez et al., 2013), or in areas where wind dynamics have been changed, as observed in Maspalomas (Hernández-Calvento et al., 2014). Similar environmental changes associated with touristic development have occurred in other dune systems on the island of Fuerteventura (Alonso et al., 2002). In this sense, we must consider that erosional geomorphological changes are key to the existence of sedimentary deficits (Hughes and Chiu, 1981; Van Thiel de Vries, 2009; Jackson and Nordstrom, 2011). Likewise, changes in vegetation cover are indicators of aeolian sedimentary inactivity, because the decreased dune mobility favours the development of vegetation (Kutiel et al., 2004; Levin and Ben-Dor, 2004; Faggi and Dadon, 2011).

Lambra has experienced less significant changes, both in the geomorphology and vegetation. Recent studies indicate that the transformation of sandy systems on the island of La Graciosa is related to changes in land use (Santana-Cordero et al., 2015). Thus, the abandonment of traditional practices (grazing, firewood, etc.) since the 1990s has favored plant recolonization and subsequent stabilization of sand sheets (García et al., 2012). However, differences in the environmental changes between the two systems studied in La Graciosa, Lambra and Jable Sur, indicate the existence of other factors. Those include the construction of buildings in the system sediment input area which occurred in Jable Sur but not in Lambra. The sandy systems that are not affected by urban-touristic development have changed little in their environmental characteristics, as observed in other dune systems in the Canaries (Alonso et al., 2004). This is the case of the Cotillo-Tostón system on the island of Fuerteventura, located a few kilometers west of Corralejo, which has a sedimentary deposit with similar characteristics to Corralejo (Meco and Stearns, 1981; Criado, 1991; Coelho et al., 1992; Ancoechea et al., 1996; Zazo et al., 2002, 2003). This example suggests that systems with similar environmental characteristics, but with different human pressures, have developed different dynamics.

However, it is possible that environmental changes in aeolian sedimentary systems of the Canary Islands are also related to natural factors, such as depletion of marine sediments

(Hernández-Calvento et al., 2014) and climate change (Petit and Prudent, 2010; Sauter et al., 2013). This phenomenon has been observed in various dune systems in Wales, where it has become evident that environmental changes are related to climate change and reductions in sedimentary input (Pye and Blott, 2012).

Although a relationship between urban-touristic development and geomorphological and vegetation changes in aeolian sedimentary systems of the Canary Islands has been detected in this work, the causes that have led to these changes are probably a combination of natural and anthropogenic factors (Pye and Blott, 2012; Hernández-Calvento et al., 2014). This may be the explanation for the existence of stabilization processes (decrease of sand sheets) in the Lambra system, where there has not been any urban development, leaving the input sedimentary area free of any buildings or infrastructures. Nevertheless, of the four systems this is the one with only minor environmental changes. Therefore it is probable that environmental changes that would have occurred through natural causes (due to lower inputs of sand, for example) have been accelerated by human disturbance, as occurred in the dune field of Maspalomas (Hernández-Calvento, 2006; Hernández-Calvento et al., 2014).

Conclusion

We have studied environmental changes in four aeolian sedimentary systems of the Canary Islands (Maspalomas, Corralejo, Jable Sur and Lambra). These changes are linked to urban-touristic development. The main environmental changes are increases in vegetation surfaces, in stabilized dunes, and in erosional landforms. Furthermore, there has been a decrease in free landforms such as barchanoid ridges, barchan dunes and sand sheets. In turn, the area occupied by urbanization has increased.

Aeolian sedimentary systems that have experienced major environmental changes coincide with those where there has been higher urban-touristic development (Maspalomas, Corralejo and El Jable Sur). In contrast, the Lambra system, which has not been affected by development, shows less significant changes. However, the existence of certain environmental changes in the latter system opens the possibility that environmental changes of aeolian sedimentary systems in the Canary Islands are also related to environmental factors, such as depletion of marine sediments and climate change.

Environmental changes associated with urban-touristic development in island contexts indicate deficiencies in the management of these protected areas, as sufficient steps have not been taken to foster a favourable conservation environment for the dune systems.

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