UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA
Departamento de Geografía

Programa de Doctorado en Oceanografía y Cambio Global

TESIS DOCTORAL

HISTORICAL RECONSTRUCTIONS OF ENVIRONMENTAL CONDITIONS AND LAND USES IN COASTAL AEOLIAN SEDIMENTARY SYSTEMS OF THE CANARY ISLANDS (SPAIN)

Aarón Moisés Santana Cordero

Abril 2017

Las Palmas de Gran Canaria

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CERTIFICA,

Que el Consejo de Doctores del Departamento, o la Comisión Académica de la Facultad, en su sesión de fecha .... tomó el acuerdo de dar el consentimiento para su tramitación, a la tesis doctoral titulada "Historical reconstructions of environmental conditions and land uses in coastal aeolian sedimentary systems of the Canary Islands (Spain)" presentada por el doctorando D. Aarón Moisés Santana Cordero y dirigida por los Doctores Luis Hernández Calvento y María Luisa Monteiro Quintana.

Y para que así conste, y a efectos de lo previsto en el Artº 6 del Reglamento para la elaboración, defensa, tribunal y evaluación de tesis doctorales de la Universidad de Las Palmas de Gran Canaria, firmo la presente en Las Palmas de Gran Canaria, a.........de...........................de dos mil............................

UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

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Título de la Tesis

"Historical reconstructions of environmental conditions and land uses in coastal aeolian sedimentary systems of the Canary Islands (Spain)"

Tesis Doctoral presentada por D. Aarón Moisés Santana Cordero

Dirigida por el Dr. D. Luis Hernández Calvento

Codirigida por la Dra. Dª. María Luisa Monteiro Quintana

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Las Palmas de Gran Canaria, a 26 de abril de 2017.

Programa de Doctorado en Oceanografía y Cambio Global

Escuela de Doctorado de la Universidad de Las Palmas de Gran Canaria

HISTORICAL RECONSTRUCTIONS OF ENVIRONMENTAL CONDITIONS AND LAND USES IN COASTAL AEOLIAN SEDIMENTARY SYSTEMS OF THE CANARY ISLANDS (SPAIN)

Reconstrucciones históricas de las condiciones ambientales y usos del suelo en sistemas sedimentarios eólicos costeros de las Islas Canarias (España).

Dirigida por: Dr. Luis Hernández Calvento

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El Director La Co-directora El Doctorando

En Las Palmas de Gran Canaria, a 26 de abril de 2017.

CONTENTS

Presentación

Esta tesis doctoral ha sido realizada por Aarón M. Santana Cordero, y dirigida por los Dres. María Luisa Monteiro Quintana y Luis Hernández Calvento.

Ha sido desarrollada en el seno del grupo de investigación Geografía Física y Medio Ambiente, integrado en el Instituto de Oceanografía y Cambio Global, IOCAG, perteneciente a la Universidad de Las Palmas de Gran Canaria, ULPGC.

La línea de investigación en la que encaja este trabajo es la de “Sistemas de dunas litorales” cuyo responsable es el Dr. Luis Hernández Calvento.

El modelo adoptado por esta tesis es el de compendio de publicaciones, con lo cual su organización ha sido la siguiente: 0) Resumen; 1) Introducción; 2) Reconstrucción histórica de las condiciones ambientales (artículo Santana-Cordero et al. 2014); 3) Reconstrucción histórica de los usos del suelo (artículos Santana-Cordero et al. 2016a; 2016b); 4) Conclusiones y perspectivas; y 5) Referencias.

Para la elaboración de esta tesis doctoral, su autor ha sido beneficiario de una beca predoctoral del programa propio de la Universidad de Las Palmas de Gran Canaria, en el período 2012-2016.

Este trabajo académico supone una contribución científica a los siguientes proyectos del Plan Nacional de I+D+i del Gobierno de España, cofinanciados con fondos FEDER: *Diagnóstico ambiental de los sistemas de dunas de Canarias para la elaboración de modelos sostenibles de gestión territorial* (Ref. CSO2010-18150), *Caracterización de procesos eco-antrópicos de los sistemas playa-dunas de Canarias como base para su gestión sostenible* (Ref. CSO2013-43256-R) y *Análisis de procesos naturales y humanos asociados a los sistemas playa-duna de Canarias* (Ref. CSO2016-79673-R).

Agradecimientos

Me gustaría agradecer a todas las personas que han tenido que ver conmigo y/o con mi trabajo de investigación a lo largo de estos años. En primer lugar, agradecer a mi familia: Pedro, Rosi, Ale, Nana y Mesi, el hecho de haber estado ahí en todo momento y apoyarme. En segundo lugar, quiero agradecer a Luis Hernández Calvento su confianza depositada en mí para llevar adelante esta investigación y haberme escuchado y ayudado en los momentos personales más duros. ¡Gracias amigo! Por otra parte, a mi codirectora, María Luisa Monteiro Quintana, Magüi, por su incondicional apoyo y su valiosa aportación a la hora de crear y analizar las fuentes orales que han formado parte de mi trabajo. Al resto de mis compañeros de grupo de investigación: Emma Pérez-Chacón Espino, Pablo Máyer Suárez, Emilio Fernández Negrín, Lidia Esther Romero Martín, Carolina Peña Alonso, Nicolás Ferrer Valero, Leví García Romero, Antonio Hernández Cordero, Elisabeth Fernández Cabrera, Natalia Cruz Avero y Laura Luisa Cabrera Vega. En especial a Emma por su gran ayuda en los escollos administrativos y académicos con los que nos hemos tenido que enfrentar durante el desarrollo de mi tesis doctoral. Mención aparte merecen también el Dr. Eduard Ariza y el Dr. Francesc Romagosa, con quienes trabajé durante mi primera estancia científica en la Universitat Autònoma de Barcelona. Al Dr. Matthias Bürgi y la Dra. Anna Hersperger, por el trabajo realizado conjuntamente conmigo en Zúrich (Suiza), durante mi segunda estancia científica, realizada en su institución, el *Swiss Federal Institute for Forest, Snow and Landscape Research WSL*. A Tobias Plieninger, de la Universidad de Copenhague (Dinamarca), por supervisar mi tercera estancia científica y aportarme nuevos puntos de vista en mi investigación. A Péter Szabó (Academy of Sciences of the Czech Republic, Department of Vegetation Ecology, República Checa), por sus aportaciones y sus interesantes discusiones sobre la *Historical Ecology* que hemos tenido. A mis amigos Ancor, Yamilé, Zeus, Nau, Chedey, Luis, Josep, José Luis, Mark y José Vicente por ser quienes son y estar siempre ahí. A todos, mil gracias y un fuerte abrazo.

Espero no haberme olvidado de nadie, pero si es así, ruego me disculpe.

0. Abstract

Coastal areas have been used by humans for millennia. Currently these environments are affected by important human pressures, e.g. settlements and tourism. From the natural point of view, these areas contain a number of ecosystems and landscapes some of which are very fragile, such as the sandy sedimentary systems (beaches and dune fields).

The main aim of this dissertation is "the study of the historical relationship between the natural processes and the human activities in the aeolian sedimentary systems of the Canary Islands". This aim can be divided in three objectives: (1) the establishment of a methodology that integrates different historical sources; (2) the study in depth of different aspects of the history of these systems to characterize their nature and dynamics, as well as the human uses on them; and (3) the determination of the interference degrees of the human activities on the natural processes of these systems.

This research has been developed in two coastal aeolian sedimentary systems located in the Canary Islands: Guanarteme (now disappeared) and La Graciosa.

The work has been done under the approach of Historical Ecology, i.e. the historical study of the nature-human relationship over ecosystems/landscapes. Therefore, a large variety of sources have been analyzed and integrated in order to get different scenarios corresponding to different phases of the history of the ecosystems/landscapes studied.

The results reveal the existence of several landforms and changes in the amount of sand in circulation in Guanarteme, and the remove of the vegetation cover and erosional processes in La Graciosa. Regarding the land use, traditional uses, such as grazing and cutting of wood for lime kilns, among others, in La Graciosa, and agriculture, urbanization, recreational uses and aggregate extraction, in Guanarteme, have definitively impacted their natural dynamics.

Finally, conclusions about sources and methods, and important findings, have been established, as well as some prospects.

Resumen

Las áreas costeras han sido, durante milenios, lugar de asentamiento prioritario para los seres humanos. Desde un punto de vista natural, estas áreas presentan ecosistemas y paisajes característicos, algunos de los cuales son muy frágiles, como los sistemas sedimentarios arenosos (playas y campos de dunas). En las últimas décadas dichos ambientes están siendo ocupados de forma masiva y, en consecuencia, afectados por importantes presiones humanas. El desarrollo urbano-turístico de las costas está siendo el principal factor de interacción con los procesos naturales.

El objetivo principal de esta tesis doctoral es “el estudio de la relación histórica entre los procesos naturales y las actividades humanas en los sistemas sedimentarios eólicos de las islas Canarias”. Este objetivo general se divide en otros tres objetivos específicos: (1) el establecimiento de una metodología que integre diferentes fuentes históricas; (2) el estudio en profundidad de diferentes aspectos de la historia de los sistemas estudiados para caracterizar su naturaleza, su dinámica y los usos humanos sobre ellos; y (3) la determinación del grado de interferencia de las actividades humanas en los procesos naturales de dichos sistemas.

La investigación se ha centrado en dos sistemas sedimentarios eólicos costeros localizados en las islas Canarias: el campo de dunas móviles de Guanarteme, en Gran Canaria (actualmente desaparecido), y los jables de La Graciosa.

El trabajo se ha realizado bajo el enfoque de la Ecología Histórica, disciplina que aborda el estudio histórico de las relaciones hombre-medio en los ecosistemas/paisajes. Para su desarrollo, una considerable variedad de fuentes ha sido analizada e integrada, con el fin de obtener diferentes escenarios, correspondientes a las diferentes fases de la historia de los ecosistemas/paisajes estudiados.

Como resultados, se presentan tres artículos publicados en revistas científicas internacionales con índice de impacto.

El primer artículo, titulado *Reconstructing the environmental conditions of extinct coastal dune systems using historical sources: the case of the Guanarteme dune field (Canary Islands, Spain)* [Reconstruyendo las condiciones ambientales de sistemas de

dunas costeros extintos utilizando fuentes históricas: el caso del campo de dunas de Guanarteme (islas Canarias, España)], fue publicado en *Journal of Coastal Conservation* en 2014, volumen 18, páginas 323-337.

En él se hace una introducción a la Ecología Histórica y se toman en consideración diferentes tipos de reconstrucciones territoriales (históricas y paleoambientales). Se plantea la necesidad de llevar a cabo un enfoque crítico con respecto a las fuentes, al asumir que muchas fuentes históricas pueden estar sesgadas por las perspectivas sociales de cada momento histórico. Se plantea la situación de las zonas costeras a nivel mundial y se presenta el objetivo principal de la investigación: la reconstrucción de las geoformas y de la vegetación que caracterizó el sistema de dunas hasta su desaparición.

El campo de dunas de Guanarteme tenía una superficie aproximada de 2,5 km^2 y se desarrollaba en el tómbolo que une la isla de Gran Canaria con La Isleta y, hacia el sur, hasta el barrio de Ciudad Jardín. El sistema se componía de dos zonas geomorfológicamente diferentes: la planicie (zona del tómbolo) donde se movían las dunas libremente, y una terraza sedimentaria alta (en torno a 50 m.s.n.m.) que entraba en el sistema en forma de cuña desde el S. Los vientos alisios, provenientes del NE, pero modificados localmente por la interposición de los volcanes de La Isleta, inducían un transporte sedimentario eólico desde la playa de Las Canteras, al NO, hasta la de Las Alcaravaneras, al SE.

Las fuentes utilizadas en esta investigación fueron diversas: documentos históricos escritos, mapas históricos, fotografías convencionales, fotografías aéreas y ortofotos, relatos de viajeros y exploradores, fuentes orales y algunas referencias bibliográficas. A todas ellas se les aplicó un método, desarrollado en este mismo trabajo, para evaluar su fiabilidad. Dicho método consiste en abordar una evaluación a cada fuente utilizada, con base en: (1) el tipo de fuente (directa/indirecta); (2) el detalle/nivel de resolución (bajo, medio, alto); y (3) los análisis aplicables (analogía, contraste, posibilidad de extracción de información espacial). Las valoraciones resultantes se estandarizaron en una escala 0-1, siendo 0 ninguna fiabilidad y 1 alta fiabilidad.

