Journal of Environmental Management 325 (2023) 116645

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Can the long-term effects of beach cleaning heavy duty machinery on aeolian sedimentary dynamics be detected by monitoring of vehicle tracks? An applied and methodological approach

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ARTICLE INFO

Keywords:
Arid coastal dune system
Maspalomas
Vehicle tracks
Mechanical cleaning
Beach-dune management

ABSTRACT

Beach-dune systems are fragile ecosystems vulnerable to changes, especially those associated to human activities. This study focuses on *El Inglés* beach (Canary Islands, Spain), which is located on the eastern limit of the Maspalomas dunefield. This is the sediment input to the dunefield, and vehicles that provide urban-touristic services circulate every day, most notably heavy duty machinery responsible for beach cleaning. The aim of this study is to make a first methodological approach and a quantitative and empirical analysis of the long-term environmental effects, especially on the topography and geomorphology, that mechanical beach cleaning services could have on the aeolian dynamics, using as an indicator the vehicles tracks mapping.

The methodology is divided into four sections: i) a spatiotemporal study of vehicle tracks on the beach; ii) a field campaign to observe beach cleaning activities *in situ* and compile data; iii) an interview with the local team responsible for beach cleaning; and iv) a general analysis of the aeolian dynamics over the almost last two decades.

Results shown not only a high correlation between vehicle tracks and heavy duty machinery tracks, but also the variation in vehicle track density was proven to follow changes in the management process and the number of tourists. Different track densities varied depending on the intensity of the presence of visitors and hence the intensity of beach use, which is not homogeneous throughout the beach. A study of the deflation surfaces as erosion process found that they not only remain steady but even increase in some areas with high vehicle track densities, with no sedimentary gain. Although management activities like cleaning and levelling may not have a direct impact on the dunefield, they were positively correlated to deflation surfaces, increasing sediment loss in the beach area. These activities could be leading an artificially-maintained steady beach contrary to documented sedimentary loss in the dunefield. In conclusion, the pioneer approach of analysing the vehicle traffic through tracks monitoring, especially beach cleaning activities, has shown the viability to detect long-term effects on the sedimentary dynamics, including sediment loss to the foredune and, therefore, inside the system.

1. Introduction

Coastal ecosystems are areas of scientific interest not only due to their fragility in the face of environmental or anthropogenic changes, but also because they are areas where terrestrial and marine factors interact. In aeolian sedimentary ecosystems, especially sandy systems like coastal dunes, wind and marine factors, among others, play important roles in terms of variations in sedimentary dynamics (Gómez-Pina et al., 2002). Due to their ecological factors and proximity to beaches, they are commonly areas with high levels of human settlement and tourist visits (Hernández-Calvento et al., 2007). In beach-dune systems, the foredune plays a crucial role in the aeolian sedimentary dynamics. Foredunes are mainly formed when plant communities which are well adapted to these ecological conditions develop in the backshore (Hesp, 1988). These plants act as sand collectors, building the first dunes within small or relatively small groups of plant individuals located parallel to the beach (Hesp, 1988). For this reason, the foredune works as a barrier against environmentally adverse conditions (Avis and Lubke, 1996; Ley-Vega de Seoane et al., 2007; Thompson and Schlacher, 2008), reducing land erosion and the entrance

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https://doi.org/10.1016/j.jenvman.2022.116645
Received 7 July 2022; Received in revised form 7 September 2022; Accepted 26 October 2022
Available online 2 November 2022

of water or sediment into inland areas (Peña-Alonso et al., 2018).

Arid aeolian sedimentary systems are specific environments located in arid regions (Hernández-Cordero et al., 2019). The most characteristic element of such areas is the vegetation, whose importance lies in its stabilizing of the sediment, reducing wind speed, and using its roots to fix the dunes (Livingstone, 1989). Foredune vegetation in arid dune systems differs in various aspects with respect to that of temperate or tropical areas. In arid systems, the vegetation usually consists of low-density shrubs, and their relative scarcity gives rise to a foredune that comprises nebkhas and shadow dunes (Hesp et al., 2021). Therefore, the morphology of these arid foredunes is a naturally fragmented structure, which implies a greater weakness than that of temperate regions considering the protective role that these geographical features play in beach-dune systems (Viera-Pérez, 2015; Hernández-Cordero et al., 2019). In addition, unlike tropical or temperate regions, arid beach-dune systems tend to change radically in short periods of time whenever a disturbance occurs (Hernández-Cordero et al., 2006; Jackson et al., 2013). For this reason, in a completely natural situation, these beach-dune systems can easily recover from environmental changes, but their fragility in dealing with human impacts is considerably greater (Williams et al., 1997).

Dunes are affected by human actions leading to new artificial dune morphologies, obstructing dune formation and sedimentary changes (Nordstrom, 1994). These actions consist primarily of urban construction, parking, beach access structures, camping and other recreational activities (Curr et al., 2000). Several beach services, such as sunbed and umbrella rental or beach cleaning also affect the dynamics of the beach-dune systems (Roig-Munar et al., 2012; Sanromualdo-Collado et al., 2021). Many similar dune systems in different parts of the world have been affected by foredune or vegetation loss as a result of beach services (Liddle and Grieg-Smith, 1975), often leading to an increase in wind speed and a decrease in aeolian sedimentary transport to inner parts of the systems (Nordstrom, 2002; Jackson and Nordstrom, 2011). Sedimentary movement related to these activities, especially beach cleaning, also causes erosion and sand compaction. Therefore, these can be leading causes of land deterioration and the degradation of dune systems (Roig-Munar, 2004).

So far, studies analysing the effects that vehicle traffic can have on beach-dune systems have been determined through assessments of fauna (Willmott and Smith, 2003; Steiner and Leatherman, 1981; Barros, 2001) and flora (Gilburn, 2012; Morton et al., 2015), or mostly only commented on at a theoretical level (Wyles et al., 2017; Zielinski et al., 2019). As a result, there remains a lack of knowledge of the dimension that these effects may have on the sedimentary erosion of coastal dune systems. In this sense, cleaning service is a primary activity when it comes to the daily maintenance of suitable hygienic conditions on beaches for the visit of bathers and is generally more exhaustive in the high season (Morton et al., 2015; Botero et al., 2017). Such cleaning is mostly carried out using heavy duty machinery such as tractors, rakes and sifters (Roig-Munar, 2004) designed to remove the waste left behind by humans. However, as well as the waste itself, this action tends to remove sediment, seaweed and small organisms from the sandy soil (Fairweather and Henry, 2003; Ariza et al., 2008). Along with the cleaning, the sandy area is also generally smoothed over after garbage collection to leave it in desirable conditions for the arrival of beach users (Owens et al., 1987; Battisti et al., 2017). Mechanical cleaning has been statistically correlated with the designation of Blue Flag certified beaches (Mir-Gual et al., 2015).

After reviewing the few existing quantitative studies on vehicle traffic, impacts on beaches and the levelling of sandy soils by cleaning services (Afghan et al., 2020), and given the call of Zielinski et al. (2019) "*for empirical studies with regard to the efficiency of different cleaning approaches on beaches with varying levels of use intensity and for methodological designs that separate the impacts of mechanical grooming from those of trampling, dune destruction, shore armouring, artificial lighting, among others*", the hypothesis raised in this study is that the vehicles, especially those related to daily cleaning, that circulate on the beaches (sediment input zones) associated to the transgressive dunefields, interfere in the long-term of aeolian sedimentary dynamics, causing a decrease in sedimentary transport, and therefore loss of sediment towards the interior (foredune and dunefield).

In this sense, the above hypothesis arises from different studies, which have shown (at different spatial and temporal scales), that there is a continued stability over time, or even a progradation along the study area of this research (*El Inglés* beach), which is the main sediment input to the Maspalomas dune system (Alonso Bilbao et al., 2001; Quevedo-Medina and Hernández-Calvento, 2014; García-Romero et al., 2016; Fontán-Bouzas et al., 2019; Di Paola et al., 2020). Nevertheless, in the last few decades, the dune system has lost a mean annual amount of approximately 45,000 m^3 of sediment input (Medina et al., 2007), causing a sediment shortage. As a consequence, mean dune height has been reduced and significant geomorphological changes have taken place, especially the reduction of mobile dunes and retrogradation along Maspalomas beach (south), the main sediment output from the dune system (Hernández-Calvento, 2002; García-Romero et al., 2016; Hernández-Cordero et al., 2019; García-Romero et al., 2019). This incongruity suggests that vehicle traffic, commonly considered harmless management practices, especially the use of heavy duty machinery for the cleaning of *El Inglés* beach over many years (long-term), may be contributing to interferences in the aeolian sedimentary dynamics, lessening sedimentary transport and producing sand loss inside the dune system. Therefore, it is important to understand these dynamics and find a way to characterize them by approaching new ways of indirect measuring and understanding these variations to accomplish a well-developed management of the dune system as a whole. Furthermore, these measurements must also be applied in the identification of effects that services as beach cleaning are having on the sedimentary dynamics as a way of indirect characterization of the dune system impacts and that have not been yet a concern for research.

The main objective of this research, following the hypothesis and the observations detected in the study area, is to detect and analyse from a first methodological approach the long-term environmental effects, associated to the topography and geomorphology, that beach cleaning with heavy duty machinery has on the aeolian sedimentary dynamics of an arid transgressive dunefield. The two specific objectives, ordered and sequenced according to the main objective and structure of the article, are as follows: i) to identify and analyse spatially and temporally the tracks derived from the vehicles that drive across *El Inglés* beach, from the intertidal area to the foredune, especially those related to heavy duty machinery used by beach cleaning service; ii) to explore the spatio-temporal relationships between variables related to sediment in beach and foredune areas and the track density of beach cleaning machinery.

2. Study area

2.1. Natural characteristics of the Maspalomas dune system

The dune system of Maspalomas (27°44′30″N, 15°35′07″O) is a natural environment located in San Bartolomé de Tirajana, in the south of Gran Canaria (Fig. 1, A). Maspalomas is characterized by an annual precipitation lower than 100 mm, and a stable average temperature of 21 °C (Hernández-Cordero et al., 2019). It is located in the southern vertex of the island over an old ravine mouth which had formed a fan delta before marine and aeolian sedimentary deposits covered it (Fig. 1, A). Since the 1960s, an increasingly complex network of urbanizations and infrastructures, including a golf course and the *El Inglés* constructions, has surrounded the dune system along its northern side (Fig. 1, A) (Medina et al., 2007).

This arid dune system which, according to the classification of Hesp and Walker (2011), is a transgressive dunefield, constituting *El Inglés* beach as the main entrance of sediment transport (27°45′00″N, 15°34′50″W), bounded to the northeast by an open-air shopping centre

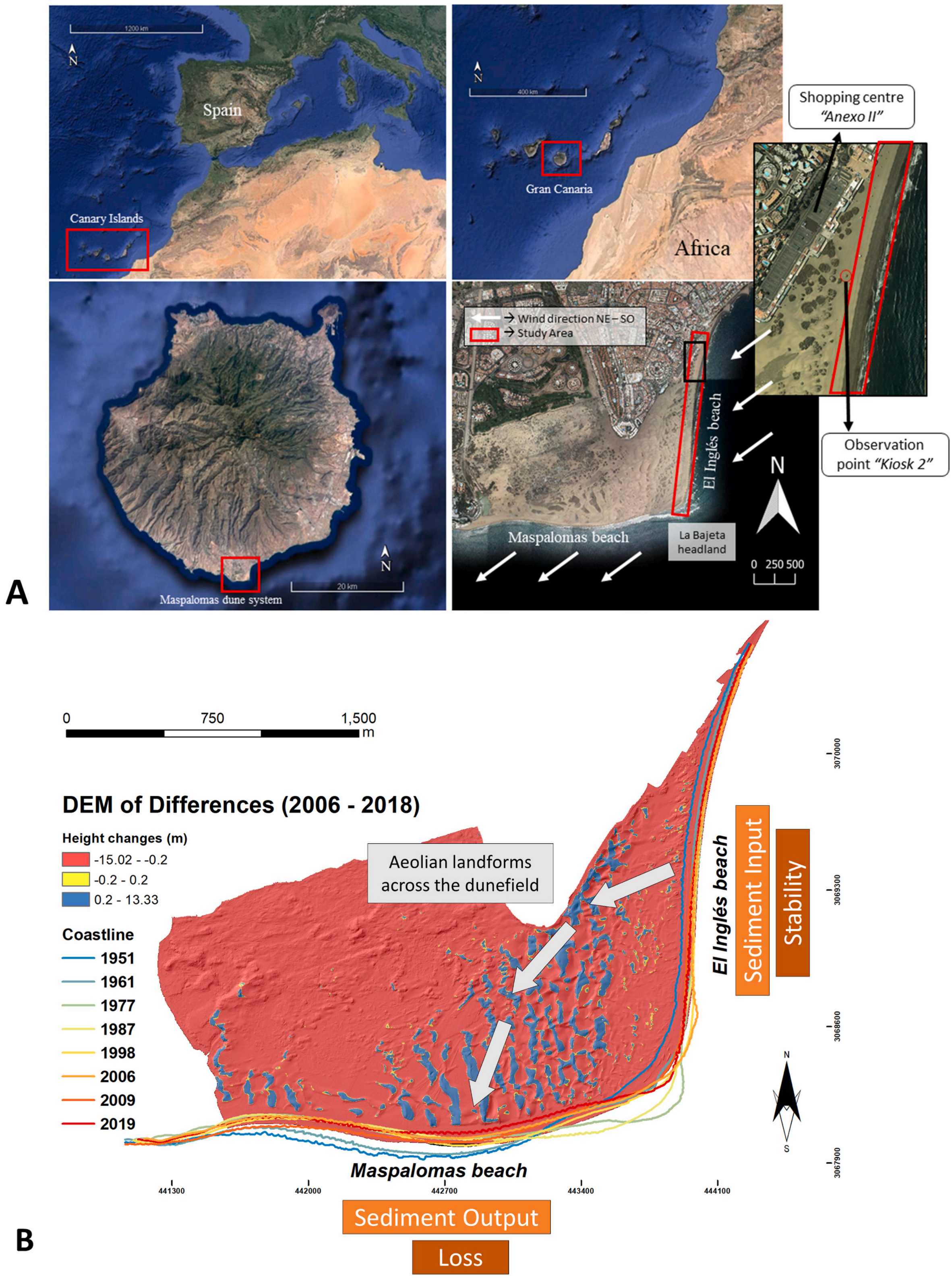

Fig. 1. (A) Location of the study site of Maspalomas dune field, Gran Canaria (Spain). White arrows indicate the main aeolian sediment transport from NE to SW (Máyer-Suárez et al., 2012). Red square indicates the study area in *El Inglés* beach. Black arrows indicate the location of the Shopping centre called "Anexo II" and the observation point of the field campaign "Kiosk 2". Source of orthophoto: IDECanarias. GRAFCAN, S.A.-Canary Islands Government (2019). (B) Digital elevation model (DEM) of differences in the dunefield of Maspalomas (2006–2018). The figure explains the hypothesis of this study, showing coastline recession in Maspalomas beach since 1961 whereas *El Inglés* beach has maintained a relatively stable coastline profile and even an increase in the beach area. Inside the dune system a general deficit can be observed. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

called *Anexo II* (not to be confused with annex to this manuscript), and to the south by the *La Bajeta* headland. The dunes then cross and leave the dune system through Maspalomas beach (27°45′38″N, 15°35′10″O) in the southwest (Fig. 1, A). The predominant winds come from the NE (Máyer-Suárez et al., 2012), making the aeolian sedimentary landforms move mainly from NE to SW, entering El Ingles beach with a NE direction, crossing the dunefield and finally leaving the system through the Maspalomas beach in the SW. Therefore, the foredune of the beach-dune system of Maspalomas is in the backshore of *El Inglés* beach.

2.2. Beach services and infrastructures on El Inglés beach: umbrellas, sunbeds, kiosks and vehicles

El Inglés beach is a popular tourist destination all year round. As a result, there is a high density of beach equipment (e.g. kiosks, sunbeds and beach umbrellas) and a number of different beach services (e.g. vigilance and cleaning). A large area of sunbeds and umbrellas can be found arranged in pairs occupying the entire northern extension of the beach and creating areas of wind shade and deflation surfaces behind them (Hernández-Calvento, 2002; Sanromualdo-Collado et al., 2021; Alonso Bilbao et al., 2001). In 2003, the Insular Plan for Land Management regulated and reduced their use and the area they could occupy. It was established that the number of sunbeds could not exceed one for each 10 m^2 of dry beach surface (Medina et al., 2007). These beach structures are occasionally surrounded by plastic nets to protect users from the wind. As recorded in the 2004 Natural Reserve Master Plan *"the plastic nets used as windbreaks to protect hammock users cause natural variations in the dynamics of the dunes because they are an obstacle to the wind dynamics"* (Medina et al., 2007). Along with the above, kiosks can also be included as structures that alter aeolian sedimentary transport, causing deflation surfaces and loss of sediment behind them, practically from their first installation in the 1970s. In addition, many of these structures are located close to the plant specimens that construct the foredune in a way that affects the sediment that reaches them and contributes to the formation of wind shadow corridors (Alonso Bilbao et al., 2007; Medina et al., 2007; Hernández-Calvento, 2002; Sanromualdo-Collado et al., 2021). Moreover, El Inglés beach has kept and steady coastline along the years, compared to the great sediment loss in Maspalomas beach, while the beaches in the north part of El Inglés beach coastlines slightly advanced thanks to the groins built there between 2004 and 2009, but not having any effect in El Inglés beach (Medina et al., 2007; Di Paola et al., 2020).

Tides in the coast are under a meso-tidal regime with a semidiurnal tide pattern, also, waves in this beach propagate with a NNE to ENE direction almost perpendicular to El Inglés beach during the year and waves from SSW to WSWS only during winter. Meanwhile in Mapalomas beach waves follow a SW travel parallel to the coast (Di Paola et al., 2020; Fontán-Bouzas et al., 2019; Fontán et al., 2012).

In the Maspalomas dunefield, the transit of off-road vehicles through the beach-dune system primarily involves security services, as police cars, the transportation of supplies to shoreline kiosks with trucks, garbage container collectors and heavy-duty machinery for beach cleaning and levelling, and, secondarily, off-road vehicles related to scientific research in the area and certain organizations (e.g. Red Cross). The vehicles related to security or social organizations consist on off-road cars that travel through the dry beach randomly when beach users are present. However, food supply and beach cleaning machinery consist on bigger trucks. All of these vehicles travel through the dry beach area, in order to not interfere with the beach users that are close to the water. The presence of these vehicles varies depending on the users present on the beach and the number of activities being carried out. However, the climatic conditions of the Canary coast, almost stable all year round, have resulted in year-round intensive tourism use and the year-round intensive presence of all the beach services required to satisfy the users' needs. Therefore, the beach service carried out by the cleaning machinery, which consists on a truck with a container attached to the back of the truck and a large shovel to level the beach, takes place every day through the whole dry beach area, irrespective of the presence or absence of users on the beach or the weather conditions. The levelling activities related to beach cleaning conform a highly negative impact for the beach because, as they travel every day and every year, it is a continuous activity that produces sediment compaction each day and would be having possible major affections in sediment dynamics on the beach (Roig-Munar, 2004; Roig-Munar et al., 2012).

In view of all the above, this study focusses on the beach area of *El Inglés*, specifically in the area from the intertidal zone to the foredune. The study area is delimited to the north by the *Anexo II* shopping centre and to the south by the *La Bajeta* headland (Fig. 1, A).

3. Methodology

3.1. Vehicle track digitalization and establishment of study plots

In order to test the long-term environmental effects of the vehicle tracks and especially heavy duty machinery tracks, it was necessary to develop a first methodological approach at different spatial and temporal scales. A total of seven variables were established (Fig. 2, A). Three steps were taken to study the effects of vehicle traffic and beach cleaning machinery. Firstly, a decadal analysis of track variation related to vehicle traffic from 2002 to 2018 was conducted based on the manual digitalization of vehicle track in orthophotos through photointerpretation. Secondly, a field campaign was conducted and an interview held with the beach cleaning personnel to observe, annotate and digitalise the tracks from the beach cleaning machinery and in this way obtain *in situ* density maps and beach width measurements. The results from the field campaign were correlated to the decadal digitalization of vehicle traffic. Finally, an analysis of the correlation between variables was made. The variables were slope, vehicle track density, deflation surfaces and sediment gain and loss through topographic profiles and linear graphics. Correlations were determined between all the variables (Fig. 2, A).

Orthophotos were obtained from the Spatial Data Infrastructure (SDI) of the Canary Islands (GRAFCAN, S.A.-Canary Islands Government) and incorporated into a geographical information system (GIS). The years chosen were since 2002 (as the first year in which spatial resolution allowed effective digitization of vehicle tracks) to 2018 (Table 1), which is to say over a total of 16 years. In each image, the vehicle tracks were digitalized using GIS through polylines which were identified by visual analysis with the orthophotos that allowed enough resolution to see tracks in the sand. Although orthophotos with lower resolutions (2 or 4 m) did not show the exact width of the vehicle wheel due to the lower resolution, the images chosen did show the approximate linear area occupied by the tracks indeed, allowing us to digitalise them through polylines to take a view on the areas with higher and lower tracks from vehicles in the beach (Fig. 2, B).

Then, density maps were obtained (kernel density) for each year individually. In addition, a map was made with the total density of tracks from 2002 to 2018 in order to see the distribution of vehicle track density along the beach in this period. Once these maps had been obtained, 6 plots were established (from the northernmost -*Anexo II Shopping centre*, P1- to the southernmost -*La Bajeta* headland, P6-) along the study site. These plots were chosen according to the 2002–2018 accumulated track density map (Fig. 2, B), which is representative of the whole study period. The geometry of the plots followed the main wind direction of the study site and included an area from the intertidal zone to the foredune.

3.2. Beach-cleaning observation field campaign

A field campaign was performed in order to establish correlations between the track densities of all the vehicles present on the beach detected through the orthophotos with respect to those from beach-

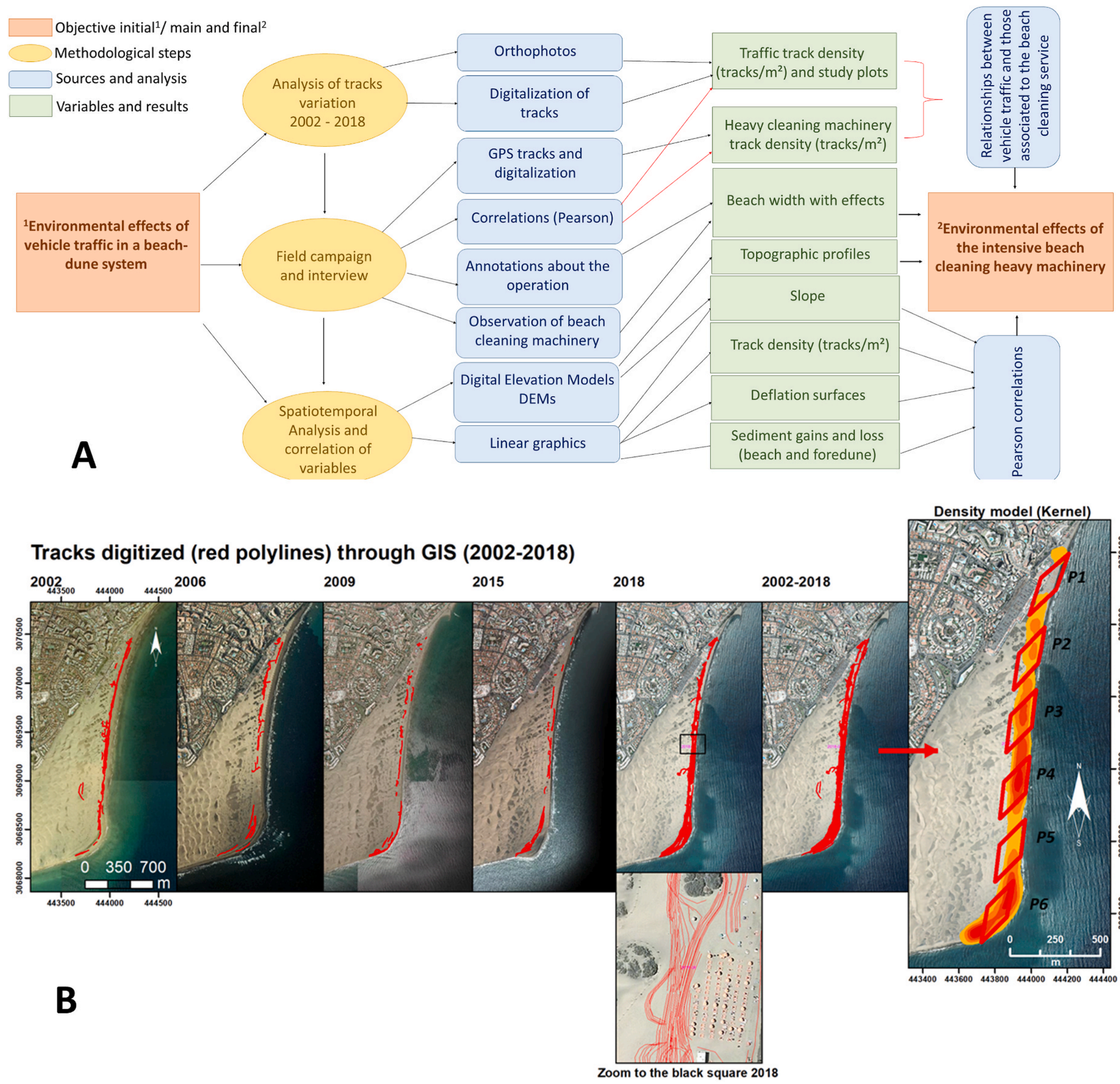

Fig. 2. Applied methodology. A: Flowchart of the methodological process. B: Working-scale digitalization of polylines with GIS from the orthophotos (years 2002–2018). On the right are the kernel density map and the study plots, which are designed to cover different density conditions (red squares P1 to P6, P = plot). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Cartographic documents used in this study.