Los resultados se dividieron en dos secciones: (a) geomorfología eólica y vegetación antes de 1850 y (b) geomorfología eólica y vegetación desde 1850. Para el primer periodo, los mapas históricos revelaron un sistema consistente en una gran duna alargada, orientación SSO-NNE, y prácticamente carente de vegetación. Durante el siglo XVIII, el sector norte de esta gran duna alargada parecía moverse hacia el E. Su sector sur permanecía retenido por la barrera que suponía la citada terraza alta. En el segundo periodo se detecta una gran entrada de arena en el sistema, el cual se traduce en un número considerable de grandes dunas transversales. El mayor número de fuentes históricas disponibles para este período (relatos de viajeros y exploradores y fuentes orales, principalmente), permitió identificar la vegetación existente.

En la discusión del trabajo se destaca que este estudio logra traspasar hacia atrás la barrera del año 1800, para caracterizar el sistema. Por otro lado, se discuten las aportaciones realizadas en relación con el conocimiento del área. También se plantean las limitaciones de abordar un estudio exhaustivo en base a fuentes cartográficas, debido a su escasa disponibilidad.

El segundo artículo, titulado *Long-term human impacts on the coast of La Graciosa, Canary Islands* [Impactos humanos históricos en la costa de La Graciosa, islas Canarias], fue publicado en *Land Degradation & Development* en 2016, volumen 27, páginas 479-489.

En la introducción se hace referencia al estado de las zonas costeras a nivel global, así como a los usos tradicionales y actuales que la han degradado. Por otra parte, se plantea el estudio histórico de estos espacios y la versatilidad de estos para ser aplicados en varios tipos de ambientes, aportando con ello referencias de publicaciones internacionales que apoyan esta idea.

El trabajo se desarrolla en la isla de La Graciosa (islas Canarias), la cual está localizada al norte de Lanzarote y tiene una superficie de 27,05 km^2. La isla cuenta con un sistema sedimentario dividido en dos áreas: una al norte (4,4 km^2) y otra al sur (8,7 km^2). Los vientos predominantes en la isla son los alisios, provenientes del NE, con una velocidad media de 18,3 km/h.

Las fuentes utilizadas fueron las fuentes documentales, las referencias bibliográficas, las fuentes orales, las fotografías aéreas, una ortofoto y el trabajo de campo. Los métodos y herramientas aplicadas fueron el análisis documental, la foto-interpretación, el análisis de las fuentes orales, SIG y GPS. Estos análisis permitieron caracterizar los cambios ocurridos en la isla, tanto en lo que se refiere a los usos del suelo como a la geomorfología eólica.

Los resultados evidencian la existencia de seis etapas, donde las variaciones de la intensidad de la presión humana sobre el medio han favorecido, en unos casos, la movilidad de los sedimentos y, en otros, su estabilización. 1) Antes de 1730, la isla estaba deshabitada y sus usos del suelo limitados en el tiempo, pues solo se llevaban los ganados a pastar entre invierno y verano. 2) En el periodo 1730-1880 (tras la erupción de Timanfaya, 1730-36) los ganados se trasladan de forma permanente a La Graciosa, con lo que la presión sobre el medio aumentó y los usos tuvieron que ser regulados. 3) Entre 1880 y 1943 se establecen los primeros pobladores, que son los que fundan Caleta del Sebo y empiezan a consumir los escasos recursos de la isla. En 1930 se funda el otro núcleo poblacional existente hoy día en la isla, Pedro Barba. 4) Entre 1943 y 1967, con la visita del Capitán General García Escámez, se inicia una etapa de inversiones en infraestructuras básicas (muelle, escuela, iglesia, cementerio, aljibes, etc), se reparten 65 lotes de tierra de labor y se construye una aguada central en el interior de la isla. 5) En 1967-1987 la presión sobre el medio se redujo considerablemente debido al descenso del número de habitantes que emigran a Lanzarote, la llegada del gas, la disponibilidad de energía eléctrica, y el fin del uso de vegetación para la quema de los hornos de cal. 6) A partir de 1987, la isla es declarada espacio natural protegido y se prohíben los usos tradicionales que venían afectando al medio. Con ello la cobertura vegetal comienza su recuperación y con ello los mantos arenosos se estabilizan.

En la discusión se plantea la dependencia de la estabilidad de los mantos arenosos de la relación hombre-medio existente. A continuación se establece el grado de interferencia del ser humano en la dinámica natural de la isla para cada fase estudiada. Por último, se hace mención a la metodología, valorando que se vuelve a traspasar la barrera temporal de 1800 impuesta normalmente por las fuentes y se resalta la integración de información proveniente de la historia oral y los SIG.

El tercer artículo, titulado *Reconstruction of the land uses that led to the termination of an arid coastal dune system: The case of the Guanarteme dune system (Canary Islands, Spain), 1834–2012* [Reconstrucción de los usos del suelo que llevaron a la desaparición a un sistema de dunas costeras árido: el caso del sistema de dunas de Guanarteme (islas Canarias, España)], fue publicado en *Land Use Policy* en 2016, volumen 55, páginas 73-85.

En la introducción de este artículo se hace referencia al estado de las zonas costeras a nivel global, destacando el fenómeno de 'litoralización', por el cual la población tiende a trasladarse a las zonas costeras a vivir. Esta tendencia constituye un grave riesgo en los espacios insulares, cuyas costas poseen frágiles ecosistemas como son los espacios dunares. Por otra parte, se habla de la gestión de estos espacios a nivel mundial y de la utilidad e importancia de la existencia de estudios sobre cambios en los usos y coberturas del suelo.

El área de estudio de este trabajo es el mismo que el del primer artículo expuesto en este resumen, con lo cual se pueden consultar sus características más arriba.

Las fuentes utilizadas han sido las referencias bibliográficas, los mapas históricos, las fotografías aéreas y ortofotos, las fotografías convencionales y fuentes orales. Estas fuentes se trataron, básicamente, mediante análisis documental, a través del cual se obtuvo la información esencial que aportaban cada una de ellas a este estudio, y el análisis cartográfico, a través del cual 9 mapas históricos fueron analizados.

Los resultados fueron divididos en dos partes: 1) 'Antes de 1900'; y 2) 'Desde 1900'. Para el primer periodo se identificaron dos usos del suelo, que fueron uso agrícola y urbanización. El primero se desarrolló en la zona sur del antiguo sistema de dunas de Guanarteme, donde está hoy Ciudad Jardín y Las Alcaravaneras. El segundo comenzó de manera dispersa, definiéndose luego en un eje norte-sur, que parte de La Isleta. En el segundo periodo se constató la existencia de cuatro usos del suelo: agricultura, urbanización, uso recreativo y extracción de áridos. La agricultura se siguió desarrollando en el mismo lugar que el mencionado para el siglo XIX. La urbanización siguió expandiéndose hacia el sur, a la vez que, desde el sur, el este y el oeste, se comenzó a desarrollar más tejido urbano, encerrando al sistema de dunas en un espacio rodeado de casas y edificios. El uso recreativo representa el uso que daban los niños al campo de dunas, el cual era su lugar de juego y esparcimiento. Igualmente, hacia el año 1936 había familias que iban a pasar los domingos al interior de las dunas. Por último, comentar que la duna de caída del sistema, que quedaba justo encima del estadio Insular (antiguo estadio de fútbol) era usada como grada por los aficionados para ver los partidos. El último uso, referente a la extracción de arena, se llevó a cabo, de acuerdo a las fuentes orales, de norte a sur y de manera sistemática. La arena sirvió como material de relleno de grandes obras, como el Puerto de La Luz y de Las Palmas, a la vez que servía como materia prima para fabricar ladrillos en la fábrica de Eufemiano Fuentes, operativa desde el año 1924. A su vez, grandes cantidades de arena eran extraídas por las personas a título personal para construir sus viviendas, cuestión que, según observó uno de los informantes, se llevó a cabo en el barrio de Guanarteme.

En la discusión se habla de los resultados y de la metodología empleada. Respecto a los resultados, se hacen comparaciones entre el sistema de dunas de Guanarteme y varios lugares en el mundo, como la región mediterránea, EEUU y Japón, en los que este tipo de sistemas han sido alterados o destruidos. Respecto a la metodología, se justifica el tipo de análisis aplicado a las fuentes cartográficas utilizadas, debido a la imposibilidad de trabajar con ellas mediante SIG, por sus características geométricas.

Las conclusiones de esta tesis doctoral son las que siguen:

1. Desde el punto de vista metodológico, considerando conjuntamente las fuentes de información y los métodos, es necesario, al abordar un estudio de reconstrucción histórica, evaluar la fiabilidad de las fuentes. En este sentido, el método desarrollado en esta tesis consiste en la aplicación de un enfoque crítico hacia las fuentes, con base en la evaluación de sus características y su contribución al estudio. Las variables utilizadas fueron: 1) el tipo de fuente, 2) el nivel de detalle o resolución de la información que proporcionaban, y 3) los análisis que les pueden ser aplicados.

2. Por lo que respecta a los factores de alteración histórica de los sistemas sedimentarios eólicos costeros áridos, la eliminación de la vegetación leñosa resulta ser uno de los principales factores. Dado que ésta estabiliza el sustrato, su eliminación tiene la capacidad de cambiar la dinámica de estos sistemas, tal y como se detecta en La Graciosa.

3. La extracción de arena también tiene consecuencias decisivas en la alteración de estos sistemas, llegando a suponer la desaparición de todo un sistema sedimentario eólico. Tal

es el caso del campo de dunas de Guanarteme, debido a la amplia magnitud de la superficie afectada y la alta intensidad en la que se desarrolló este proceso extractivo.

4. Las motivaciones que subyacen detrás de las acciones que conllevan la alteración o desaparición de un sistema de este tipo son económicas y económico-sociales. Esto ha quedado comprobado tanto en el caso de La Graciosa, donde se pretende mejorar las condiciones de vida de los pobladores de la isla, como en el de Guanarteme, en cuyo origen se encuentra la decisión política de construir una infraestructura (un nuevo puerto) y la ampliación de la ciudad de Las Palmas hacia el norte.

Por su parte, las perspectivas de este trabajo se exponen a continuación:

Perspectivas.

1. La creación de un archivo de memoria ambiental para las islas Canarias. Este estaría basado en el conocimiento del pasado inmediato de nuestro territorio, involucrando a los ciudadanos como donantes de memoria, e influenciaría al progreso científico de Canarias. Este archivo sería construido en torno a fuentes orales, fotografías y videos, y sus interpretaciones, sobre los elementos físicos y las realidades sociales de nuestros ecosistemas y paisajes.

2. La creación de una plataforma online de SIG histórico, a través de un geoportal o de una infraestructura de datos espaciales, que contendría todo nuestro conocimiento histórico sobre nuestros ecosistemas y paisajes, al que la población en general podría acceder y enriquecer (mediante sus aportaciones).

1. Introduction

Global change is a phenomenon negatively affecting the entire planet Earth. Thus, all ecosystems on the planet are influenced by human activities (Vitousek et al. 1997), with changes in land use being one of the most important (Foley et al. 2005). Although human influence on the planet has a historical character, recently this influence has become a notable pressure on our natural systems (Ellis et al. 2013).

1.1. Coastal areas: recent evolution and current state

Coastal areas have historically been affected by humans (Nordstrom 1994). As in other environments, human pressure on these areas has become more and more significant with time. Furthermore, intense coastal population growth in recent decades (Bajocco et al. 2012) has put increasing pressure on these domains. Martínez et al. (2007) report that currently 41% of the world population lives in these areas. This intense coastal development has notably been undertaken over sandy beach ecosystems (Defeo et al. 2009). In the case of Spain, as well as the broader Mediterranean coastal region, this has been a trend and it has resulted in accelerated and intense urban development in these areas (Ariza 2011).

Globally, agriculture, natural resource extraction and settlement are the most influential forms of land use (Klein Goldewijk 2013). However, Bajocco et al. (2012) indicate that fires, intensive agricultural practices, land abandonment, urban sprawl, and concentrated mass tourism are the land uses that most degrade coastal landscape characteristics in typical Mediterranean regions. Of these land uses, tourism has largely been an activity carried out in coastal areas worldwide (Gormsen 1997) with inevitable environmental consequences (Davenport and Davenport 2006; Gössling 2002). Its development has a strong relationship with international travel, which has increased since 1950 (Gormsen 1997). Additionally, most of the time, tourism implies urbanization, therefore these two land uses are somehow linked. Thus, urban sprawl at the coast can be a result of tourism and the migration of people towards the coasts (Bajocco et al. 2012), which boosts residential land use. However, vegetation and sand extraction have negative consequences for sedimentary landscapes.