Type (Source)	Year	Scale	Spatial resolution (m)	RMS (m)
Orthophotos	2002[1]	1:18,000	1	< 1
	2006[1]	1:18,000	0.4	< 1
	2009[1]	1:25,000	0.4	< 1.5
	2015[1]	–	0.25	< 1.5
	2018[1]	–	0.2	< 1.5
	2003[3]		4	
LiDAR data through flight (DEM)	2006[2] *	–	2 and 4	–
	2009[2]	–	2	–
	2015[2]	–	2	–
	2018[1]	–	2	–

RMS = Root mean square. ^ flight with GSD de 22.5 cm/píxel. [1]SDI Canarias (Canary Islands Government-Grafcan S.A.) [2]National Geographical Institute (Spain). * DEM was resampled at 4 m spatial resolution to compare with the year 2003.

cleaning activities.

The fieldwork was carried out on 9th April 2021. The aim of this campaign was to differentiate the tracks of the cleaning machinery from those made by the rest of the vehicles. The campaign, which started at 03 a.m. from the observation point in kiosk 2 of *El Inglés* beach (Fig. 1, A), consisted of routine observation of the beach cleaning machinery during its working hours through the dry beach. Pictures were taken before and after the arrival of the beach cleaning machinery. While there, notes were made about anomalies in the beach cleaning process, the number of tracks and the routes the vehicles took. Afterwards, the tracks were followed on foot with a GPS to register their coordinates. The GPS additionally registered the coordinates of structures (plants, kiosks or garbage containers) found along the routes.

Finally, measurements of the width of the beach, where effects (especially tracks) of the heavy duty cleaning machinery were detected, were taken at different points along the study area (one at the beginning, five along the beach depending on the structures found on the route, and two more at the end of the route taken by the machinery), all of them covering a surface from the foredune to the beginning of the intertidal, because beach cleaning machinery does not work over the wet sand of the intertidal as the shovel could be damaged and sea water already levels the sand. In addition, measurements of the width of the cleaning machinery were also taken. The campaign finished at 7:30 a.m., after the beach cleaning work had concluded.

Once the GPS data had been obtained, the tracks were digitalized through polylines, considering number of tracks and beach width. With this information, we obtained an empirical density map of tracks due to beach-cleaning machinery in the study area. Finally, a GIS-based raster correlation (ArcMap GIS program) and scatterplots (SAGA GIS program), were made between the digitalized 2002–2018 track density map and the cleaning machinery track map obtained from the field campaign.

3.3. Interview with the beach-cleaning service staff

On March 17th, 2021, an interview was held (Appendix I) with some of the beach-cleaning staff to corroborate the information in the public beach cleaning activities report. It was a semi-structured conversation (Fogerty, 2007) about the main aspects of the cleaning and levelling of *El Inglés* beach. The interview lasted 90 min and notes were taken of all the questions and answers related to this service. During the interview, recent images of the study site were provided to the employees to allow them to indicate the main routes of the beach-cleaning service. In addition, the staff provided a drawing with the main physical characteristics of the machinery used for cleaning the beach.

3.4. Analysis of variables and topographic profiles

Subsequently, the different variables were analysed using spatial geoprocessing, field calculators and zonal statistics tools. Deflation surfaces (m^2) were digitalized using polygons inside each plot according to the Sanromualdo-Collado et al. (2021) criteria, and surface data were obtained from them. Raster digital elevation models (DEM) for each of the 5 years were then used to calculate sediment surface area (m^2) and volume (m^3) in each plot (Table 1, Fig. 3). Data related to track density (tracks/m^2) in each plot were obtained from the density maps (kernel) using zonal statistics tools in GIS.

In addition, a polyline in the middle of each plot was drawn to obtain the topographic profiles from LiDAR for each year. This allowed a comparison of the changes in the topographic beach profile between years depending on the track density of each plot. Finally, beach slope per plot and year was calculated from these profiles.

Topographical DEMs and DEMs of Differences (DoDs) were cleaned, corrected and calculated (Table 2) using geomorphic change detection (GCD) software, including the calculation between raw and threshold error (Wheaton et al., 2010a,b).

3.5. Beach and foredune differences in volume

The sediment surface area and volume data in each plot were divided into beach and foredune, and these, in turn, were divided into gains and losses. All these variables were later compared to the track density, the profile gradient and the deflation surfaces. The area of the foredune in

Table 2
DoD error (%) from DEMs used to calculate beach and foredune loss and gains between 2003 and 2018.

Sedimentary process/ time period	2003–2006	2006–2009	2009–2015	2015–2018
Accumulation	16.34	8.48	9.44	6.44
Erosion	19.45	8.75	6.78	6.55

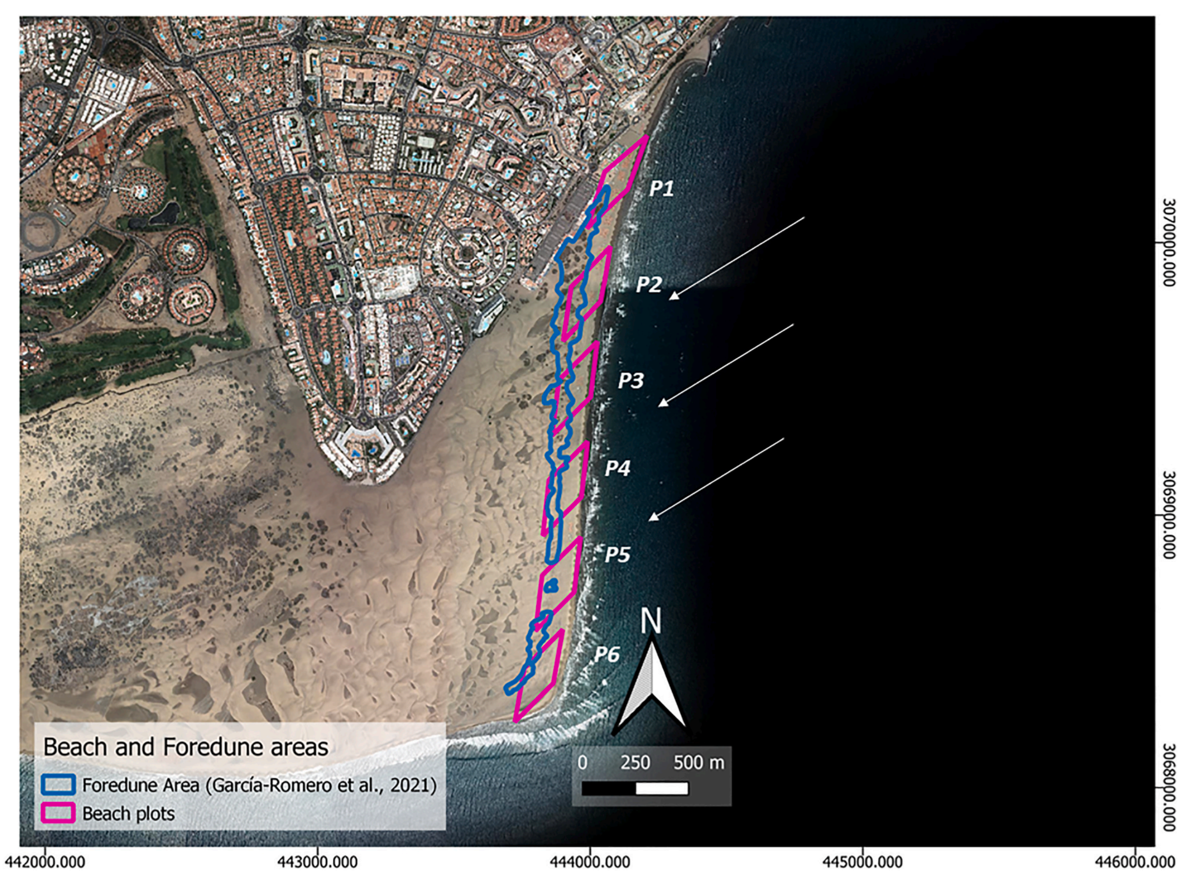

Fig. 3. Beach and foredune areas used for the analysis of sediment gains and losses. Foredune area from García-Romero et al. (2021). Plots are named from 1 to 6 (P = plot) and white arrows indicate the main wind direction.

each plot was taken from the polygons used in García-Romero et al. (2021) (Fig. 3). The foredune area of 2003 was used as this was the closest year to the start of the study period. Volume and surface area data of foredune gains and losses were calculated directly from the Cut Fill tool in ArcGIS. The same was done for the area related to the beach only (Fig. 3), and all the information was exported into a datasheet. Scatter plot charts were generated to show the time evolution of gains and losses of volume in the beach and foredune for each plot. The same action was performed for the deflation surfaces (m^2), track density (tracks/m^2) and slope (metres). Finally, a Pearson correlation analysis (p value < 0.05) was performed in R software (R Core Team, 2018) for all the variables.

4. Results and discussion

4.1. Track variation in El Inglés beach (2002–2018)

As can be seen in Fig. 4, areas were identified with a higher relative track density per m^2 (between 168 and 1030 tracks/m^2, dark blue), with a lower relative density (between 42 and 257.5 tracks/m^2, white) and with two medium relative track densities (between 84 and 772.5 tracks/m^2, light blues). Moreover, the accumulated track densities over the study period (Fig. 4, years 2002–2018) shows values between 333 a 1332 tracks/m^2). The area with the lowest track density was located to the north of the study area. A large area of constant track density was observed over time located in the middle of the beach, except for the years 2006 and 2015 when track densities were low in this area. In the southern part of the beach, near *La Bajeta* headland (Fig. 1, A) and entering Maspalomas beach, a large area with a high density of tracks could be identified that was only not repeated in 2002, when its density was low.

On this basis, from the 6 plots established and grouped according to accumulated track densities throughout the study area (2002–2018), it was observed that plot 1 surrounds the area with the lowest density, while plots 4 and 6 delimit the places with the highest track density. Plots 2, 3 and 5 have medium densities (Fig. 4, bottom right).

As tracks in these years were identified from orthophotos, they are an indirect measure of global traffic on the beach. The resolution of the orthophotos does not permit the differentiation of tracks due to heavy duty machinery responsible for the beach-cleaning service from those due to ordinary traffic related to other beach services.

In 2004, the Master Plan of the Special Natural Reserve of the Dunes of Maspalomas (BOC No. 245 of December 20, 2004) was published, establishing the permitted and forbidden uses and activities on the beaches. This Master Plan was developed in order to mitigate/reverse the possible impacts of activities and equipment on the beach. The effect of this Plan can be seen by comparing the relative density maps of 2002 and 2006 (Fig. 4), with a substantial observable change in track density

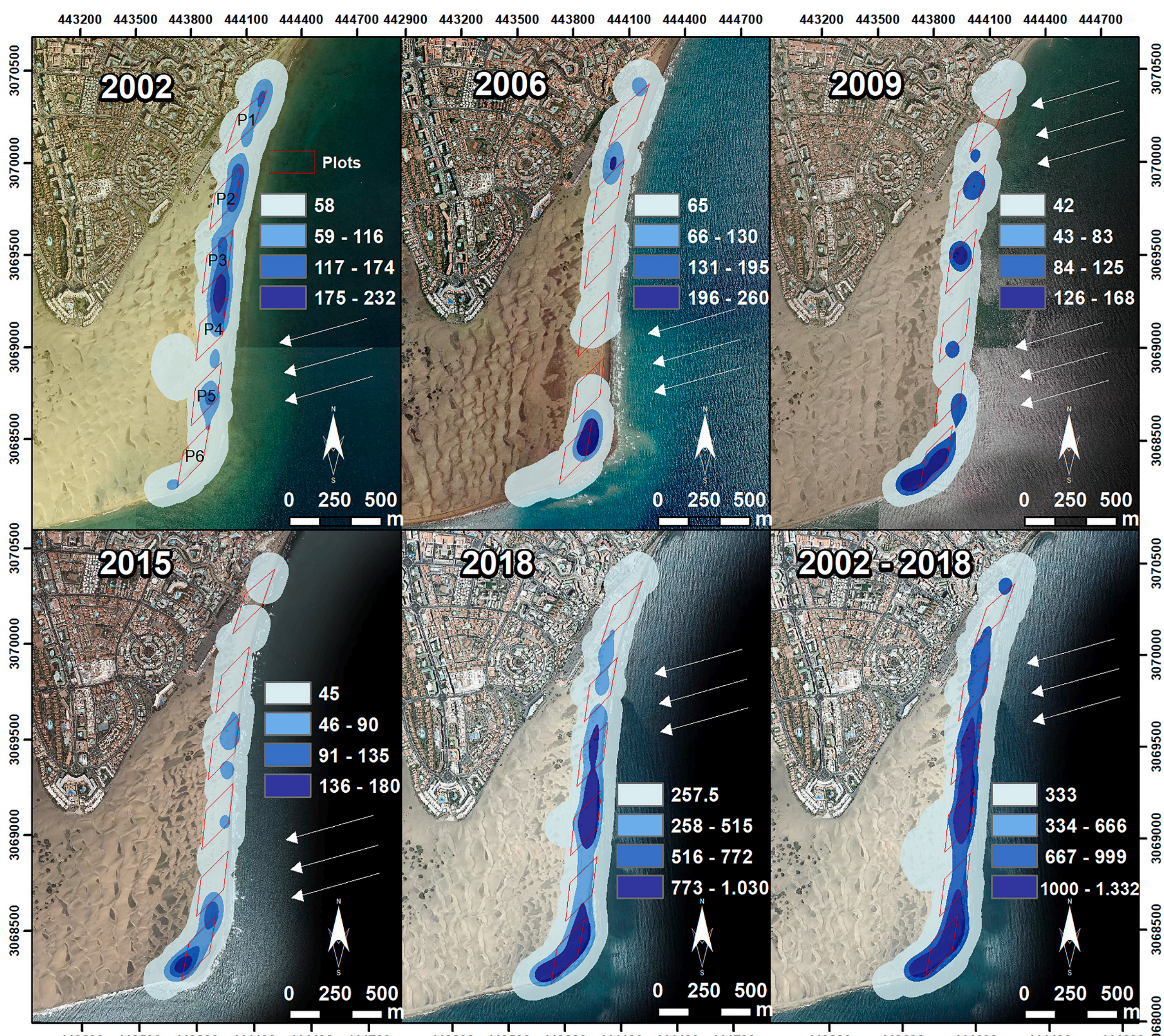

Fig. 4. Relative track densities (kernel: tracks/m^2) per year (2002, 2006, 2009, 2015 and 2018) and accumulative track density between 2002 and 2018. White arrows indicate the main wind direction.