This situation is especially harmful in islands, due to their fragility from the environmental point of view. The Canary Islands are a good example of this phenomenon, since they have experienced significant development in their coastal areas that has exerted an important human pressure on valuable ecosystems and their processes (Santana-Cordero et al. 2016).

1.2. Historical Ecology

1.2.1. Origins and evolution of the discipline

Humans have always shown a certain interest in their relationship with the natural world. This interest became a field of study that evolved as various subdisciplines during the formation and establishment of the sciences in the 18th and 19th centuries. Thus, some ecological problems with historical implications arose in those centuries. For instance, in 1769, Barrington proposed that sweet chestnut (*Castanea sativa*) was not native to Britain. Another example was the Ruined Landscape theory which indicates that the degradation of the Mediterranean landscapes was caused by deforestation in the past. These kinds of ideas were treated by various subdisciplines, such as landscape history, environmental history, historical geography, environmental archaeology, forest history or historical ecology, which were developed within at least four academic disciplines: history, ecology, geography and anthropology (Szabó 2015).

There have been different approaches through which to address this topic, and that is why several trends in historical ecology coexist.

There are three main trends in historical ecology: the anthropological (Crumley 1994; Balée 2006), ecological, and conservation/restoration ecological and ecological planning (Bürgi and Gimmi 2007). Regarding the first one, Crumley (1994) argues that anthropology theoretically adapts to historical ecology by bridging the natural and social sciences and the humanities through its approach. The ecological trend integrates the human dimension in the analysis of patterns and processes in landscapes and ecosystems (Domon and Bouchard 2007; Bürgi et al. 2015). Within this trend some experimental research normally focused on ecosystems (e.g., woodlands) can be considered, in which sediment, compositional/dendrochronological and statistical/modeling analyses play a central role (Hermy et al. 1999; Ireland et al. 2011; Mladenoff et al. 2002). The conservation/restoration ecological and ecological planning trend, also called applied historical ecology (Swetnam et al. 1999), applies historical knowledge to conservation/restoration tasks (Egan and Howell 2005; Grossinger et al. 2007). This last trend has been developed above all in North America.

The work undertaken here has been performed in line with the ecological trend of historical ecology.

1.2.2. Definition and major objectives

There are many definitions of historical ecology in the literature (Szabó 2015). Although it is not an objective of this work to define historical ecology, efforts will lead to highlight the different definitions and propose some of them to be the most complete ones. In his review, Szabó (2015) offers a list of definitions gathered by examining the historical ecological literature.

If we effectively assume that three trends of historical ecology exist, there will be several definitions that fit adequately with the term historical ecology. Therefore, accordingly, three definitions are provided. For the anthropological trend, Balée (2006) states that historical ecology is a research program 'concerned with comprehending temporal and spatial dimensions in the relationships of human societies to local environments and the cumulative global effects of these relationships'. For the ecological trend, historical ecology encompasses 'the scientific attempts to elucidate the past of ecosystems; it aims at uncovering past ecosystem dynamics and their drivers, using and combining a large variety of historical data sources' (Gimmi and Bugmann 2013). Finally, the restorationists/conservationists define historical ecology as 'a restorationist's guide to reference ecosystems' (Egan and Howell 2001).

Some authors have highlighted the major objectives of historical ecology. Firstly, Bürgi and Gimmi (2007) suggest the following three objectives: (1) preserving cultural heritage in ecosystems and landscapes, (2) understanding historical trajectories of patterns and processes in ecosystems and landscapes, and (3) informing ecosystem and landscape management. Secondly, Crumley (2007) establishes that 'the goal of historical ecologists is to use scientific knowledge in conjunction with local knowledge to make effective and equitable management decisions'. Thirdly, Rick and Lockwood (2013) identify another goal: 'to understand past and present human-environment interactions, but it is also concerned with understanding natural variation before and after human arrival'.

1.2.3. Sources and methods

One characteristic of historical ecology is the use of different sources to work with.

Bürgi and Gimmi (2007) consider the following sources as typical in historical ecology: 'historical documents, such as maps, management plans, land survey records, repeat photography, aerial or terrestrial, and oral history interviews. Biological archives, such as tree rings, pollen, diatoms and charcoal sediments, fire scars and bark peelings, archaeological evidence and ecosystems and landscapes themselves'.

When working with a variety of sources we must carry out a source critical approach (Bürgi et al. 2010). Forman and Russell (1983) establish a procedure to critically evaluate the sources used in four steps: (1) first- or second-hand observation; (2) purpose or possible bias of the statement; (3) author's knowledge of the subject and; (4) context of the statement. Similarly, Santana-Cordero et al. (2014) (one of the papers of this dissertation) developed a method to determine the reliability of the sources.

Regarding the methods, to my knowledge no literature exists that addresses this topic in the field of historical ecology. Nevertheless, documentary analysis and spatio-temporal analysis through historic maps, aerial photographs and pictures seem to be present in many studies. Furthermore, the GIS tool is quite usual in study cases.

1.3. Historical reconstruction of the characteristics of coastal ecosystems and landscapes of the Canary Islands

In the Canary Islands, several general studies of landscape reconstruction have been undertaken. Santana Santana (1992) studied the reconstruction of plant landscapes in

Gran Canaria, based on bibliographic, historical sources as well as toponymy. Naranjo Cigala and Hernández Calvento (1995) carried out a change analysis in the landscapes on the Gran Canaria mountain peaks. Martín Galán (2001) reconstructed the landscape of Las Palmas de Gran Canaria and the process of city growth with time. At coastal areas, Hernández Calvento (2006) studied the evolution of the coastline in the Maspalomas dune field (Gran Canaria) through photo-interpretation and bibliographic sources. Finally, in these same areas (i.e., coastal areas) a line of investigation by the *Grupo Geografía Física y Medio Ambiente* of the Universidad of Las Palmas de Gran Canaria has been developed. In this regard, Santana-Cordero et al. (2010, 2012) studied the historical evolution of the Maspalomas and Guanarteme dune fields (Gran Canaria) by integrating different kinds of sources. Thus, the island of Gran Canaria constitutes an interesting example of the development of these types of studies.

The main interests in reconstructing the characteristics of coastal sedimentary systems of the Canary Islands are: (1) retrieval of territory memory through oral and other sources, as patrimonial elements (cultural and natural) of our history. This serves as background to the harmful short-term management of the landscapes of the archipelago. (2) From (1) we can learn how to reconstruct landscapes and avoid the harmful impacts of such management practices.

An interesting paradox arises when the environmental characteristics of the coastal sedimentary systems are threatened by the development of tourism-related facilities, i.e., the most important economic activity of the archipelago is destroying the environment that makes tourism possible. Undoubtedly, the key question here is the planning and management of these resources to avoid their degradation.

The above mentioned ideas have led us to select the Guanarteme dune field and La Graciosa island for this dissertation. The Guanarteme dune field has disappeared due to the development of the Port of La Luz and Las Palmas and the growth of the city of Las Palmas. We have been able to reconstruct the dune field (environmentally and culturally), thus discovering the natural and human processes that led to its disappearance. La Graciosa has been less affected by human activity. Nevertheless, our study reveals how human actions have modified the natural dynamics. These two cases show different phases in the evolution of these kinds of landscapes.

1.4. This dissertation: justification and aims

Prior to the research that supports this dissertation, the historical dimension in the study of the dune fields of the Canary Islands had not been addressed. Earlier studies focused on these systems were developed in the fields of aeolian geomorphology and vegetation cover and management, all of which were related to tourism development (especially for the Maspalomas dune field, Gran Canaria). Nevertheless, it is important to state that these previous studies provided views of the temporal evolutions of the dune fields from the first aerial photographs available to the present, i.e., since the 1960s.

To expand the temporal dimension in these kinds of studies was essential to understand the current natural dynamics and the degree that human pressure had exerted on them. This approach allows us to get mid-term history of the systems studied and to understand the evolution model of these systems (e.g., the case of Guanarteme, Gran Canaria), spanning several centuries and observing how it evoluted from its original natural state to its present complete disappearance. This model can be used to compare the evolution of other dune fields of the Canary Islands, which are in different evolutionary phases than Guanarteme, and alert us to the impacts that our activity has on them.

On the other hand, to overcome the limitations involved in the use of aerial photographs, we had to use other type of sources, such as historical written documents, historical maps, old pictures and oral sources. The challenge in using these was how to work with each one and how to integrate the information provided by each source. In order to solve these issues, the reading of international scientific literature was a key question, as well as to contact and work with national and international scientist from other research institutions, whose support in analyzing the data helped us greatly.

Having summarized the scientific background, the main aim of this dissertation is "the study of the historical relationship between the natural processes and the human activities in the aeolian sedimentary systems of the Canary Islands". This aim can be divided in three objectives: (1) the establishment of a methodology to integrate different historical sources; (2) the study in depth of different aspects of the history of the aeolian sedimentary systems of the Canary Islands, to characterize their nature and dynamics, as well as the human uses on them; and (3) the determination of the interference degrees of the human activities on the natural processes of these systems.

2. Historical reconstruction of environmental conditions

Reconstructing the environmental conditions of extinct coastal dune systems using historical sources: the case of the Guanarteme dune field (Canary Islands, Spain)

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Journal of Coastal Conservation (2014) 18:323–337

DOI 10.1007/s11852-014-0320-5

Abstract

The reconstruction of environmental conditions allows us to categorize an area before it has suffered disturbances or even completely disappeared. The aim of this study is to gain insight into the natural conditions of the Guanarteme dune system (Gran Canaria, Canary Islands, Spain) before it disappeared, focusing on studying its processes, landforms and vegetation cover. To this end, both primary sources and bibliographical references have been used as the basis of a description for the environmental state of this system between the 15th century and the middle of the 20th century, when the system was considered extinct. The different shapes and forms of the dunes over the centuries have enabled us to study the system evolution: its landforms have changed both in shape and number, as has the volume of sediments. This variation becomes obvious when we study the appearance of the system at the different dates of analysis. These changes are linked to the aeolian sediment dynamics, which are fairly stable from the 15th century until the last third of the 19th century, when a large amount of sediment in circulation was observed together with the shift of large aeolian landforms.

Keywords: Historic mapping; Oral sources; Dunes; Canary Islands; Historical reconstruction; Vegetation.

Introduction

The reconstruction of the natural conditions for a given area can be performed from two complementary approaches: the paleoenvironmental, focused on the study of the evolution of natural processes over long-term periods (thousands of years to hundreds of thousands of years); and historical, which includes the study of natural and human processes, for periods of hundreds of years, mostly, except for specific work addressing historical reconstructions for periods before more than a thousand years ago (Domínguez-Castro et al. 2012). The first approach is based on the analysis of natural logs, as sample dating or interpreting landforms, while the second is based on the analysis of documental and/or oral sources (Arbogast et al. 2010; Gautreau 2010; Gimmi and Bürgi 2007; Grossinger et al. 2007; Hansen et al. 2010; Hanson et al. 2010; Hunter and Sluyter 2011; Levin et al. 2010; McLeman et al. 2010).

In the reconstruction of aeolian environments these two approaches are applied, sometimes in a complementary way (Provoost et al. 2011). Such is the case of dune systems associated to Lakes Michigan and Huron, in the United States (Arbogast et al. 2010; Hansen et al. 2010). Studies about changes in sediment dynamics by winds are also relevant, like those conducted in North American Great Plains (Hugenholtz et al. 2010), which are associated with major climatic events such as drought (Hanson et al. 2010).

The historical approach has been widely used by various disciplines, among which the

Applied Historical Ecology should be cited, whose main objective is to bring historical knowledge to the management of ecosystems (Swetnam et al. 1999). From this perspective, the historical information is considered an essential step for the natural dynamics of a given territory and/or ecosystem, and to establish, if necessary, ecological reference conditions in order to implement restoration actions (Fritschle 2009). This requires differentiating spatiotemporal changes caused by natural processes, such as those arising from climate change, from those induced by human action, something that becomes more relevant in areas with a considerable degree of transformation (Harris et al. 2006; McAllister 2008). Furthermore, ecosystems are controlled by both types of change, natural and human, as their existence and evolution have been developed under certain natural conditions that have been altered significantly by human hands and constantly intervened in time through traditional conserving practices (Krebs et al. 2012).

In research focused on reconstructing the historical changes experienced by some ecosystems due to human activities, many works have focused on highly dynamic environments such as wetlands, forests and river systems (Gautreau 2010; Gimmi and Bürgi 2007; Gimmi et al. 2011; Grossinger et al. 2007; Krebs et al. 2012; McAllister 2008; Ratas and Puurmann 1995).

These investigations are based on various data sources. One of these records are of natural origin, which may have been destroyed as a result of the action of certain processes such as those related to the erosion, a serious handicap for the reconstruction of the environmental features of any territory.

On the other hand, it is necessary to adopt a source critical approach due to the characteristics of the historical sources. In this regard, the historical sources provide partial information of the object of study, so it is necessary to consult as many sources as available (documentary and oral) to complete this information, and consider who has produced the documents and his/her intention, since sometimes the author may offer a biased view based on this latter aspect. This happens with the travelers/explorers written accounts or in the case of historical cartography, which demonstrates the technical skill of the authors (Levin et al. 2010). Therefore, to address historical research we assume that the source material is fragmented and dispersed and conditioned or "contaminated" by the human hand (McAllister 2008).

In environmental research addressing processes developed in recent decades, oral records are a very important resource for obtaining new information (Riley and Harvey 2007; Robertson and McGee 2003), being one of its most interesting aspects precisely the possibility to be used as sources for historical research (Sloan 2008) through techniques that enable its systematic collection (Benadiba 2007). The availability of oral sources is an exciting opportunity, as brings together into one document a set of aspects that are normally dispersed by their different topics, allowing us to treat such information in an integrated manner. Apart from this, the oral sources offer confirming, contrasting or refuting the information from alternate sources such as documentaries (Benadiba and Plotinsky 2001), while serving as a complement to other sources of information (reports, travelers/explorers written accounts, historical maps, aerial photography, street-level photography, etc..), covering sometimes gaps left by these alternative sources (Gimmi and Bürgi 2007; Riley and Harvey 2007).

With regard to coastal dune systems, these areas are characterized by the interactions between physical and biotic, marine and terrestrial processes. These relationships provide high dynamic and natural fragility, so they are easily alterable (Hugenholtz et al. 2010; Paskoff 1998). In recent decades there has been a continuous human occupation of the coast, which has prompted an intense transformation of sandy environments (Bajocco et al. 2012; Nonn 1974) and especially in the areas of coastal dunes. Therefore, the dynamics and evolution of these environments have undergone major transformations (Jackson and Nordstrom 2011), that in many cases have resulted in their disappearance.

In this context, this study focuses on the now extinct dune system of Guanarteme, located on the island of Gran Canaria (Canary Islands, Spain). This island has undergone intense transformations over recent decades, due to the socioeconomic change that has driven it from a traditional society, up until the 1970s, to its current state as a service society, in which beach holiday tourism has played, and continues playing nowadays, an hegemonic role. In this sense, its last remaining field of mobile dunes, located in the south of the island (Maspalomas), is undergoing significant changes, identified through diachronic studies, that may lead to its disappearance in the next century (Hernández-Calvento et al. 2007; Hernández-Cordero et al. 2006). From this point of view, many natural systems, some of them very fragile, are a key issue for tourism development. However, this activity generates degradation on these natural systems. Therefore, the protection of these areas is needed, due to they can ensure sustainable development (Williams and Ponsford 2009). In the case of the Canary Islands, tourism development has impacted on the beach and the dune systems, used as a tourist attraction, degrading them. By this reason, this degradation involves not only environmental damage but also an economic impact (Cabrera-Vega et al. 2013). As similar to other mobile dune fields in the island, in the case of Guanarteme, the beaches where sand entered and left the field are the only remainings, since the dune field itself has been occupied by the city of Las Palmas de Gran Canaria, the capital of the island. The study of the evolution of this second dune field is of scientific interest for two main reasons: on the one hand, it represents a model to base on, with appropriate modifications, future evolution patterns of the other remaining dune fields, which much of the island's economy is based on; on the other hand, its recovery through collective historical memory is of social interest, as it is an area that is remembered with a certain nostalgia and that is recognised as part of the city's natural heritage and, indeed, of the city's identity.

To this end, the natural conditions of this system have been studied in a research project, together with the accompanying socioeconomic development. This paper presents the study carried out on the reconstruction of the natural conditions of the Guanarteme dune field before it disappeared during the 1960s. The main objective is the reconstruction of the landforms and the vegetation that characterized the dune system until it disappeared occupied by the urban growth.

Methods

Study area

The study area is located at the northeast of the island of Gran Canaria, Canary Islands (Spain) (Fig. 1).

The Guanarteme dune field covered a surface area of approximately 2.5 km^2 (Martín Galán 2001) characterised by processes resulting from aeolian sediment dynamics. This area was located in the sandy isthmus between the island of Gran Canaria and La Isleta, a small island lying to the northeast of the main island. This dune field was framed by two sandy beaches: Las Canteras to the west and Las Alcaravaneras to the east. Information available shows that it was an area of intense aeolian dynamics, which explains both the almost nonexistence of any natural vegetation within this area, and the historical concern of the inhabitants of the area, corresponding to today's Ciudad Jardín and Las Alcaravaneras (Fig. 2), that the port installations, roads and nearby crops would all be invaded by the sand.

The prevailing north westerly winds (trade winds from the NE modified by the interference of La Isleta) moved the sand from NW to SE. So Las Canteras beach acted as the input area for the sand, that was transported as free dunes southeastward (as it corresponds to an arid system), to finally disappear once again into the sea in the area of Las Alcaravaneras beach. These dunes advanced over the flat surface between the input and the output areas, as well as along a sedimentary terrace (high terrace) some 50 m above sea level, which stuck into the dune field from the south as a V-shaped wedge, where landforms typically found in conjunction with topographic obstacles were formed.

This area represented the land of northward growth for the city of Las Palmas de Gran Canaria, from the middle of the 19th to the mid-20th century when the city spread from the historic old town (around the Guiniguada gully) to join up with La Isleta. In this in-between area, other scattered population settlements appeared, linked to the presence of a harbor where the Port of la Luz and Las Palmas is located today (Fig. 2).

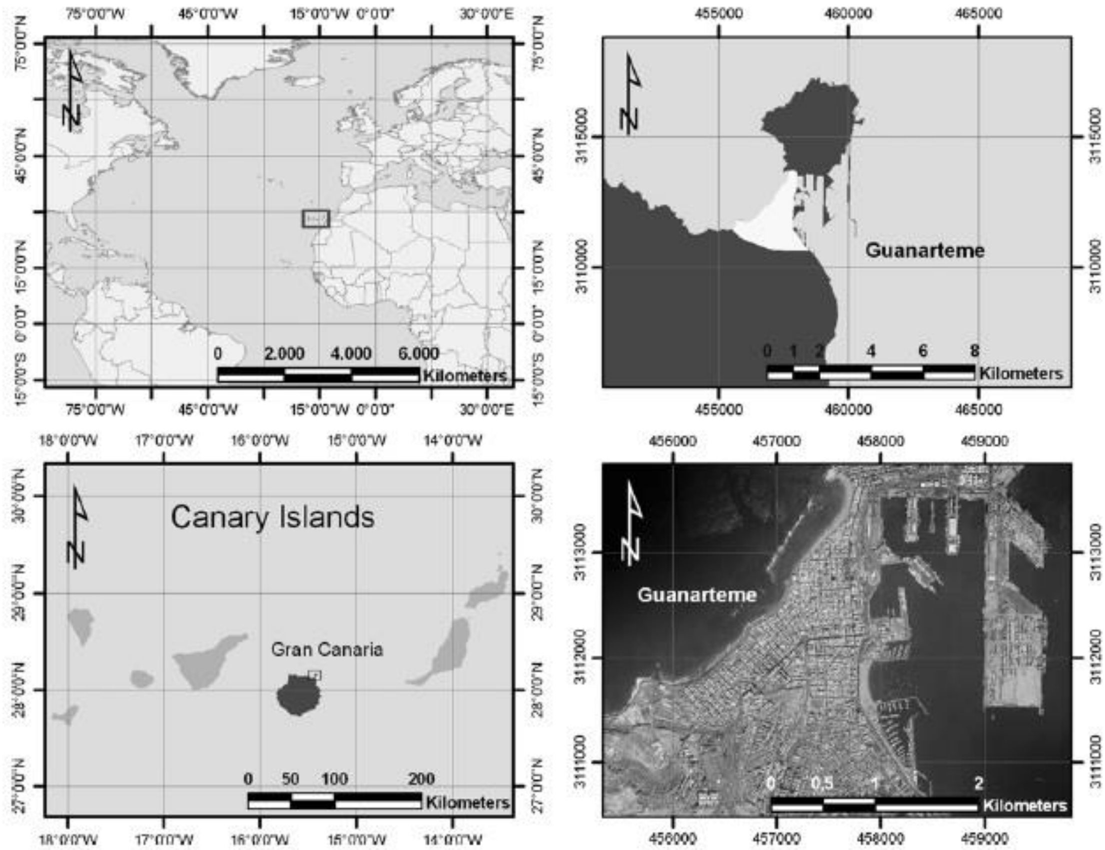

Fig. 1 Study area.

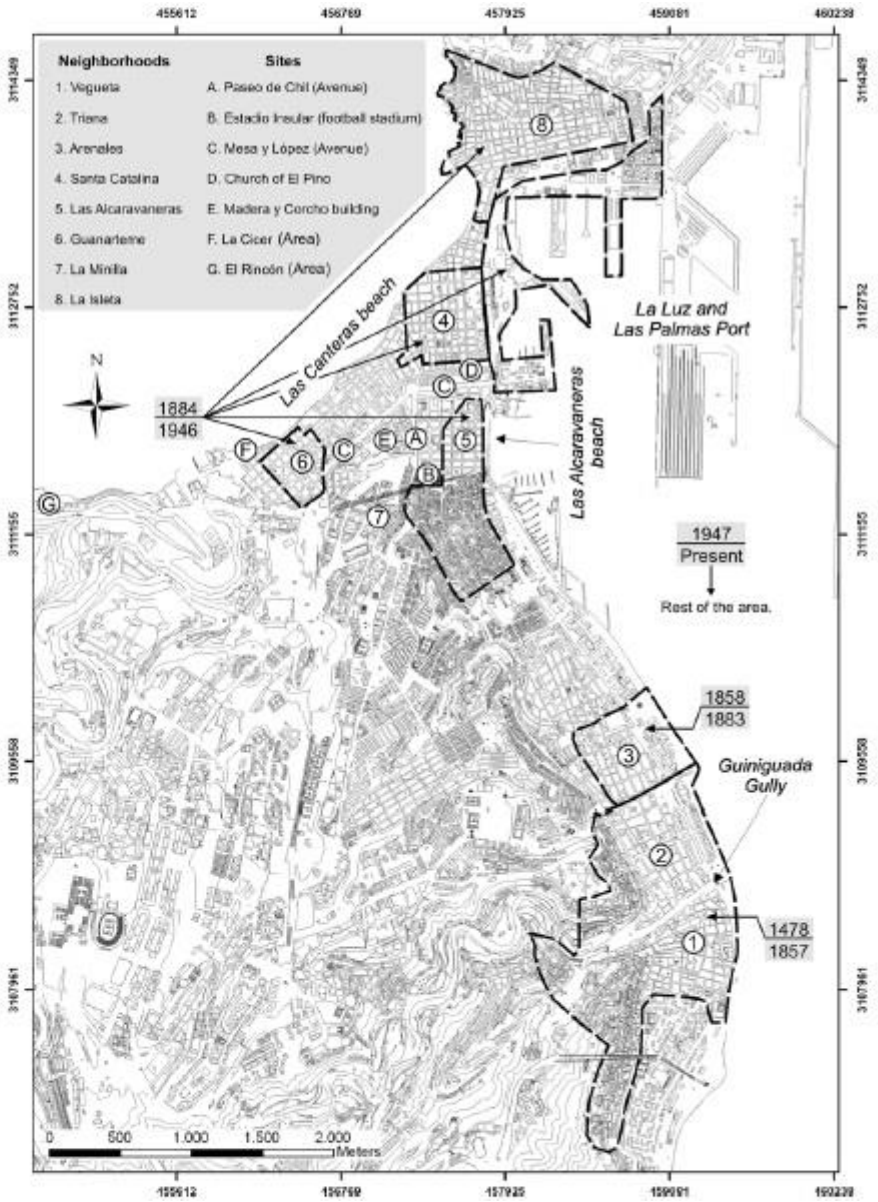

Fig. 2 Urban evolution of the city of Las Palmas.