patterns. There was also a marked change in relative track density between 2015 and 2018. The recovery in touristic activity between 2009 and 2018 (Table 3) could also have caused an increase in the number of vehicles, requiring more security and supplies to beach catering services due to the increase of potential beach users that year (which can be inferred from the increase in the number of tourists in the municipality). Therefore, the years with an increase in tourism suffered a more pronounced increase in track density, while the year in which the management and regulation plan was implemented resulted in a change in the distribution pattern of vehicle tracks.

4.2. Beach-cleaning campaign and heavy duty machinery tracks identification

Data obtained from the field campaign showed that the cleaning machinery only worked over the northern half of the beach (Fig. 5). The route of the cleaning machinery covered the first three established plots, coinciding with areas of low and medium track density and not reaching the plots with higher track density. In addition, the highest track densities of the cleaning machinery coincided with the points of highest density (dark blue) in the general density track map (Fig. 6).

As a result of the field observation campaign, it was possible to verify that beach cleaning did not adhere to the plan described by the beach cleaning staff of San Bartolomé de Tirajana during the interview, which said that the beach was cleaned in its entirety from north to south (Appendix I). This is because, towards the south, the beach has experienced an increase in the presence of unusual stones that could damage the machinery. These stones have appeared in the sand replacement area defined for the MASDUNAS project, financed by the Gran Canaria Council with the aim of restoring the Maspalomas foredune (Sanromualdo-Collado et al., 2021b). This area also coincides with the end of the sector with the greatest presence of beach users.

The analyses that were undertaken revealed a strong correlation and positive trend (0.688) and R^2: 41.01%, between the tracks associated to beach cleaning machinery and the total vehicle tracks obtained through orthophotos (accumulative from years 2002–2018) (Fig. 5). Likewise, there are strong correlations and positive trend too, for the years 2002 (0.604; R^2: 36.85%), 2006 (0.690; R^2: 45.07%), 2009 (0.507; R^2: 28.45%) and 2018 (0.52; R^2: 25.92%), while for the year 2015 there is a low degree of correlation (0.204; R^2: 5.16%).

The presence of stones and the consequent reduction in the number of tourists are likely to be the main reasons why the cleaning work was reduced to the northern half of the beach, which is the area with the greatest presence of beach users.

According to the results, the beach-cleaning machinery density map of the tracks obtained through the field campaign largely coincided with the density track maps obtained on a decadal scale (Fig. 6). Therefore, it can be argued that of all the vehicles present in the study site, the heavy duty cleaning machinery is one of the main contributors to the tracks and hence to the effects on the beach-dune system.

4.3. Topographic profiles along El Inglés beach with different track density conditions

The topographic profiles in each plot (Fig. 7) varied between 180 and 200 m of beach length. These differed from each other and, in general, the 2003 profile (green) stood out in all the plots with a different behaviour. The rest of the years tended to be similar, with a few exceptions. In addition, the height of the profile varied for each plot, from maximum values of 8.5 m in the plots to the north to 2.7 m in the plots to the south.

Regarding slope changes, these were more noticeable when variation in the height of the profile was less, as in the case of profiles 3, 4, 5 and 6 where height only varied from approximately 1 to 3 m. Areas where the slope was less steep were related to plots with the highest range of profile height, as in the case of profiles 1 and 2 where height varied from approximately 1 to 8 m (Fig. 7).

After the building of the *Anexo II* open-air shopping centre in the north of *El Inglés* beach due to the tourism and residential growth of the area, the first line of dunes at this point was lost (Hernández-Calvento, 2002). The increases in the height of the profile at the beginning of plots 1 and 2, especially in plot 1, correspond to the aforementioned shopping centre and not to the foredune. In the areas with the highest track density, as is the case of plots 4 and 6, the variation in profile height was continuous. This could be due to the presence of tracks along the entire plot (Fig. 4), together with the decrease in the slope due to sediment compaction and levelling of the beach (Munar, 2002; Roig-Munar, 2004).

The area closest to *La Bajeta* headland, in the south of the study area (plot 6), is a point of changing conditions due to the coastal dynamics of the area tending tend to vary continuously as the result of western storms (Alonso Bilbao et al., 2001). Therefore, the profile of the beach was variable, as were the changes in the slope. It is thus difficult to determine the variability of the large presence of tracks in this area because of the constantly changing sedimentary dynamics of the system. Regardless of the cause, it can nevertheless be affirmed that the profile in this plot remains constant over time and that the slope does not vary significantly.

4.4. Analysis of the spatial and temporal variation of the variables analysed and their trends

Results showed that the number of vehicle tracks remained stable or increased slightly in all plots, experiencing a very marked increase in 2018, as a consequence of the recovery in touristic activity. In contrast, it can be seen that the slopes of the profiles, although they increased slightly, as in plots 2 and 3, generally remained stable over time (Fig. 8).

On the other hand, deflation areas tended to increase over the years, except in plots 1 and 2 where no deflation areas were identified due to occupation by the open-air shopping centre, and in plot 5 where they decreased over the years (Fig. 8).

The technical improvements introduced in heavy duty machinery over time, as well as the increase in the number of cleaning vehicles, have led to an increase in the number of tracks present on the beach. In any case, according to the measurements taken in the campaign (Fig. 6, right and Table 4), the areas where the beach is wider, either due to the absence of infrastructures or due to a stronger low tide, correspond to a greater area of movement for heavy duty machinery, causing an increase in the number of tracks when trying to cover all the beach area.

In *El Inglés* beach, deflation surfaces were formed when the first kiosks and containers were installed (Díaz Guelmez and Hernández-Calvento, 2004; Sanromualdo-Collado et al., 2021). These have been moved and located at different points on the beach over the years. Consequently, these surfaces have not been formed by the presence of vehicles on the beach but have been influenced by it. In addition, the higher the track density, the greater the possibility that the deflation surfaces will increase (Balbuena et al., 2003). Therefore, if activities such as beach cleaning play a role in sediment compaction and modify the sedimentary dynamics in beach-dune systems, they will maintain or increase these deflation surfaces due to the loss of sediment (Fig. 8).

With the construction of an open-air shopping centre in the north of *El Inglés* beach a significant part of the foredune was lost, and the wind and sedimentary transport to the south were altered (García-Romero et al., 2021; Sanromualdo-Collado et al., 2021; Hernández-Cordero

Table 3
Number of tourists in San Bartolomé de Tirajana. Data source: Canary Institute of Statistics. Economic and Social Council of the Canary Islands: 2003 Annual Report (ISTAC Canarias).

Year	2002	2006	2009	2015	2018
No. of tourists	2,649,974	2,003,509	1,592,286	1,967,832	2,472,801

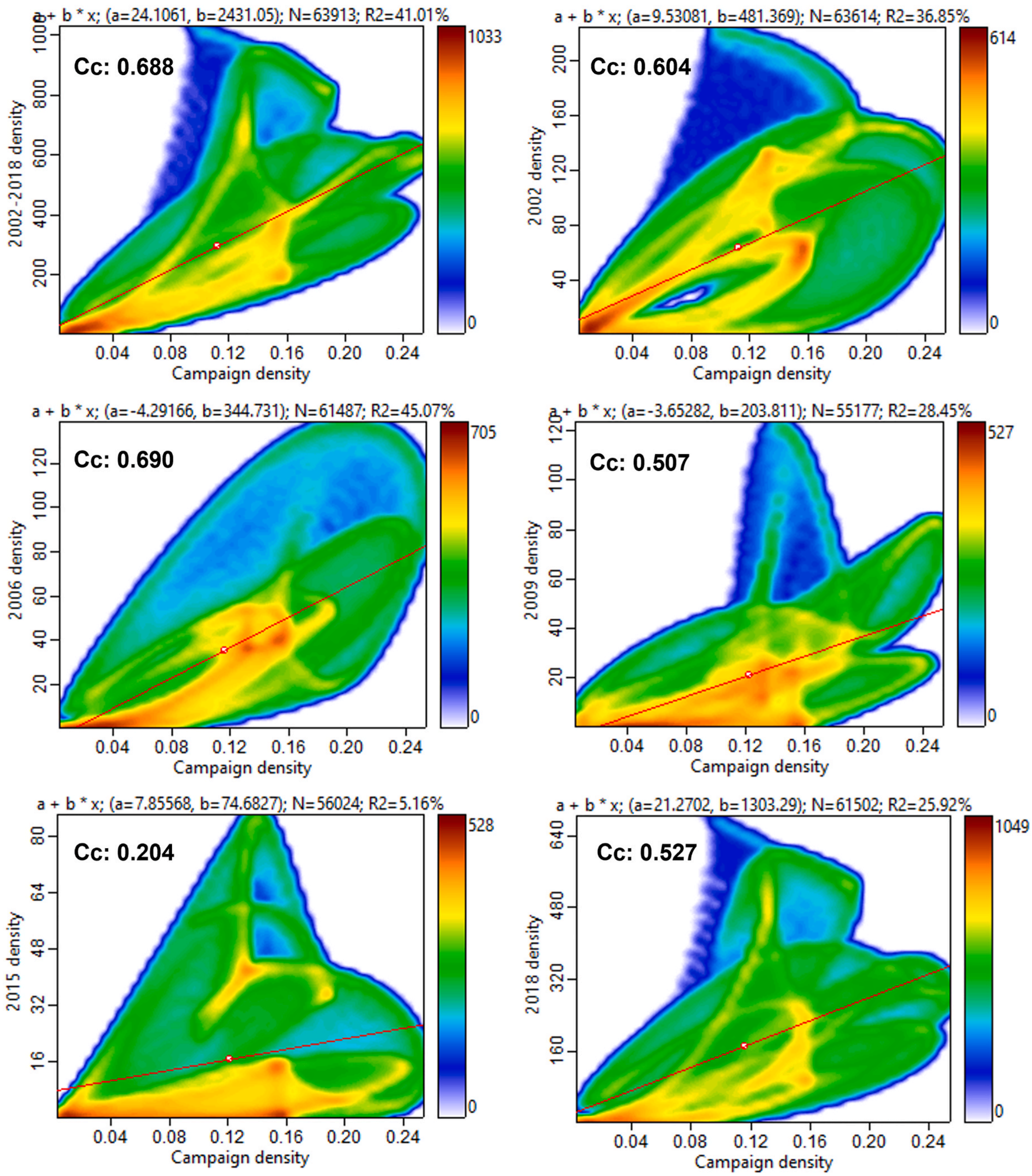

Fig. 5. Scatterplot and Correlation (Cc) between orthophoto-based track density maps (from years 2002–2018) and the beach-cleaning machinery density map obtained from the field campaign.

et al., 2006). Therefore, there are no deflation surfaces in this area. This point of the environment is a narrow area that is formed only by the beach and in which the upper area of the beach profile is supported by the wall of the urbanization, so that the sediment is not lost. In addition, as observed in the field campaign, the sand is not only levelled, but also displaced towards the ends of the beach with the front shovel of the truck, accumulating the sediment in these points (north and south). For this reason, the plots further north do not suffer sediment loss or the formation of deflation surfaces since they maintain a continuous supply of sediment after each daily cleaning. Likewise, at these points in the study area the slope follows an expected beach profile, since it does not undergo changes due to storms and the sand is artificially distributed, maintaining the profile.

In general, *El Inglés* beach maintained a stable profile over the study period (Fontán-Bouzas et al., 2019), and the slope of the beach did not vary by more than 1 m in any of the plots. This profile variation differs considerably from highly dynamic beaches where the slope varies between 2 and 5 m (Bértola et al., 2009). In addition, the variation of the slope in the study area is an unusual situation in dynamic beach systems, and much less common in eastward-facing beaches in the Canary Islands (Di Paola et al., 2020).

As the foredune is the sediment entry point into the dunes (Hesp, 1988), the amount of sediment that reaches the foredune determines the size of the dunes. Most of these inputs come from the beach, so the actions carried out in this area can lead to important effects on the size of the dunes (Servera et al., 2007).

Therefore, when the activities carried out on the beach cause sediment loss in it, there is simultaneously sediment loss in the foredune

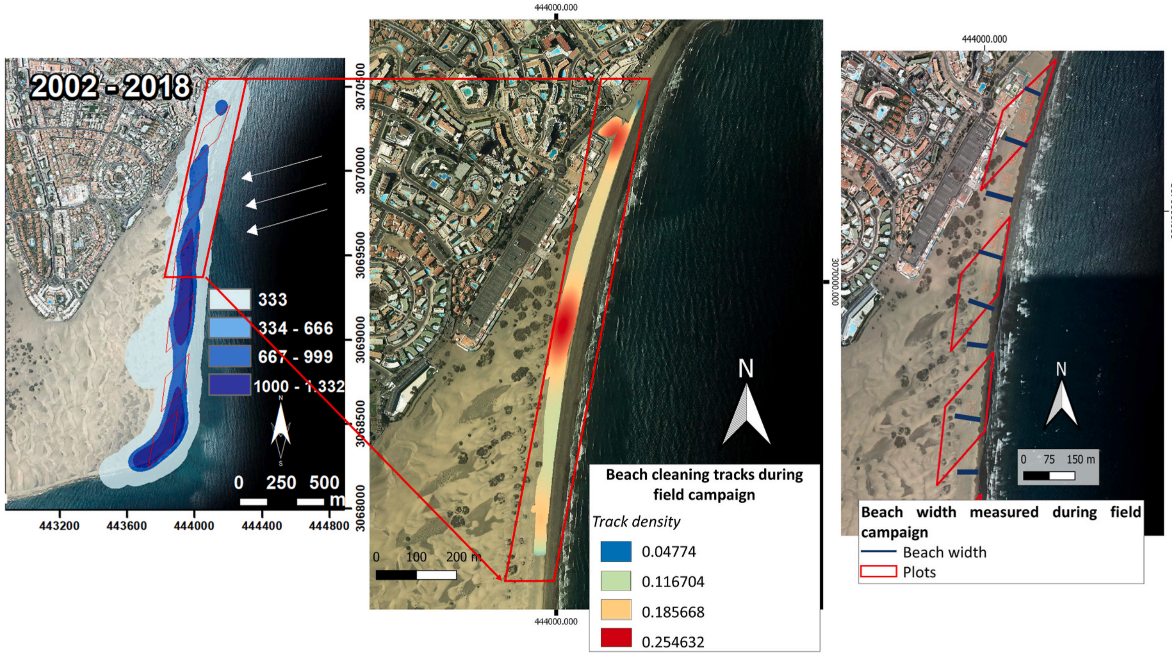

Fig. 6. Comparation between accumulated track densities (2002–2018) and observed beach cleaning with heavy duty machinery paths during the field campaign (centre). The map on the right shows the location where beach width was measured during the field campaign.

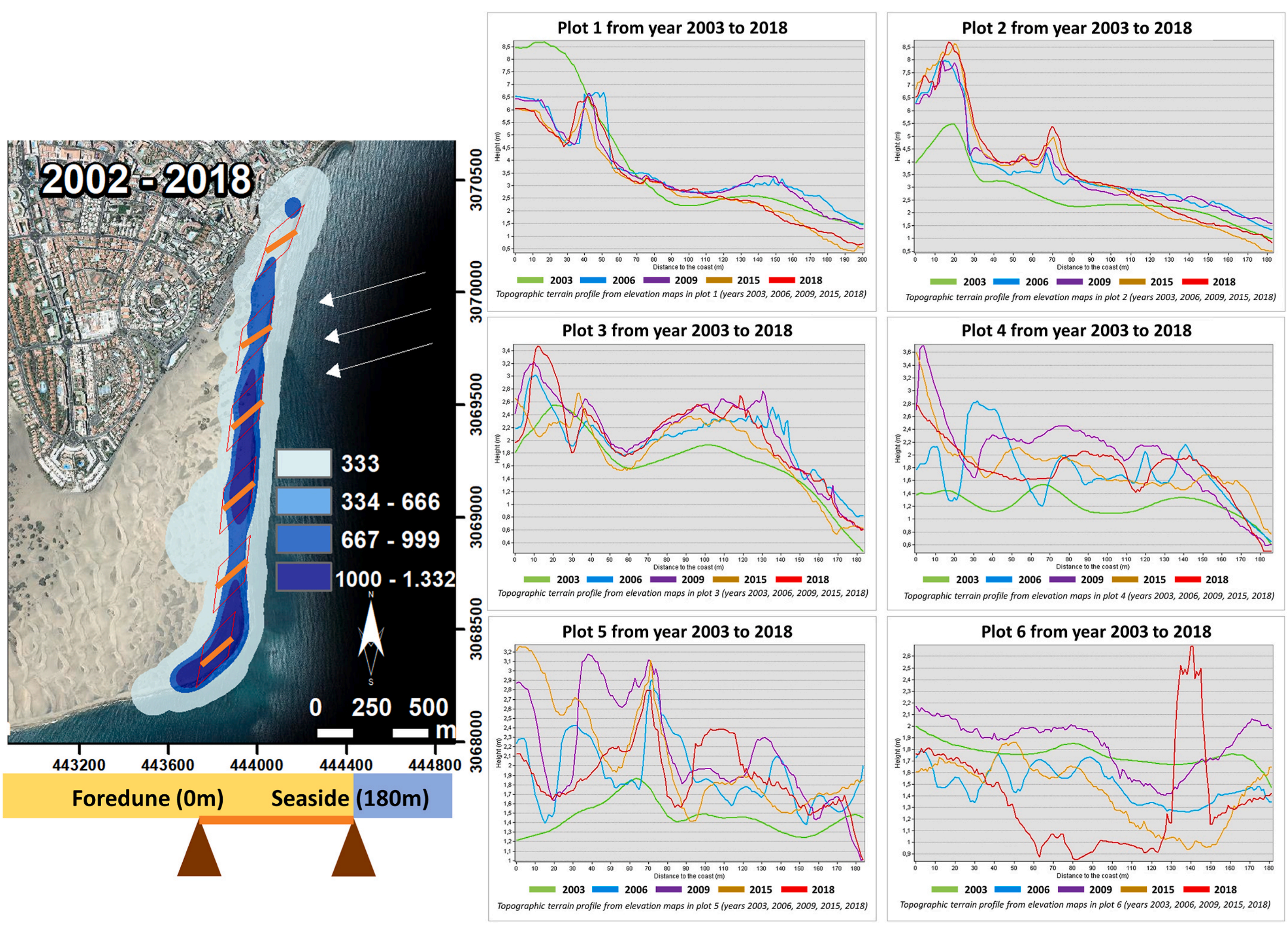

Fig. 7. Topographic profiles in *El Inglés* beach through the years. Foredune is 0 m and the seaside is 180 m. Orange lines indicate the topographic profile digitalised in each plot (P). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

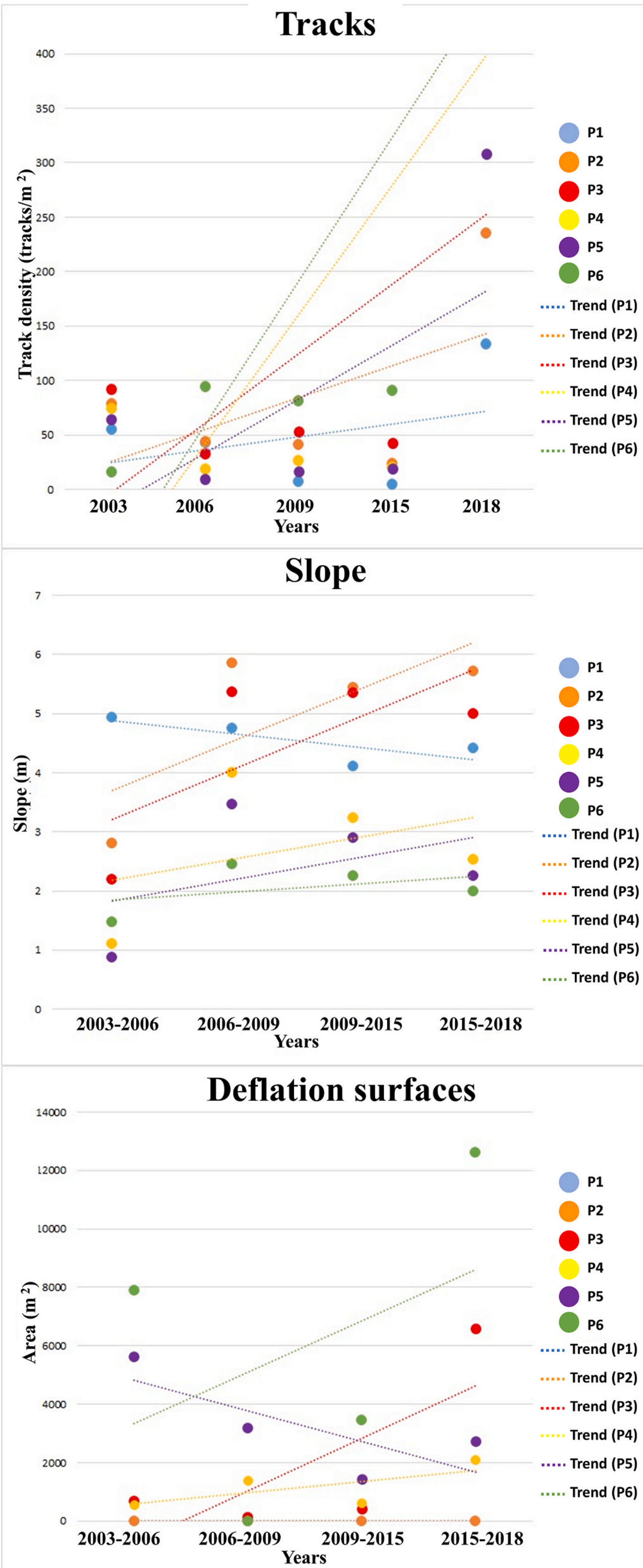

Fig. 8. Variation of the variables in each plot through the years.

(Roig-Munar, 2004). The same happens for sediment gain (Fig. 9). Sediment loss in both zones could have increased over time due to continuous compaction and remobilization/flattening of the sand and, therefore, to the modification of the wind sedimentary dynamics. Sediment loss on the beach over time coincides with the increase in vehicle tracks, so we can gather that these tracks are contributing to erosion on the beach, that these conditions are reflected in the foredune, and that they may represent an obstacle to sediment entry into the system.

4.5. Relationships between variables related to sediment transportation from the beach to the foredune by aeolian dynamics and the beach-cleaning service

The correlation between pairs of variables was analysed using Pearson's coefficient. The results showed significant correlation with values above 0.4. A significant positive correlation (0.41) was detected between the density of tracks (Tracks) along the beach and the deflation surfaces (Deflation Surface), while the correlation obtained between the slope and the deflation surfaces was also significant, but negative (-0.55) (Fig. 10).

Deflation surfaces had a positive correlation (0.42) with the surface area of sediment loss in the beach area (Surface L Beach). Losses in terms of foredune sediment volume (Volume L FD) were positively related to beach volumetric losses (Volume L Beach) (0.49) and to beach surface area sediment loss (Surface L Beach) (0.56) (Fig. 9). In summary, the greater the number of vehicle tracks, the more deflation surfaces, less slope and greater sediment losses both in the beach and foredune area of the plots.

5. General discussion

5.1. Relationship between vehicle tracks and heavy duty machinery tracks and its role on the aeolian sedimentary dynamics

This study, which pretends a first proposal to understand if the vehicle traffic, especially the heavy duty machinery of the beach cleaning service, affect long-term aeolian sedimentary dynamics, not only showed that the heavy duty machinery account for the majority of the vehicles tracks, but these, though not the only factor influencing the variation of the sedimentary dynamics, are related to the decrease in sediment volume of the dune system. Moreover, the heavy duty cleaning machinery constitutes a large structure and is used exclusively for remobilizing the sand and levelling it (Fig. 11), while the rest of vehicles present on the beach cover a smaller area and are more concentrated in the same place, according to the regulations that exist for them. Beach cleaning is an activity that is carried out daily regardless of the presence or not of users and/or beach structures according to the interview conducted with the local team responsible for this operation (Appendix I). For this reason, it can contribute to an important extent to sediment loss in the dune system. Given that the field campaign data generally matched the results of the decadal track analysis, it can be considered that the activities associated to heavy duty cleaning machinery are one of the agents that contributing to sediment loss in the foredune for a long time in the Maspalomas dunefield, more specifically *El Inglés* beach, that is, practically the hypothesis proposed by this research (Figs. 9–11).