Sources

The following sources (Fig. 3) have been used to reconstruct the natural characteristics of this dune system:

- Primary sources have played a vital role as they have provided us with much interesting data, including the height of the dunes or what they looked like during the 19th century:
  - Historical written documents: these 19th century documents provide data on the solutions arising from administration to avoid the invasion of the properties by the mobile dunes. Gazette no. 68 (1868) of the Sociedad Económica de Amigos del País de Gran Canaria (Economic Association of

Friends of the Country of Gran Canaria [hereinafter SEAPGC]), and the unpublished manuscript of González Velazco (Las dunas ó médanos del Ystmo de Guanarteme en la Gran Canaria, dated between 1875 and 1884, according to Martín Galán (2001)).

- Historical maps: these maps have been consulted in archives and in published map collections. For this study five historical maps have been used: military map by Próspero Casola (1599, approximate scale (a.s.) 1:13500); three maps of Las Palmas city, 1742 a.s. 1:10800, 1773 a.s. 1:11400 and 1792 a.s. 1:9800 (made by Antonio Riviere, Joseph Ruiz Zermeño, and Luis Marqueli, respectively) (Marqueli 1995; Riviere 1995; Ruiz Zermeño 1995); and the 'Plano de la bahía de Las Palmas' (Map of the Bay of Las Palmas) from 1879 (Dirección de Hidrografía 1995; a.s. 1:20000). They have played a key role in the geomorphological reconstruction of the study area to as far back as 1599. However, it is important to bear in mind that their main original purpose was to map the city rather than those areas that were not occupied at the time.
- Street-level photographs: the digital photography catalogue of the Fundación para la Etnografía y el Desarrollo de la Artesanía Canaria, FEDAC (Cabildo Insular de Gran Canaria) (Foundation for Ethnography and the Development of the Canary Craft, Gran Canaria Island Council) was consulted. Only some of the available photos were used in this study. These photographs were essential for the identification of specific elements in the territory from the end of the 19th century up until 1954.
- Aerial photographs and ortophotos: the oldest aerial photograph, 1954, has been particularly useful. Its scale is 1:2650 and its spatial resolution 0.73 m. The city was still spreading at that time, so the photo shows some sandy areas. Current ortophotos have also been of considerable use in the identification of certain landmarks, such as buildings and other infrastructure, used in this study as spatial references to apply geometrical adjusts to the aerial photography.
- Travelers/explorers written accounts: data given by geologist Léopold Von Buch, based on his field observations, have been essential to determine the high of the dunes to the early 19th century (1815). On the other hand, descriptions written by journalist Olivia Stone, in 1883–84, have been relevant for the present analysis.
- Oral sources: five interviews were carried out, and they enabled us to gather very useful information about the dune field and their immediate surroundings. This technique has been developed based on Fogerty (2005), considering an interview as a semi-structured conversation between an interviewer and an interviewee. The interviewees, born between 1924 and 1947, contributed significant information based on their early memories of some areas (Santa Catalina, Guanarteme or La Isleta). The interviews were

done between February, 2010, and June, 2012. We should point out that these oral sources represent a fundamental part of our research as there are very few documentary sources available on this study area, particularly for the second third of the 20th century.

- Bibliographic references.
  - The most relevant references for this study have been: Martín Galán (2001), who performes a deep analysis on the urban evolution of Las Palmas de Gran Canaria; and Santana Santana (1992), who studies the historical evolution of landscapes of Gran Canaria, through documentary sources, since 15th to 19th century.

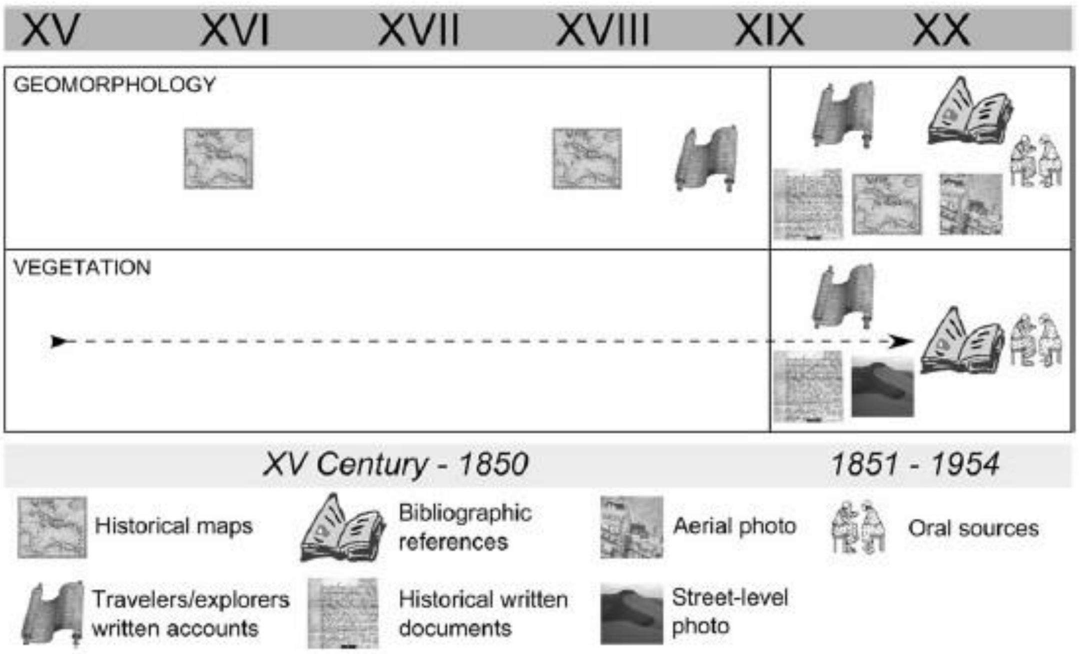

Fig. 3 Sources used, classified by type, environmental factor and century they provide information about. Further divided by periods of study considered: 15 th century - 1850; 1851–1954

For the 16th century we have the first image of the study area where we can see, with certain limitations, the environmental factors studied to determine its configuration. The 18th century maps are an improvement because they allow the possibility to analyse and contrast the represented elements. This comparative analysis has been done by graphic information extraction of aeolian landforms, overlaying the maps, to obtain an image that integrates the information contained in them. For the nineteenth century we have travelers/explorers written accounts, street-level photographs, a historic map and historical documents that allow us to analyse data and supplement the information provided by all the sources. Finally, for the 20th century we have references, oral sources and the aerial photograph of 1954 (Fig. 3).

Considering the availability and quality of the sources, the study period was divided into two parts: 15th century-1850. This decision is based on improving the spatial accuracy that present historical maps from the late nineteenth century and the incorporation of street-level photography as a new source.

Methodology

Using aeolian geomorphology and vegetation featuring of the system as guidance, the information extracted from each source consulted has merged according to a chronological order (Fig. 3) to obtain several pictures of the natural state of this system throughout the period studied.

To assess the reliability of the sources we have adopted a source critical approach on the basis of their characteristics and contribution to the study. The variables chosen for this evaluation have been: 1) the type of source, 2) the detail level and/or resolution of the information provided, and 3) the analyses that could be applied. Each variable has several categories: thus, we have established two categories of source type, direct and indirect. The first one refers to those sources that provide information that has not been interpreted, e.g. street-level and aerial photographs; the second one refers to those documents containing information that has been previously interpreted (bibliographic sources, historical written documents, explorers/travelers written accounts, oral sources and historical cartography). A value of 1 is assigned to direct sources and 0.5 to indirect ones.

The detail level/spatial resolution determines the extent and quality of information that can be extracted from the sources. To assign one of these categories for each source we have paid attention to the “scale” that is expressed in the information and/or the level of detail. For example, we have considered whether each source provides information of regional, insular or local (municipal) scale. The categories of this variable are “low”, “medium” and “high”, and their values 0.25, 0.5 and 1, respectively.

Three distinct analyses were applied: (i) analogy; (ii) contrasting of information between two or more sources and; (iii) the possibility for extraction of spatial information. By analogy we mean the possibility to establish similarities and differences between the study area and other similar systems, such as Maspalomas in this case, by comparing their respective elements and dynamics. Contrasting of information involves verifying the data provided by a source through its comparison with other sources of the same or different nature. The extraction of spatial information refers to the ability of the sources to show or describe the location of territorial elements. The latter analysis is particularly interesting for historical cartography and aerial and street-level photography. For each of these analyses a value of 0.1 is added, so that the maximum score that each source can acquire for this variable is 0.3.

The values of reliability obtained by each source, within the range 0.75–2.3, were standardized on a 0–1 scale indicating the relative reliability of each source. Normalizing values (reliability level value (rlv)) have been obtained by dividing the sum of the values of all categories (Σcv) between 2.3; therefore, Σcv/2.3=rlv. Finally, we have established three categories regarding reliability levels: low (<0.33), medium (0.33 to 0.66) and high (>0.66). Table 1 presents the assessment criteria, showing the values of each category.

Table 1 Criteria selected to evaluate the reliability of historical sources

Main characteristics	Source type		Detail/resolution level			Applicable analyses		
Categories	Direct	Indirect	Low	Medium	High	Analogy	Contrast	Spatial information extraction
Values	1	0.5	0.25	0.5	1	0.1	0.1	0.1

Results

The reconstruction of the natural characteristics of the Guanarteme dune field has been undertaken bearing in mind two of the most relevant factors linked to these types of natural systems: aeolian geomorphology (major landforms) and vegetation. In addition, an assessment of the reliability of the sources has been conducted using the method developed.

Assessment of the reliability of the sources

The evaluation of the sources reveals that the aerial photography (AP), street-level photographies ($SLP_{1,2}$), an explorers/travelers written accounts (WA_1), a historic map (HM_5) and one oral source (OS_2) have a high reliability (>0.66). Next, in the group of sources of medium reliability (0.33 to 0.66), bibliographical sources (BS1,2),HM1–4, historical written documents ($HWD_{1,2}$), a WA_2 and $OS_{1,3,4,5}$ are found. No low reliability sources have been used.

In order to better appreciation of results shown in Table 2, the data of the reliability of each source is depicted in a graph (Fig. 4) with a time scale. It can be appreciated how in the second period, near to the present time, there are more sources available and more reliable information.

Table 2 Calculation of reliability level for each source, according the assessment criteria.

Main characteristics	Source type	Detail/resolution level	Applicable analyses			∑ of category values (∑cv)	Reliability level value (rlv) (0–1) ∑cv/2.3
Sources[a]	Direct/indirect	Low/medium/high	Analogy	Contrast	Spatial information extraction		
AP	1	1	0.1	0.1	0.1	2.3	1
SLP_1	1	1	0.1	0.1	0.1	2.3	1
SLP_2	1	0.5	0.1	0.1	0.1	1.8	0.78
BS_1	0.5	0.5	0.1	–	–	1.1	0.48
BS_2	0.5	0.5	0.1	0.1	–	1.2	0.52
HWD_1	0.5	0.5	0.1	0.1	–	1.2	0.52
HWD_2	0.5	0.25	0.1	0.1	–	0.95	0.41
WA_1	0.5	1	0.1	–	–	1.6	0.70
WA_2	0.5	0.5	0.1	–	–	1.1	0.48
HM_1	0.5	0.25	0.1	–	0.1	0.95	0.41
$HM_{2,3,4}$	0.5	0.5	0.1	0.1	0.1	1.3	0.57
HM_5	0.5	1	0.1	0.1	0.1	1.8	0.78
OS_1	0.5	0.5	0.1	0.1	–	1.2	0.52
OS_2	0.5	1	0.1	0.1	–	1.7	0.74
OS_3	0.5	0.5	0.1	0.1	–	1.2	0.52
OS_4	0.5	0.25	0.1	0.1	–	0.95	0.41
OS_5	0.5	0.25	0.1	0.1	–	0.95	0.41

[a] AP: Guanarteme dune field and the city of Las Palmas de Gran Canaria (CECAF 1954); SLP_1: Vegetation planted in rows near to Las Canteras beach, 1890-1895 (FEDAC 2011); SLP_2: Row of *Traganum moquinii* on Las Canteras beach, 1875-1880 (FEDAC 2011); BS_1: Análisis y reconstrucción de los paisajes históricos (Santana Santana 1992); BS_2: Las Palmas ciudad y puerto: cinco años de evolución (Martín Galán 2001); HWD_1: Boletín 68 (SEAPGC 1868); HWD_2: “Las dunas ó médanos del Ystmo de Guanarteme en la Gran Canaria” (González Velazco 1875–1884); WA_1: Descripción física de las Islas Canarias (von Buch 1999);WA_2: Tenerife and its six satellites; or, The Canary Island Past and Present (Stone 2004); HM_1: Planta del sitio de Canaria by Próspero Casola 1599 (Archivo General de Simancas); HM_2: Antonio Riviere, circa 1742 (Riviere 1995); MH_3: Joseph Ruiz Zermeño, 1773 (Ruiz Zermeño 1995); MH_4: Luis Marqueli, 1792 (Marqueli 1995). (Dirección de Hidrografía, 1995); $OS_{1–5}$; interviews conducted between 02/2010 and 06/2012.