Areas with higher track densities correspond to areas where the cleaning machinery has a longer beach width to work in, according to the measures taken in the campaign (Fig. 6, right). Given the width of these areas, a higher number of routes are required to clean the area correctly in its entirety. In addition, the machinery has a larger surface area to move through, leading to a greater number of manoeuvres or turns. As noted in the campaign (Table 4), at the beginning of the work schedule the cleaning machinery takes a long time to clean the northern part of the beach due to the considerably greater number of turns that are required compared to the rest of the beach because of the presence of sports facilities in this sector. This, along with the daily movement of sand by the machinery to the northern part of *El Inglés* beach, explains why the track density in this area is higher than in other parts of the study site.

Table 4
Width of the different transects of *El Inglés* beach measured during the field campaign (9th April).

Beach transects (Field campaign)	North	North entry to the beach	Kiosk 2	Red Cross kiosk	Isolated nebkha (Foredune)	Middle Beach 1	Middle Beach 2	South end
Width (m)	39	44	45	45	57	32	31	62

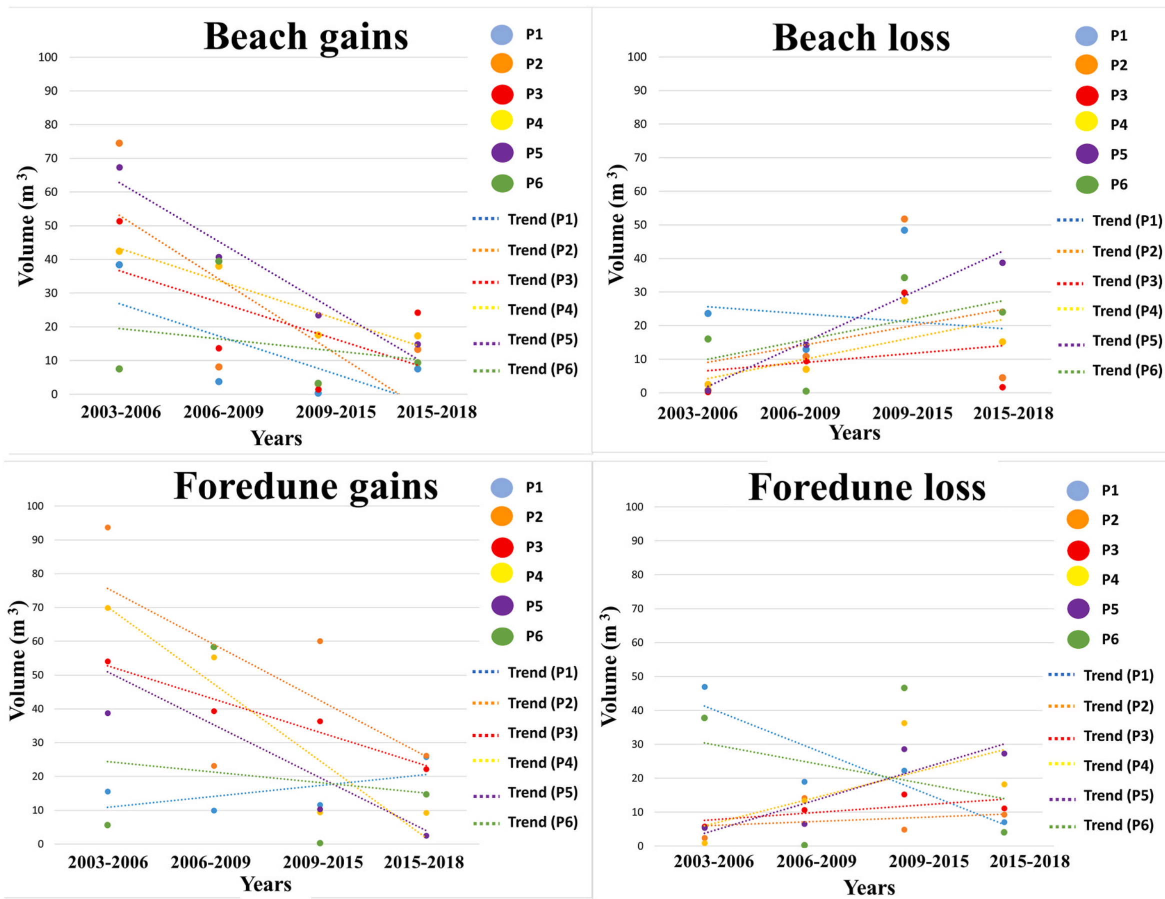

Fig. 9. Beach and foredune gains and losses for each year and each plot.

In the correlation analyses carried out in this study (Fig. 10), track density is only correlated with the deflation surface variable. As explained, it is not detected that vehicle tracks have a direct impact on sediment loss or gain inside the system, but rather they increase the degree of sand compaction and erosion in the beach area, preventing sediment transportation within the dune system (Roig-Munar, 2003). The traffic, cleaning, levelling and displacement of sand by the heavy duty machinery could be contributing to the stabilization of the beach coastline and profile in an artificial way. Thus, the global sedimentary loss in the system is not reflected on the input beach, which has an artificially-maintained steady profile, but in the inner zones of the system and on the output beach (Maspalomas beach).

Beach-dune systems are dynamic systems in which a large number of variables interact with each other and in which, therefore, possible impacts may be related to several variables. Bearing this in mind, it is difficult to find a single variable that is responsible for the impacts identified within the system. However, the correlation analysis shows that the vehicle track density on the beach contributes, along with other elements previously identified (e.g. kiosks, umbrellas and sunbeds, windbreaks) (Sanromualdo-Collado et al., 2021a,b), to the formation and maintenance of deflation surfaces. The impact of vehicle track density gives rise to deflation surfaces on the beach that cause sediment loss in the first line of dunes. Deflation surfaces appear in the beach area and behind the dunes, and so this variable is related to sediment gain and loss both inside and outside the dune system. In addition, by being positively related to vehicle tracks, deflation surfaces serve as a junction point between traffic and sediment gain or loss in the system. Therefore, although track densities are not directly correlated with sediment loss or gain, they are indirect causes or proxies of these impacts in the dune system. On the other hand, in areas where fewer crossings are made by vehicles, deflation surfaces are scarcer, causing the sediment not to be lost and allowing it to be transported by the wind to the foredune and, in this way, introduced into the system.

5.2. *Proposals for beach management. Vehicle traffic and beach cleaning service*

In view of the observations made in this research, it is proposed that it might be convenient for the majority of vehicle traffic to be specifically routed along pre-established pathways at the back of the beach. These pathways should be natural, and their layout should take advantage of the wooden stakes already present in the beach. Moreover, the pathways need to be some distance from the foredune so its formation and/or the vegetation on it are not affected. To clarify, this proposal is just a first idea to a proper management of beach cleaning activities and other vehicular activities related. Is supposed that maybe

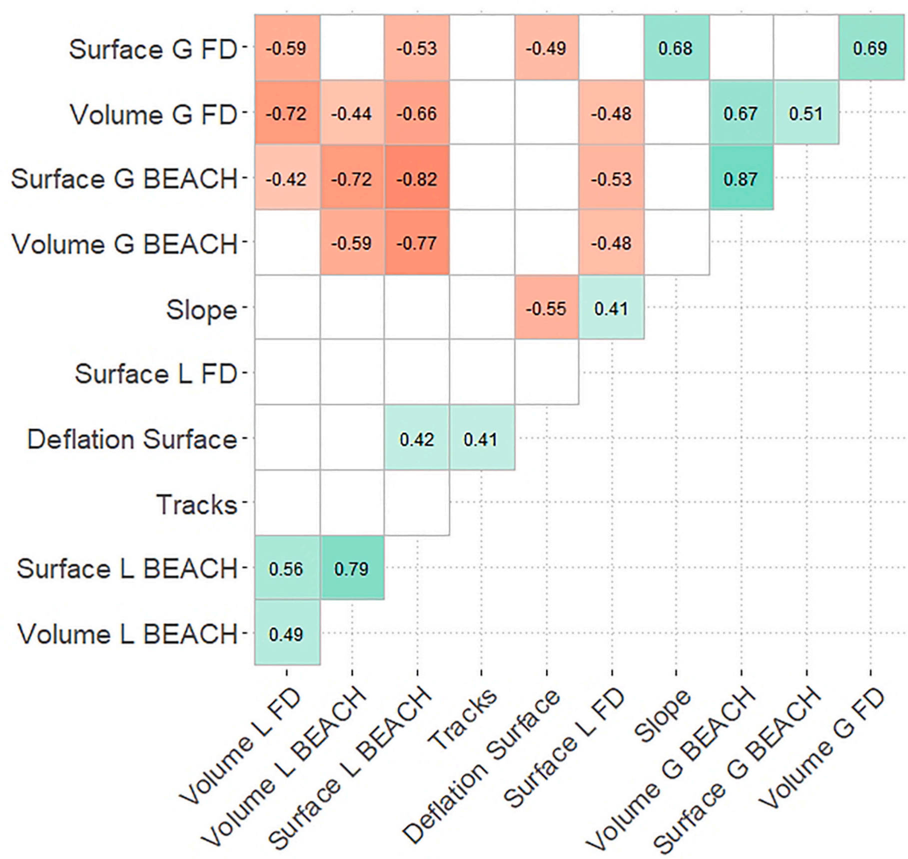

Fig. 10. Correlation between variables in each plot of *El Inglés* beach. (L = Losses; G = Gains; FD=Foredune). Only results with p value < 0.05 are shown.

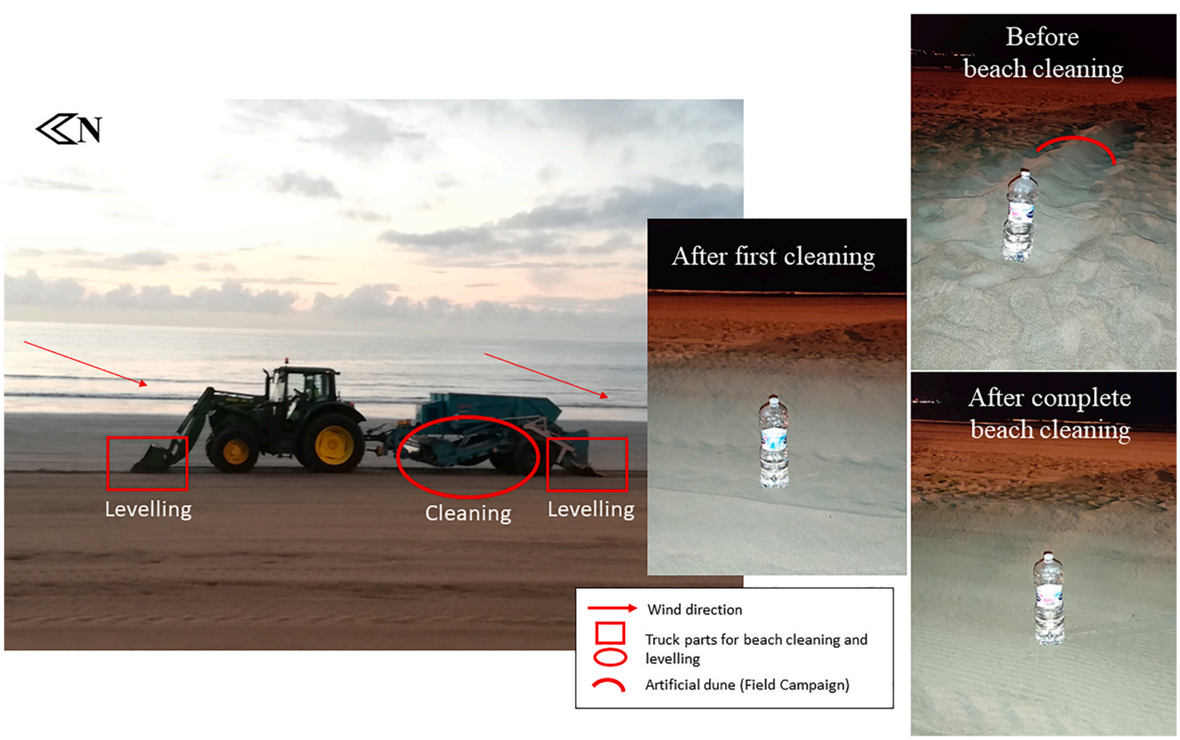

Fig. 11. Heavy cleaning machinery and evolution of an artificial sand dune formed during the field campaign (9th April 2021) in the study area due to beach cleaning. At the back of the truck there is a plastic longitudinal tyre used for the levelling of the sand after its sift.

these pathways would allow sediment movement along the beach and avoid compaction, and if clearly marked would not be impacted by the presence of beach users. They would allow sediment transportation across the beach as the whole beach would not be criss-crossed by vehicular traffic. Therefore, the effects of regular vehicles, beach cleaning machinery and their traffic distribution along the beach would be interesting to study in greater detail in future works in order to achieve the best management practices, and if needed, limit this activity, but further research and trial and error are still needed for this new concerned impact.

A series of measures are proposed that could be applied to improve the cleaning and reduce the indirect impact on the dune system. Currently, cleaning is carried out from north to south, interfering in the NE-SE wind dynamics. Changing the beach cleaning routes, following the direction of the wind, could facilitate the movement of sand by the machinery itself in its natural wind direction despite the remobilization and compaction of the soil, since wind transport would not be cut off. In turn, in times of high wind dynamics and wind speed, users present on the beach are scarce due to the discomfort caused by the strong trade winds characteristic of this geographical area. Therefore, at such times levelling activities could be reduced or even supressed in order to facilitate transport within the dune system. The sand that is collected could be distributed on a regular basis throughout the beach, avoiding sediment compaction, instead of taking it to a specific point (usually the areas at the northern and southern ends of the beach where several turns and manoeuvres are made by the machinery). In addition, time and effort are being wasted in levelling the beach when it is not necessary. Currently, cleaning tractors are not permitted to approach the foredune vegetation, but as we observed in the *in situ* observation campaign this is not always possible due to the size of the machinery and the presence of obstacles on the beach, such as garbage containers or kiosks. As a result, the tractors sometimes work close to the vegetation at the top of the foredune. It would therefore be convenient for specific pathways to be established for all vehicular traffic in *El Inglés* beach, ensuring that some distance is maintained from the foredune.

5.3. Perspectives from this research

Conventional methodologies used in geomorphological research in general, and in coastal aeolian geomorphology research in particular, depend on spatial scale (Carter and Woodroffe, 1994; Sherman, 1995). Based on this, problems can arise when attempting to extrapolate findings from one scale to another (either temporal or spatial) (Cooper and Pilkey, 2004). For this reason, it should be noted that the *in situ* observation of the beach cleaning activity in this research was carried out just once. Even though, according to the interview carried out, it seems that the cleaning operation is routine and invariable every day, the results cannot be considered definitive with respect to management and control measures of the service and only serve as an approximation to what anomalies which could be happening and associated to this activity. In the future, on the one hand, carrying out the same type of field campaign at different times of the week (weekdays and weekends) would be convenient, and this way to increase the temporal scale. On the other hand, these campaigns should be accompanied by high-resolution and high-precision topographic surveys to increase the spatial scale, such as terrestrial laser scanner or drone, before and after the daily beach cleaning to quantify more precision the effect of this activity, and at the same time relate these topographic surveys to airflow (*in situ*), sediment properties and regional daily wind and wave data.

Even subjected to the restrictions derived from orthophotos availability, which in this preliminary approach have made it necessary to assume the time of taking the orthophoto as representative of the year in which it was taken, it has been possible to find relationships in the long-term between vehicle tracks and sedimentary dynamics. From this, it is expected that subsequent analysis based on a larger number and more frequent orthophotos allow to improve the methodology proposed to identify changes in long-term sedimentary dynamics from monitoring vehicle tracks.

6. Conclusions

The methodology proposed in this research has allowed detecting evidence of the long-term effects on the topography and geomorphology by vehicles, especially those associated to the beach cleaning service, using tracks.

Vehicle traffic plays a role in the variation of the sedimentary aeolian dynamics of the beach-dune system of Maspalomas. This variation affects the sediment supply to the foredune, causing ecological changes in the dunefield (Special Natural Reserve of the Dunes of Maspalomas). It was found that beach cleaning is the main source of vehicle tracks present in *El Inglés* beach.

The study site comprises an artificially-maintained steady beach with insignificant slope variation in the topographic profile, contrary to the documented sedimentary deficit in its associated dune system. This might be leaded by the activities related to vehicular traffic, beach cleaning, levelling and displacement of sand, among others.

It has been shown that beach cleaning does not have a sole and direct impact on sediment loss in the system but rather contributes to the maintenance of deflation areas which are responsible for sediment loss in the beach, foredune and dunefield of Maspalomas.

In conclusion, the present study offers a new approach to the management of these ecosystems through the consideration of three important aspects observed in *El Inglés* beach: i) vehicle traffic affects the aeolian sedimentary dynamics of an arid transgressive dunefield; ii) beach cleaning service can artificially maintain the beach profile causing sedimentary loss in the dune system; iii) activities such as beach cleaning contribute to sediment loss and, therefore, loss in the foredune and dunefield. The proposed approach determined through this preliminary analysis opens the way for future research perspectives into this subject.

Finally, through the applicability of this study, possible management measures are discussed to reduce the environmental impact of the beach cleaning service, which could make this service more environmentally sustainable.

Credit author statement

Silvia Pinardo-Barco: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing - original draft, Writing – review & editing. **Abel Sanromualdo-Collado:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing – review & editing. **Leví García-Romero:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing - original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This work is a contribution of the funding received through the direct subsidy SD-20/07 of the ACIISI-Government of the Canary Islands granted to the ULPGC (project reference CEI 2020-10). A. Sanromualdo-Collado is the beneficiary of a PhD contract (BES-2017-082733) of the Spanish Ministry of Economy, Industry and Competitiveness, supported by the European Social Fund (ESF). Leví García Romero is the beneficiary of a Posdoctoral contract of the Canary Islands Agency for Research, Innovation and Information Society (Catalina Ruiz program) and by the European Social Fund (ESF). We thank Dr. Nicolás Ferrer-Valero for the coastline map shown in Fig. 1, Dr. Carolina Peña-Alonso for her support during the field campaign, and Professor Luis Hernández-Calvento for his support in this research. Final thank to RED PROPLAYAS network.

APPENDIX I

Interview with the beach cleaning staff

1. When did the beach cleaning start?

Coordinated team cleaning started in 1970, when enterprises were set up to start cleaning the beach. Between 1980 and 1990 the cleaning increased and employees started to clean in a more exhaustive way. The beach cleaning process that you see today began around 2000, using more numerous and more advanced heavy duty cleaning machinery and trucks.

2. On what days and at what times is the beach cleaned? How does the process function?

The beach cleaning can be divided into 4 parts:

- The truck to clean up larger pieces of rubbish present in the sand has a 1 cm mesh size and cleans every day from 3 a.m. to 5 a.m. This cleaning is more exhaustive on Sundays in the areas with a higher occupation of bathers.
- Levelling is done according to beach demand, not every day, from 5 a.m. to 9 a.m. (+ collection of rubbish bins), and so no heavy duty cleaning machinery will generally be present when the beach users arrive.
- Manual collection by employees of the garbage that the truck could not collect (4 employees) is done from 5 a.m. to 11 a.m.
- Garbage collection with spades from 8:30 a.m.–9 a.m.

Each beach in the Maspalomas dunefield is cleaned by one cleaning truck and one levelling truck that go from the start of the beach to its end before turning and returning to the start, cleaning parallel to the sea line. They repeat each route as many times as needed. On Sundays, more intensive cleaning is done in areas with higher occupation.

3. In which parts is the cleaning more concentrated?

The areas with the most exhaustive cleaning are those with a higher presence of users, more specifically where the highest number of garbage containers are found. These areas go from the Maspalomas lighthouse to kiosk 7 and from kiosk 5 in *El Inglés* beach to the northern part of the beach.

4. In which areas can you find a higher accumulation of sand?

There is more sand present in the high beach areas, especially in areas where emergency vehicles pass through, which is why we have to clean them more exhaustively to avoid sand accumulation that can interfere with vehicle manoeuvring. Moreover, the beach area that is actually cleaned will depend on the tide regime, sometimes being more sometimes being less.

5. What do you do with the cleaned sand?

The sand that we clean falls from the truck and the levelling part of the truck levels the terrain leaving it smooth. However, when it is smoothed the sand is extended along the coast so the beach is left as regular as possible, removing all possible irregularities. This sand movement is carried out depending on the areas with higher sediment loss and when needed. It is sometimes moved to the intertidal area or the high beach area.

6. Who regulates the beach cleaning service or which plan do they follow? What legal capacity do they have? Is it a licensed service?

The beach-cleaning service is licensed and was approved in 2017, with a validity of 12 years. The associates form part of a group of three companies.

References

Afghan, A., Cerrano, C., Luzi, G., Calcinai, B., Puce, S., Pulido Mantas, T., et al., 2020. Main anthropogenic impacts on benthic macrofauna of sandy beaches: a review. J. Mar. Sci. Eng. 8 (6), 405. https://doi.org/10.3390/jmse8060405.

Alonso Bilbao, I., Montesdeoca Sánchez, I., Vivares Rimón, A., Alcántara Carrió, J., 2001. Aproximación a la modelización de la dinámica litoral de las playas de El Inglés y Maspalomas (Gran Canaria). Vector (18), 17–27.

Alonso Bilbao, I., Sánchez-Pérez, I., Rodríguez, I., Pejenaute-Alemán, I., Hernández-Calvento, L., Menéndez-González, I., Hernández-Cordero, A., Pérez-Chacón, E., 2007. Aeolian dynamic changes due to the obstacle generated by Traganum moquinii. In: Conf. Int. sobre Restauración y Gestión las Dunas Costeras (ICCD 2007), pp. 11–18.

Ariza, E., Jimenez, J.A., Sarda, R., 2008. Seasonal evolution of beach waste and litter during the bathing season on the Catalan coast. Waste Manag. 28 (12), 2604–2613. https://doi.org/10.1016/j.wasman.2007.11.012.

Avis, A.M., Lubke, R.A., 1996. Dynamics and succession of coastal dune vegetation in the eastern Cape, South Africa. Landsc. Urban Plann. 34, 237–253. https://doi.org/10.1016/0169-2046(95)00217-0.

Balbuena, R., Botta, G., Draghi, L., Rosatto, H., Dagostino, C., 2003. Compactación de suelos. Efectos del tránsito del tractor en sistemas de siembra directa. Spanish J. Agric. Res. 1 (2), 75–80.

Barros, F., 2001. Ghost crabs as a tool for rapid assessment of human impacts on exposed sandy beaches. Biol. Conserv. 97 (3), 399–404. https://doi.org/10.1016/S0006-3207(00)00116-6.

Battisti, C., Bazzichetto, M., Poeta, G., Pietrelli, L., Acosta, A.T.R., 2017. Measuring nonbiological diversity using commonly used metrics: strengths, weaknesses and caveats for their application in beach litter management. J. Coast Conserv. 21 (2), 303–310. https://doi.org/10.1007/s11852-017-0505-9.

Bértola, G.R., Cortizo, L.C., Isla, F., 2009. Dinámica litoral de la costa de Tres Arroyos y San Cayetano, Buenos Aires. Revista de la Asociación Geológica Argentina, p. 64.

Botero, C.M., Anfuso, G., Milanes, C., Cabrera, A., Casas, G., Pranzini, E., Williams, A.T., 2017. Litter assessment on 99 Cuban beaches: a baseline to identify sources of pollution and impacts for tourism and recreation. Mar. Pollut. Bull. 118 (1–2), 437–441. https://doi.org/10.1016/j.marpolbul.2017.02.061.

Carter, R.W.G., Woodroffe, C.D., 1994. Coastal evolution: an introduction. In: Carter, R.W.G., Woodroffe, C.D. (Eds.), Coastal Evolution: Late Quaternary Shoreline Morphodynamics. Cambridge University Press, Cambridge, pp. 1–32.

Cooper, J.A.G., Pilkey, O.H., 2004. Longshore drift: trapped in an expected universe. J. Sediment. Res. 74, 599–606. https://doi.org/10.1306/022204740599.

Curr, R.H.F., Koh, A., Edwards, E., Williams, A.T., Davies, P., 2000. Assessing anthropogenic impact on Mediterranean sand dunes from aerial digital photography. J. Coast Conserv. 6 (1), 15–22. https://doi.org/10.1007/BF02730463.

Díaz Guelmez, G., Hernández-Calvento, L., 2004. Análisis de la evolución de las superficies de deflación eólica en la Playa de El Inglés (Gran Canaria, islas Canarias) mediante técnicas de fotointerpretación y teledetección (1960-2002). In: Conesa García, C., Álvarez Rogel, Y., Mártinez Guevara, J.B. (Eds.), Medio Ambiente, Recursos Y Riesgos Naturales: Análisis Mediante Tecnología SIG Y Teledetección. Asociación de Geógrafos Españoles, Murcia, pp. 177–187.

Di Paola, G., Rodríguez, G., Rosskopf, C.M., 2020. Short-to mid-term shoreline changes along the southeastern coast of Gran Canaria Island (Spain). Rendiconti Lincei. Sci. Fis. Nat. 31, 89–102. https://doi.org/10.1007/s12210-020-00872-3.

Fairweather, P.G., Henry, R.J., 2003. To clean or not to clean? Ecologically sensitive management of wrack deposits on sandy beaches. Ecol. Manag. Restor. 4, 227–228.