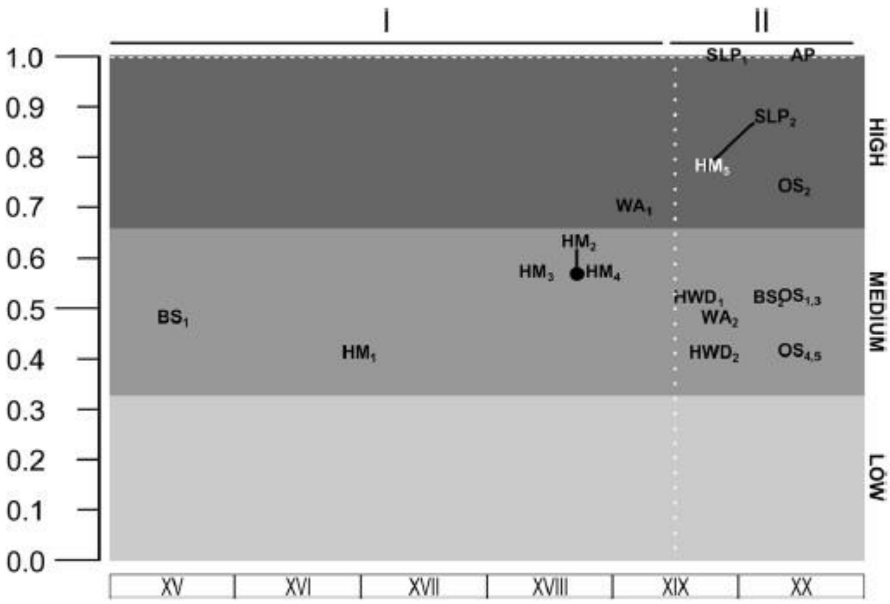

Fig. 4 Level of reliability of the sources and their temporal location (level of reliability from Table 2). Three categories were established: low (<0.33); medium (0.33–0.66); and high (>0.66). The vertical line indicates the split established in the study period (upper lines indicate

the numbers of the two sub-periods).

Aeolian geomorphology and vegetation before 1850

The information that dates back the furthest comes from Santana Santana (1992) in his reconstruction of the historic landscapes of Gran Canaria. This author states that, by the 15th century, psammophile communities, palm groves and thermophile forests were present in the study area and its immediate environs. In all probability, the psammophile community would have been the most widespread, given the large expanse of the dune field. According to this author, the species dominating this community would have been the following: *Traganum moquinii, Zygophyllum fontanesii, Cyperus laevigatus* and *Schizogyne glaberrima*. These species are just widely extended nowadays on Maspalomas dune field, as well as on other dune fields of the Canary Islands.

In terms of the geomorphology of the area studied, the oldest source that enables us to classify it is a military map drawn up by the engineer Próspero Casola in 1599 (Fig. 5). Its level of detail and the inclusion by its author of certain place names render it extremely useful for this study, both as the oldest cartographic reference source available and due to the quality of the information it provides. According to the map, the dune field at that time was a long landform running NNE—SSW, near to Las Canteras beach, of a notable size and linked to the place name “médanos de arena” (sandbanks, i.e. dunes); at the same time, numerous hummock dunes are depicted across the whole area, which we deduce must have been produced by the interaction of vegetation with the moving sand, as it happens today in other parts of the islands with similar characteristics. So, we have deduced the existence at that time of a transverse ridge that was stabilised or semistabilised due to the vegetation and/or by topographic effects, near to the west coast of the study area, as well as small dunes in the rest of the area conditioned to a greater or lesser extent by the vegetation.

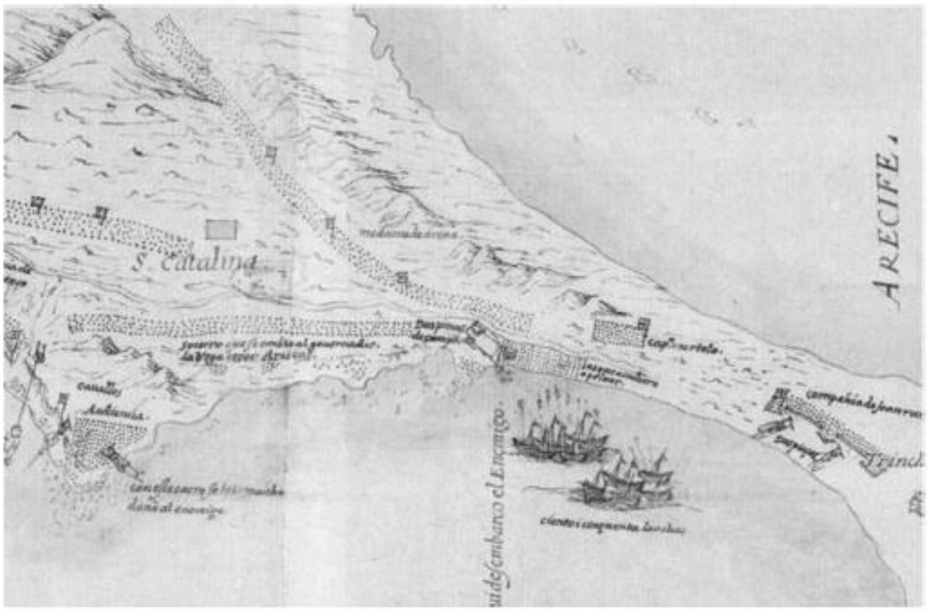

Fig. 5 'Planta del sitio de Canaria' (Map of Canaria besieged). Drawn up by Próspero Casola, 1599 (AGS 2011)

The historic reconstruction of the 18th century geomorphology was carried out based on three maps of the city of Las Palmas de Gran Canaria (dated circa 1742 (by Antonio Riviere), 1773 (by Joseph Ruiz Zermeño) and 1792 (by Luis Marqueli), see Fig. 6) on which the dune field appears.

Examination of these maps reveals once again the presence of the above-mentioned large dune associated with the name monte de arena (sand hill) on those dating from 1742 to 1792, which would have been located perpendicular to the effective winds and parallel to the fluvial terrace, some 50 m above sea level (Fig. 7).

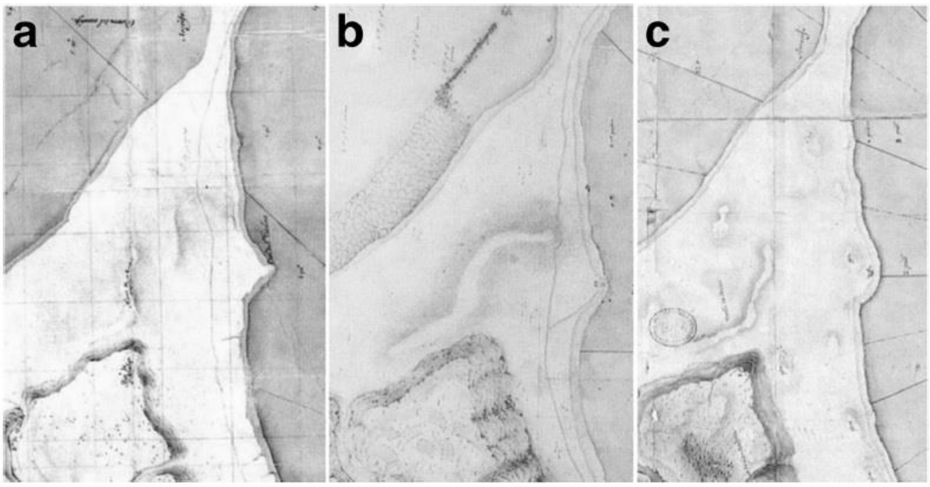

Fig. 6 18th century maps (a: Antonio Riviere, circa 1742 (Riviere 1995); b: Joseph Ruiz Zermeño, 1773 (Ruiz Zermeño 1995); c: LuisMarqueli, 1792 (Marqueli 1995)).

The appearance of this long dune in various sources leads us to contemplate two possibilities: i) firstly, that the authors have copied from each other, which would lead us to consider only the oldest map as valid; ii) secondly, that the various documents really do represent the different locations of the above-mentioned dune. As far as the first possibility is considered, it is worth remembering that the copying of part, or all, of pre-existing maps was a common practice at the time. In this sense, visual analysis suggests that there are some coincidences that can be consider suspicious, at least in some elements of the territory, such as the coastline. Nevertheless, it is also true that notable differences were detected, particularly in terms of the relief, and if we look at the different shapes of the drawings intended to illustrate the presence of the fluvial terrace. These same singularities can be seen in the representation of the road links. Thus, we can see how the road that linked the city to the port adapts to the topography, presumably as a result of the movement of the dunes.

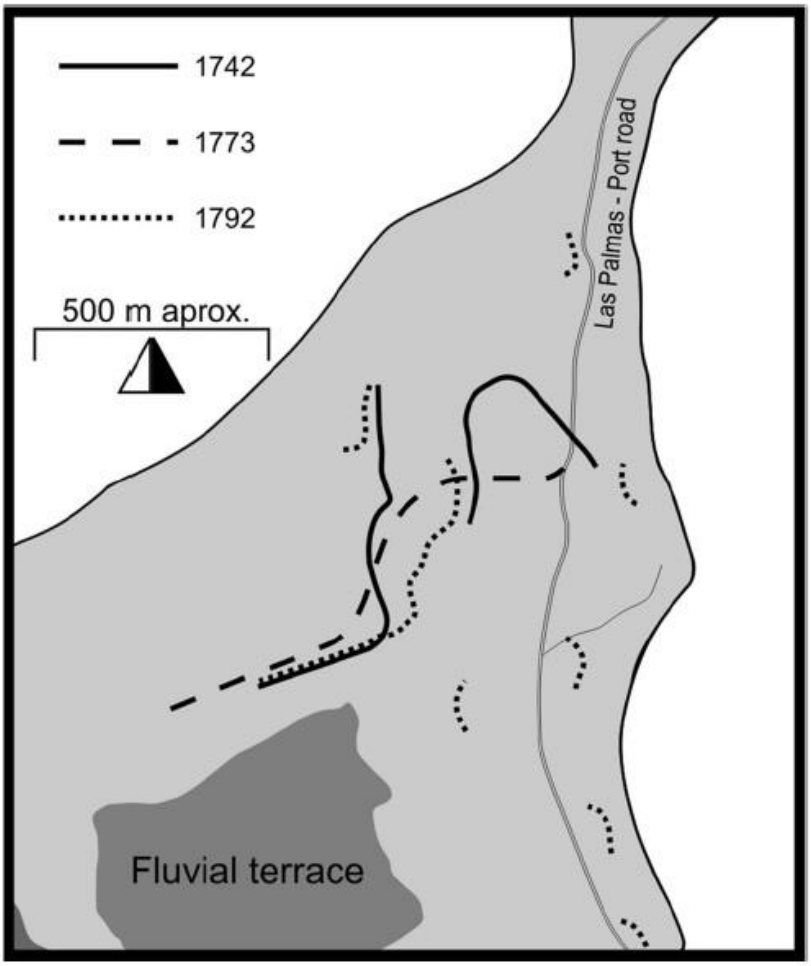

Fig. 7 Location of the dunes on the different dates analysed.

The points outlined above lead us to expect that the various maps would roughly reflect, from their authors' perspectives, the position of the main mounds of sand located on the

Guanarteme isthmus at each moment. This possibility is supported by the representation of the dunes dating back to the 16th century, which gives a general configuration of the terrain that is fairly similar to that found in the 18th century maps analysed. If we bear in mind all the above-mentioned documents, we will find that the dune has neither exactly the same shape nor position, which would suggest that each map reflects the situation as it was at the time the map was drawn up, and that they therefore present the evolution of the above-mentioned aeolian landforms. Other elements are also represented in the same area, possibly smaller dunes that change in shape and position, and sometimes disappear completely. However, it is important to remember that dunes constitute exotic landforms and in some case landscape landmarks, hence the associated toponymy (médanos de arena).

The above-mentioned long dune must has been of a really extraordinary size, which would explain why it was included in the maps (whereas the other smaller dunes were often left out) and given the toponym monte de arena (sand hill). The fact that this dune maintained a similar shape for nearly 200 years (from 1599 to 1792) is also of interest. However, as we can see in the 18th century maps, one part of the dune, the SW tip, is always in the same position, while the other, to the NE, appears to move. This may be explained by the aeolian dynamics of the topographical obstacle represented by the above-mentioned high sedimentary terrace. In turn, on the eastern edge appears to move, as it takes on a N-S direction in the 1742 map, but it is curved in shape in the 1773 map (facing NE) and 1792 (facing NNE). It would therefore correspond to a transverse ridge, although some parts of the front might be a bit sinuous, as it occurs in the Maspalomas dune field, so it could also be classified as a barchanoid ridge.

The eyewitness reports of the geologist Léopold von Buch 1815 (von Buch 1999) are particularly useful for the first half of the 19th century. He reports 30 or 40 foot high dunes on the Guanarteme isthmus, i.e. the sandy mounds at that time were between 8.35 m and 11.14 m high. These heights are entirely comparable with the deposits observed in other dune systems in the Canary Islands, such as those of Maspalomas (Gran Canaria), and Corralejo (Fuerteventura).

Aeolian geomorphology and vegetation from 1850 to 1954

During this period, the city of Las Palmas de Gran Canaria grew out to the north from the original old town with the constitution of the district of Arenales, while some settlements were also founded around the La Luz bay as a result of the construction of the port (Puerto de la Luz y de Las Palmas).

Olivia Stone, who visited the island between 1883 and 1884, gives the following description of the dune field:

“the sand is disposed in hills, valleys, small tablelands, and plateaus, over which when one begins to walk their extent seems to be much greater than would be supposed from a distant view".

In reference to the vegetation cover, this author says that "*looking at this stretch of dune, nothing appears but sand and a few stunted tamarisk bushes*" (Stone 2004) […] to that, SEAPGC (1868) adds that "*planted there in an attempt to stabilize the sand*".

We can therefore assume that at the end of the 19th century, the landscape was dominated by aeolian landforms and that the transport of sediment prevailed over the presence of vegetation. This quote suggests the possibility that tamarisk (*Tamarix canariensis*) could be found in the dune field, although its presence would not seem to be due to natural causes, but rather to the fact that the inhabitants of the city of Las Palmas had planted these shrubs (Fig. 8) as part of an activity proposed by the SEAPGC to fix the dunes, which were threatening to invade the crops, the port installations and the transport infrastructures (SEAPGC 1868).

Fig. 8 Vegetation planted in rows near to Las Canteras beach (1890–1895). Tamarisks, among other species, can be seen (FEDAC 2011a).

On the other hand, the street-level photographs show some clearly differentiated areas within this dune system. One such is the foredune, which is characteristic of these systems. Just as we can see on the upper part of the El Inglés beach, which is the input area to Maspalomas dune field from, there is some evidence to show that on Las Canteras beach, which acted as the entry system for sand to the Guanarteme dune field, there were rows of *Traganum moquinii* plants (Fig. 9). These rows of *Traganum* *moquinii* plants are crucial for dune systems in the Canary Islands and neighboring arid areas (from Morocco to Mauritania, as well as Cape Verde), as they are the first natural obstacle the sediments encounter when transported into the system. They modify the aeolian dynamics and, thereby, the sedimentary dynamics, shaping the first sand to be retained (hummocks). At the same time, this set of dunes and vegetation is known as a foredune, and it plays a determining role in coastal dune fields, not only because of its ability to form dunes further up the beach but also because it represents a barrier that protects the whole system from marine erosion.

On the 1879 map (Fig. 10), a series of barchanoid ridges can be seen, supporting the idea that there was a large mobile dune from the end of the 16th century to the 18th century (based on the interpretation of the maps from those centuries). As in 1879, the dune field was basically made up of structures with a similar geomorphology to those depicted on the earlier maps (Fig. 11).

Fig. 9 Row of *Traganum moquinii* on Las Canteras beach (1875–1880) (FEDAC 2011b).

Fig. 10 ‘Plano de la bahía de Las Palmas’ (Map of the Bay of Las Palmas). Representation of the dune field in 1879 (Dirección de Hidrografía 1995).

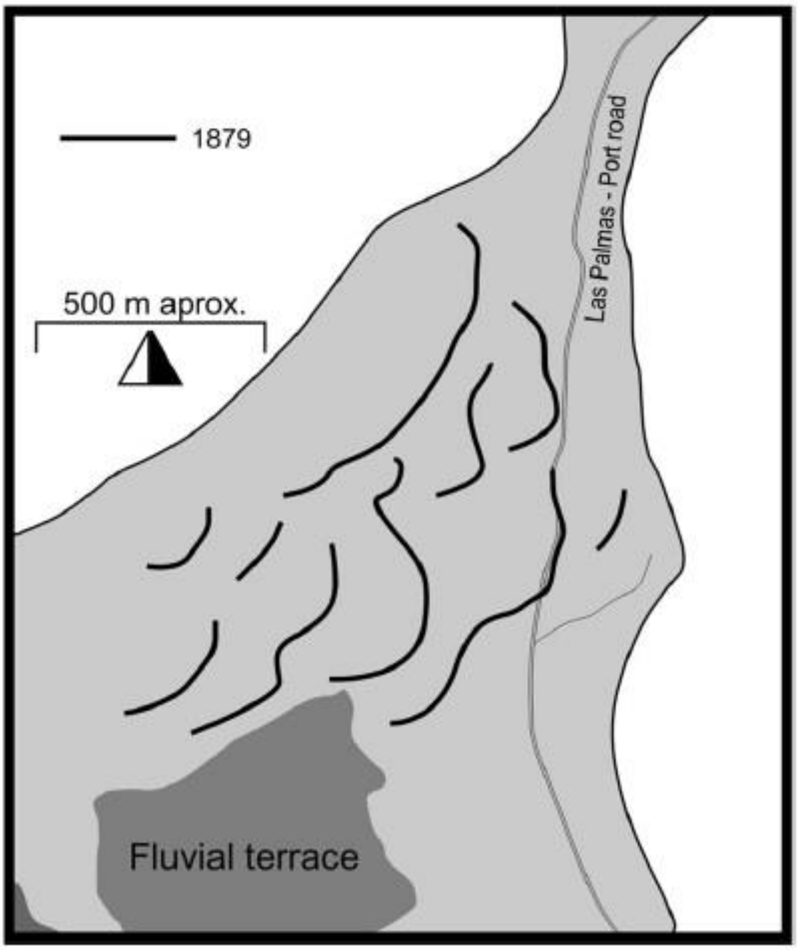

Fig. 11 Location of the dunes in 1879.

The size of the landforms represented suggests that a large amount of sediment was in circulation at the time, freely transported following the direction of the effective winds NW-SE, given the lack of any serious obstacles. It could be that, as compared to the previous period, sediment had accumulated for natural reasons or that human activities along the coast (such as the extraction of aggregate and rocks for building work or the cutting down of vegetation) had dismantled the stabilized or semi-stabilized dunes, thereby inducing the reactivation of the aeolian sedimentary system.

During the 20th century, the dune field area was gradually occupied by the development process that shaped the city of Las Palmas de Gran Canaria, which spread out from the south (Arenales district) and from the north (La Isleta).

In 1954 there were still some areas where the dunes moved “freely”, until they were definitively dismantled, as shown by the aerial photo taken that year (Fig. 12).

One of the interesting aspects of the fluvial terrace is the fact that it constitutes a topographic obstacle that generates specific landforms, as we have commented on for the previous period, given the influence that the terrace exerts on the wind flow. Thus, in the previous section we described a large dune, whose static part (its SW part) was linked to this terrace. If we look at the current classifications for relief shapes related to aeolian sediment dynamics, we can conclude that this dune could have been, by sectors, an echo dune and a climbing dune. An echo dune is normally formed in front of the cliffs that impede the flow of wind currents and the circulation of sediment, that runs into them at right angles along existing drainage channels, sometimes reaching the upper part of the cliff. Nevertheless, if the slope is less than 60°, the sand will move along these channels to the cliff-top as climbing dunes (Pye and Tsoar 1990).

Fig. 12 Aerial photograph of the Guanarteme dune field and the city of Las Palmas de Gran Canaria, 1954.

As far as this last interpretation is considered, oral sources available and valid for the second third of the 20th century offer information about the above-mentioned echo dune. The second eye-witness, born in 1929, tells us that it was possible to walk up from the current Madera y Corcho building (in the dune field) to La Minilla (on the fluvial terrace) (Fig. 2) across the sand, which would indicate that there was, indeed, a large dune that was at least partially supported by the NW slope of the terrace.

The existence of this dune would enable sand to travel from Las Canteras beach (from the area known as La Cicer, at the W) to the top of the terrace (in the area currently occupied by the Madera y Corcho building, at the base of the terrace, and the residential development La Minilla, in the upper part). Here, cliff-top dunes formed, and moved forwards more quickly as they were exposed to the effective winds. This idea has been confirmed by the information found in the Geological Map of Spain (Instituto Tecnológico y Geominero de España, ITGE 1989), on the page showing Gran Canaria. This map is drawn to a scale of 1:25.000, and shows the existence of "arenas eólicas (dunas de Guanarteme) [Aeolian sand (Guanarteme dunes)]" on top of the above-mentioned fluvial terrace. Some remains of these aeolian deposits can still be found today, although they are located in a very run-down area, full of rubble. The transit of this sand along the top of the platform would have given rise to a falling dune on the E edge of the terrace itself, on the stretch of current Paseo de Chil avenue, where the Estadio Insular (football stadium) stands today (see Fig. 2). This landform was visible until just a few decades ago, and it was used for recreational purposes, as it enabled people to watch the football matches in the stadium for free. The transport of sediment along the top of the high terrace would have been produced mainly when the wind was strong, and would probably have included processes of grain selection, as it has been noted for other aeolian sediment systems in the Canary Islands with similar characteristics (Hernández-Calvento 2006).

As far as the rest of the landforms are considered, eyewitness 2 gives the following testimony of the shape of the dune:

"It was very long. It started here from […] more or less where the church of El Pino stands, towards Guanarteme, […] bordering on… […] La Minilla, all that way. The mountain was all there; all leaning towards Guanarteme. […] Yes, in one straight line. Yes, in one line. Well, (with) waves […] But all in one line, in one line, of course…"

This fragment tells us that the appearance of the dune field in the second third of the 20th century was not substantially different from that shown in the 1879 Map of the Bay of Las Palmas, which shows the dune field made up of barchanoid ridges.

The reconstruction of the vegetation in the 20th century has been based on eye-witness reports.

Interpretation of the oral sources suggests that the main species of vegetation naturally present in the dune field were *Launaea arborescens, Zygophyllum fontanesii, Traganum moquinii, Schizogyne glaberrima, Sisymbrium erysimoides, Plocama pendula* and *Beta patelaris.*

As far as the cover is considered, these sources report the area studied as not having much vegetation. In this sense, eyewitness number 3 told us:

"You walked because this was very big and it was all mountains, and everything was mountains, mountains and all of them dunes. There was nothing else here, no plants or anything, no animals or anything. There was nothing in the dunes." She then goes on to say that "the dunes we went up were just clean sand. Clean, clean sand".