Fogerty, J.E., 2007. Oral history and archives: documenting context. In: History of Oral History: Foundations and Methodology, pp. 197–226.

Fontán, A., Alcántara-Carrió, J., Correa, I.D., 2012. Combined beach - inner shelf erosion in short and medium term (Maspalomas, Canary Islands). Geol. Acta 10, 411–426. https://doi.org/10.1344/105.000001756.

Fontán-Bouzas, Á., Alcántara-Carrió, J., Albarracín, S., Baptista, P., Silva, P.A., Portz, L. y, Manzolli, R.P., 2019. Multiannual shore morphodynamics of a cuspate foreland: Maspalomas (gran Canaria, canary islands). J. Mar. Sci. Eng. 7 (11), 416. https://doi.org/10.3390/jmse7110416.

García-Romero, L., Hernández-Cordero, A.I., Fernández-Cabrera, E., Peña-Alonso, C., Hernández-Calvento, L., Pérez-Chacón, E., 2016. Urban-touristic impacts on the aeolian sedimentary systems of the Canary Islands: conflict between development and conservation. Island Stud. J. 11 (1), 91–112. https://doi.org/10.24043/isj.336.

García-Romero, L., Delgado-Fernández, I., Hesp, P.A., Hernández-Calvento, L., Hernández-Cordero, A.I., Viera-Pérez, M., 2019. Biogeomorphological processes in an arid transgressive dunefield as indicators of human impact by urbanization. Sci. Total Environ. 650, 73–86. https://doi.org/10.1016/j.scitotenv.2018.08.429.

García-Romero, L., Hernández-Cordero, A.I., Hesp, P.A., Hernández-Calvento, L., Santana del Pino, A., 2021. Decadal monitoring of Traganum moquinii's role on foredune morphology of a human impacted arid dunefield. Sci. Total Environ. 758, 143802 https://doi.org/10.1016/j.scitotenv.2020.143802.

Gilburn, A.S., 2012. Mechanical grooming and beach award status are associated with low strandline biodiversity in Scotland. Estuarine. Coast. Shelf Sci. 107, 81–88. https://doi.org/10.1016/j.ecss.2012.05.004.

Gómez-Pina, G., Muñoz-Pérez, J.J., Ramírez, J.L., Ley, C., 2002. Sand dune management problems and techniques, Spain. J. Coast Res. (36), 325–332. https://doi.org/10.2112/1551-5036-36.sp1.325.

Hernández-Calvento, L., 2002. Análisis de la evolución del sistema de dunas de Maspalomas, Gran Canaria, Islas Canarias (1960-2000). Doctoral thesis. Universidad de Las Palmas de Gran Canaria.

Hernández-Calvento, L., Zújar, J.O., Jiménez, N.S., Suárez, P.M., 2007. Aproximación al análisis del desplazamiento de las dunas de Maspalomas (Gran Canaria, Islas Canarias). Investigaciones recientes (2005-2007) en geomorfología litoral: actas de la IV Reunión de Geomorfología Litoral. Palma de Mallorca, pp. 107–112, 3-5 May 2007, (Universitat de les Illes Balears).

Hernández-Cordero, A.I., Pérez-Chacón Espino, E., Hernández Calvento, L., 2006. Vegetation colonisation processes related to a reduction in sediment supply to the coastal dune field of Maspalomas (Gran Canaria, Canary Islands, Spain). J. Coast. Res. 48, 69–76. Special Issue.

Hernández-Cordero, A.I., Peña-Alonso, C., Hernández-Calvento, L., Ferrer-Valero, N., Santana-Cordero, A.M., García-Romero, L.y, Espino, E.P.C., 2019. Aeolian sedimentary systems of the canary islands. In: The Spanish Coastal Systems. Springer, Cham, pp. 699–725. https://doi.org/10.1007/978-3-319-93169-2_30.

Hesp, P., 1988. Surfzone, beach, and foredune interactions on the Australian south east coast. J. Coast Res. 15–25.

Hesp, P.A., Walker, I.J., 2011. Coastal dunes. In: Shroder, J.F., Landcaster, N., Shermann, D.J., Bass, A.C.W. (Eds.), Aeolian Geomorphology: Treatise on Geomorphology, vol. 11. Academic Press, San Diego CA, pp. 328–355. https://doi.org/10.1016/B978-0-12-374739-6.00310-9.

Hesp, P.A., Hernández-Calvento, L., Gallego-Fernández, J.B., Miot da Silva, G., Hernández-Cordero, A.I., Ruz, M.-H., García-Romero, L., 2021. Nebkha or not? -Climate control on foredune mode. J. Arid Environ. 187, 104444 https://doi.org/10.1016/j.jaridenv.2021.104444.

Jackson, D., Cruz-Avero, N., Smyth, T., Hernández-Calvento, L., 2013. 3D airflow modelling and dune migration patterns in an arid coastal dune field. J. Coast Res. (SI 65), 1301–1306. https://doi.org/10.2112/SI65-220.1.

Jackson, N.L., Nordstrom, K.F., 2011. Aeolian sediment transport and landforms in managed coastal systems: a review. Aeolian research 3 (2). https://doi.org/10.1016/j.aeolia.2011.03.011.

Ley-Vega de Seoane, C., Gallego-Fernández, J.B., Vidal-Pascual, C., 2007. Manual de Restauración de Dunas Costeras. Dirección General de Costas del Ministerio de Medio Ambiente. Rural y Marino, Madrid, Spain, p. 240.

Liddle, M.J., Grieg-Smith, P., 1975. A survey of tracks and paths in a sand dune ecosystem. II. Vegetation. J. Appl. Ecol. 909–930. https://doi.org/10.2307/2402098.

Livingstone, I., 1989. Monitoring surface change on a Namib linear dune. Earth Surf. Process. Landforms 14 (4), 317–332. https://doi.org/10.1002/esp.3290140407.

Máyer-Suárez, P., Pérez-Chacón Espino, E., Cruz Avero, N., Hernández Calvento, L., 2012. Características del viento en el campo de dunas de Maspalomas (Gran Canaria, Islas Canarias, España).

Medina, R., Camus, P., Requejo, S., Luque, A., Alonso, I., Hernández, L., Hernández, A., 2007. Estudio integral de la playa y dunas de Maspalomas (Gran Canaria). Ministerio de Medio Ambiente, Madrid (Spain).

Mir-Gual, M., Pons, G.X., Martín-Prieto, J.A., Rodríguez-Perea, A., 2015. A critical view of the Blue Flag beaches in Spain using environmental variables. Ocean Coast Manag. 105, 106–115. https://doi.org/10.1016/j.ocecoaman.2015.01.003.

Morton, J.K., Ward, E.J., de Berg, K.C., 2015. Potential small- and large-scale effects of mechanical beach cleaning on biological assemblages of exposed sandy beaches receiving low inputs of beach-cast macroalgae. Estuar. Coast 38, 2083–2100. https://doi.org/10.1007/s12237-015-9963-1.

Munar, F.X.R., 2002. Análisis de capacidad de carga en los espacios litorales, calas y playas, situados en áreas naturales de especial interés de la isla de Menorca. In: Turismo y transformaciones urbanas en el siglo XXI. PhD University of Almería, pp. 325–335.

Nordstrom, K.F., 1994. Beaches and dunes of human-altered coasts. Prog. Phys. Geogr. 18 (4), 497–516. https://doi.org/10.1177/030913339401800402.

Nordstrom, K.F., 2002. The role of human in transforming coastal landscape. In: J. Coast. Res., 36. Proceedings, International Coastal Symposium, Northern Ireland 2002.

Owens, E.H., Robson, W., Foget, C.R., 1987. A Field Evaluation of Selected Beach-Cleaning Techniques. Arctic. Arctic Institute of North America, pp. 244–257.

Peña-Alonso, C., Gallego-Fernández, J.B., Hernández-Calvento, L., Hernández-Cordero, A.I., Ariza, E., 2018. Assessing the geomorphological vulnerability of arid beach-dune systems. Sci. Total Environ. 635, 512–525. https://doi.org/10.1016/j.scitotenv.2018.04.095.

Quevedo Medina, U., Hernández-Calvento, L., 2014. Evolución reciente de la línea de costa en un sistema playa-dunas deficitario (Maspalomas, Gran Canaria). In: XVI Congreso Nacional de Tecnologías de la Información Geográfica 2014, Alicante, pp. 163–171, 978-84-940784-4-6|84-940784-4-5.

Roig-Munar, F.X., 2003. Análisis de la relación entre capacidad de carga físicay capacidad de carga perceptual en playas naturales de la isla de menorca. Invest. Geográficas (Esp) 31, 107–118.

Roig-Munar, F.X., 2004. Análisis y consecuencias de la modificación artificial del perfil playa-duna provocado por el efecto mecánico de su limpieza. Invest. Geográficas (33), 87–106. https://doi.org/10.14198/INGEO2004.33.07.

Roig-Munar, F.X., Martín-Prieto, J.A., Rodríguez-Perea, A., Pons, G.X., Gelabert, B., Mir-Gual, M., 2012. Risk assessment of beach–dune system erosion: beach management impacts on the balearic islands. J. Coast Res. 285, 1488–1499. https://doi.org/10.2112/JCOASTRES-D-11-00187.1.

R Core Team, 2018. R: A Language and Environment for Statistical Computing [WWW Document]. Vienna, Austria. URL. https://www.r-project.org/.

Sanromualdo-Collado, A., García-Romero, L., Peña-Alonso, C., Hernández-Cordero, A.I., Ferrer-Valero, N., Hernández-Calvento, L., 2021. Spatiotemporal analysis of the impact of artificial beach structures on biogeomorphological processes in an arid beach-dune system. J. Environ. Manag. 282, 111953 https://doi.org/10.1016/j.jenvman.2021.111953.

Sanromualdo-Collado, A., Hernández-Cordero, A.I., Viera-Pérez, M., Gallego-Fernández, J.B., Hernández-Calvento, L., 2021b. Coastal dune restoration in el Inglés beach (gran Canaria, Spain): a trial study. Rev. Estud. Andaluces 41, 187–204. https://doi.org/10.12795/rea.2021.i41.10.

Servera, J., Rodríguez-Perea, A., Martín-Prieto, J.A., 2007. Los sistemas playa-duna de las Baleares. In: Fornós, J.J., Ginés, J., Gómez-Pujol, L., Edits (Eds.), Geomorfología Litoral. Migjorn i llevant de Mallorca. Palma, Mon. Soc. Hist. Nat. Balears, vol. 15, pp. 61–74.

Sherman, D.J., 1995. Problems of scale in the modeling and interpretation of coastal dunes. Mar. Geol. 124, 339–349. https://doi.org/10.1016/0025-3227(95)00048-4.

Steiner, A.J., Leatherman, S.P., 1981. Recreational impacts on the distribution of ghost crabs Ocypode quadrata Fab. Biol. Conserv. 20 (2), 111–122. https://doi.org/10.1016/0006-3207(81)90022-7.

Thompson, L.M.C., Schlacher, T.A., 2008. Physical damage to coastal dunes and ecological impacts caused by vehicle tracks associated with beach camping on sandy shores: a case study from Fraser Island, Australia. J. Coast Conserv. 12, 67–82. https://doi.org/10.1007/s11852-008-0032-9.

Viera Pérez, M., 2015. Estudio detallado de la duna costera de Maspalomas (Gran Canaria, Islas Canarias): interacción "Taganum moquinii"-dinámica sedimentaria eólica en un entorno intervenido. Recomendaciones de cara a su gestión. PhD. Thesis. Universidad de Las Palmas de Gran Canaria, p. 572. http://hdl.handle.net/10553/17572.

Wheaton, J.M., Brasington, J., Darby, S.E., Merz, J.E., Pasternack, G.B., Sear, D.A., Vericat, D., 2010a. Linking geomorphic changes to salmonid habitat at a scale relevant to fish. River Res. Appl. 26, 469–486. https://doi.org/10.1002/rra.1305.

Wheaton, J.M., Brasington, J., Darby, S.E., Sear, D.A., 2010b. Accounting for uncertainty in DEMs from repeat topographic surveys: improved sediment budgets. Earth Surf. Process. Landforms 35, 136–156. https://doi.org/10.1002/esp.1886.

Williams, A.T., Randerson, P., Sothern, E., 1997. Trampling and vegetation response on sand dunes in South Wales, UK. In: The Ecology and Conservation of European Dunes, pp. 287–298.

Willmott, H., Smith, T., 2003. Effects of mechanical cleaning, and its cessation, on the strandline fauna at Sand Bay. Somerset Archaeol. Nat. History 147, 263–273.

Wyles, K.J., Pahl, S., Holland, M., Thompson, R.C., 2017. Can beach cleans do more than clean-up litter? Comparing beach cleans to other coastal activities. Environ. Behav. 49 (5), 509–535. https://doi.org/10.1177/0013916516649412.

Zielinski, S., Botero, C.M., y Yanes, A., 2019. To clean or not to clean? A critical review of beach cleaning methods and impacts. Mar. Pollut. Bull. 139, 390–401. https://doi.org/10.1016/j.marpolbul.2018.12.027.