This witness clearly underlined the fact that the sand was “clean”, which leads us to think that there was very little vegetation present and such as there was, was relegated to its edges, as Olivia Stone’s comments at the end of the 19^{th} century indicated. In the same way, eye-witness number 2 states

“that part of the dune getting close to that mountain (edge of the dune field) was when you started to see a bit (of vegetation)” […] “I think that they were the two edges to the dune (where the vegetation was) coming very close together … where there wasn’t any more sand but just… what you could see was the mountain…”.

These ideas can be explained if we consider that the different species of vegetation could only grow up in those places where sediment was stabilized, so it seems that likely the areas with most vegetation were the edges of the dune field, together with some sections of the fluvial terrace. At the same time, they also explain that there was a large volume of sand being transported, which prevented vegetation from taking hold or spreading.

Discussion

This research constitutes the most thorough study undertaken to date of a dune field occupied by the urban development, as it is the case of the extinct Guanarteme dune field. Also, this study is one of the few ones that addresses a reconstruction of environmental conditions previous to 1800, a temporal boundary that characterizes the availability of sources at global scale (Szabó and Hédl 2011).

During the investigation, the formation of some aeolian landforms has been identified and explained, paying particular attention to those originating in the environs of the fluvial terrace, as they represent a unit apart from the rest in terms of sediment circulation and dune formation. It is also worth mentioning the identification of changes that occurred in the aeolian sediment dynamics between the 16th and 19th centuries, thanks to the interpretation of historical maps, the origins of which may lie in anthropic activities. Lastly, a foredune has been identified, something that had not previously been considered in this study area, which typically presents hummock dunes, conditioned by the presence of *Traganum moquinii*.

From these results, it would be of interest to make an analysis by applying paleoenvironmental methods such as those used by Arbogast et al. (2010) and Hanson et al. (2010), in order to reconstruct the processes experienced by the system during the previous centuries and millennia. However, the area of study has been occupied by a part of the city of Las Palmas de Gran Canaria, which prevents the collection of samples in the dunes to date these changes. The only possibility would be to collect such samples at specific points of the underlying substrate, but this would not reveal the processes concerning dunes themselves but their sedimentary substrate. In the area of the Canary Islands, however, those methods could be applied to other dune systems, but always in areas where the material or the underlying substrate are stabilized since these dune systems have high rates of mobility (Cabrera-Vega et al. 2013).

We neither have the ability to conduct a comprehensive study using historical cartographic documents and ancient texts, such as those carried out by Gautreau (2010), Levin et al. (2010) and Hunter and Sluyter (2011), due to lack on this type of documents for the entire study period. This is one of the reasons that justifies having sources of diverse nature in the development of this research, something that, on the other hand, has enriched and completed it.

Nevertheless, the reference conditions have been identified for various stages along the evolution of this system. Despite this, it is obvious that its disappearance makes impossible the application of restoration efforts based on such information. However, the establishment of reference conditions is a basic step for understanding the natural functioning of this system. Similarly, these data are needed to reconstruct its environmental history, which helps to know the relationship of a society with its natural area (Hughes 2006).

The method implemented is a key part of this study, which validates the sources by reliability levels. It is a simple and direct method which could be applied in other studies within the framework of Historical Ecology, whenever working with different types of sources and/or accuracy. In this regard, several methods have been proposed (e.g. Bertolo et al. 2012; Bürgi and Russell 2001; Grossinger et al. 2007), but new methodological contributions are claimed from the scientific literature.

This research is innovative in comparison to other studies carried out to date in these kinds of areas, the arid dune systems, as it is based on the integration of sources and techniques drawn from a variety of scientific disciplines. It is also relevant its contribution to bringing History to Ecology, notably distanced scientific areas (Szabó and Hédl 2011), using an integrative approach. Thus, we have used geographic technologies (maps and the interpretation of aerial photographs) together with sources and other analyses typically used in History, such as Oral History, which is a characteristic technique of this type of studies (Bürgi and Gimmi 2007). In this sense, in this field the integration of these techniques is necessary.

Conclusions and prospects

If we consider the results obtained in terms of the methodology used, three main conclusions arise: firstly, the application of a historical approach, in which different sources have been used and integrated, has enabled us to fill a large part of the gap existing in the environmental information available for the extinct Guanarteme dune field.

Secondly, this study makes a methodological contribution through the method developed to assess the reliability of sources.

Thirdly, the analogy with other still-active dune systems of similar characteristics such as the dune system of Maspalomas on Gran Canaria (beyond being one of the applied analyses), is important because it has enabled us to address the structure and functioning of this dune field, and to come up with an image of what the landforms and processes of the past might have looked like. Similarly, some of the species of vegetation that were found in the outlying areas of this singular system have been identified.

The results obtained from this study point the way for future work that may be considered as three-fold: firstly, more in-depth work is needed on the Guanarteme dune field, broadening the scope of the data through further archive material and interviews, in order both to gather more information in terms of the territory that has been the object of this study and also to help to develop and polish the methodological aspects of this type of studies.

Secondly, this type of methodologies could also be applied to the reconstruction of the natural characteristics of other dune systems in the Canary Islands and surrounding area, opening up the time-span considered to date, which has been limited by the availability, or lack thereof, of aerial photographs to the end of the 1950s. The inclusion of oral sources enables us to look several decades further back, although it is true that this aspect needs to be addressed urgently, given the fact that potential eye-witnesses are already quite old.

Thirdly, proposals that go beyond the scope of this study include the specific interest of working with GIS using historical content, not just as a research tool but also as a source of information for society at large, that can be consulted on-line, through Geoportals or Spatial Data Infrastructure (SDI), to help to understand the space and time dimensions of land. In this way, and in relation with the prospects already mentioned, there is an urgent need for the creation of an archive of environmental memory for the Canary Islands, by means of which our knowledge of the immediate past of our territory could be broadened, involving citizens at large as “memory donors”, in the scientific progress of the Canary Islands.

Finally, dune fields are ideal objects of study when examining historical changes in territory, as 1) their landforms are very dynamic and their current state can tell us about natural processes and/or human alterations that may have taken place there, and 2) their elements (at least the most noteworthy among them) tend to be depicted on historical maps, which enriches the historical approach to their study.

Acknowledgments

This piece of work is a contribution to project CSO2010-18150 of the Spanish National Plan of R&D + I (innovation), co-financed by European Regional Development Funds. The basic research has been possible thanks to a student grant, awarded by the SpanishMinistry of Education.We would like to thank a number of institutions for giving us permission to reproduce some of the figures included in this article (the Simancas General Archive of the Spanish Ministry for Culture, the Ministry of Defense and FEDAC). Authors would like to thanks the anonymous reviewers for their comments, which have improved our manuscript. The translation to English was carried out by Heather Adams (ULPGC) and revised by InvestigAdHoc. Authors would like to thank Instituto de Historia y Cultura Militar de España for its authorization to publish the historical maps of the Fig. 6.

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3. Historical reconstructions of land use

Long-term human impacts on the coast of La Graciosa, Canary Islands

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Land Degradation and Development (2016) 27:479–489

DOI 10.1002/ldr.2369

Abstract

Global change is affecting coastal areas and leading them to degradation. This is severe in sand dunes and sand plains, because they are very fragile ecosystems. The objective of this paper is to characterize the relationship between the historical land uses and the aeolian sedimentary dynamics in an arid coastal system, the island of La Graciosa (Canary Islands) since the second half of the 18th century. The methodology is based on the interpretation of historical documents, aerial photographs and oral testimonies to characterize the changes in the island, in terms of both land use and aeolian geomorphology. The results suggest the existence of six stages during which the intensity of human pressure on the environment changed.

Keywords: Historical ecology; Historical land uses; Land use/land cover changes; Alteration; La Graciosa; Canary Islands.

Introduction

The Earth's system is being affected by global change, and there is a need to understand the origin of these changes, their processes and rates and to contribute to developing an adequate framework for studying it (Harris et al., 2006; Jackson & Hobbs, 2009; Alphan, 2012). Vitousek et al. (1997) indicate that no ecosystem is currently free from human influence, and Foley et al. (2005) suggest that land use is the main process responsible for the global change. In this context, coastal areas represent priority locations for human settlements (Steffen et al., 2004), and therefore, these areas are subject to continuous degradation by human activity (Lin, 1996; Bajocco et al., 2012). In this sense, coastal dune systems are one of the most altered coastal environments (Thomas & Wiggs, 2008), which have traditionally been impacted by many activities such as grazing, agriculture or forestry (Granados Corona et al., 1988; Kutiel et al., 2004; Levin & Ben-Dor, 2004) and more recently by the building trade and tourism. These activities diminished the extension of the natural systems, despite the efforts performed in their appropriate management and conservation during recent decades (Jackson & Nordstrom, 2011). On the other hand, research about the landscape history involving various types of ecosystems have been developed in recent decades. These studies provide the keys to understand their function and current status. At the same time, they contribute to the basic knowledge on which to base their management and/or ecological restoration (Bellarosa et al., 1996; Swetnam et al., 1999; Rhemtulla & Mladenoff, 2007; Stringer & Harris, 2014). It has been defined a common conceptual framework in the field of historical ecology (Egan & Howell, 2005), where the reconstruction of the features of a natural system is a main issue to address. This topic tries to identify and characterize the elements and environmental dynamics of an ecosystem and/or human activities that influence it at a certain historical period from different sources. These reconstructions were carried out in different environments, such as wetlands (Grossinger et al., 2007; Stein et al., 2010), forest systems (Gimmi & Bürgi, 2007; Gautreau, 2010), river environments (McAllister, 2008), arid environments (Hoffman & Rohde, 2007; McLeman et al., 2010) and coastal areas (Bajocco et al., 2012; Roig-Munar et al., 2012; Santana Cordero et al., 2014), among others.

The use of multiple sources and methods is one of the main characteristics of historical ecology studies (Bürgi & Gimmi, 2007; de Mûelenaere et al., 2014; Raska et al., 2015). Some of these are historical maps, written accounts by travellers/explorers, conventional photographs, aerial photographs and oral sources (Rhemtulla & Mladenoff, 2007; Gimmi & Bugmann, 2013). This range of source types enables one to widely explore the history of a place, in both temporal and spatial sense. Furthermore, for these works, with an inherent geographical focus, of special interest are the broad possibilities supplied by geographic information systems (GIS) (Rumsey & Williams, 2002; McLeman et al., 2010).

Most of the studies analysing the consequences of the historical uses on aeolian sediment dynamics of the coastal systems have focused on temperate regions, there being few that address these changes in arid systems. In temperate regions, the impacts on aeolian sedimentary dynamics and soils and the apparition of erosion processes have been mainly induced by the use of herbaceous vegetation by grazing activities (Granados Corona et al., 1988; Cerdà & Lavee, 1999; Kutiel et al., 2004; Levin & Ben-Dor, 2004; Mekuria & Aynekulu, 2013; Angassa, 2014). However, in the coastal dunes at arid regions, where shrub species are more commonly found than herbaceous species (Johnson, 1977, 1982; Doing, 1985), the impacts by grazing are lower.

In this study, we hypothesize that aeolian sedimentary dynamics in sand arid systems has been historically altered by the direct utilization of wood by humans, instead of herbaceous vegetation by grazing activities. To test this hypothesis, we conducted an investigation on an island laboratory (La Graciosa, Canary Islands, Spain), which was gradually colonized since the 18th century, using a multi-source-based methodology. We have sufficient historical sources to determine the land uses developed since then and their consequences on aeolian sedimentary dynamics. From this hypothesis, the aim of this paper is to explain the relationship between the land uses and covers, and the aeolian sedimentary dynamics.

This island can be defined as a laboratory for testing hypotheses around some issues regarding aeolian sedimentary dynamics in arid environments because it meets four conditions: (1) the climate is arid; (2) it presents aeolian sedimentary mantles; (3) human activities are present since the 18th century; and (4) the use and exploitation of its resources and its environmental consequences are documented in historical sources.

Materials and methods

The island of La Graciosa, with an area of 27.05km^2, is located north of Lanzarote, in the Canary Islands (Spain) (Figure 1). From a geological point of view, it is located on a shallow marine platform, and it is formed by the accumulation of lavas and pyroclastics of mafic and ultramafic compositions that surfaced during the late Pleistocene and Holocene (de la Nuez et al., 1997). At the same time, sedimentary processes resulted in the formation of eolianites and palaeosols, slightly cemented (Ortiz et al., 2006). Currently, over half of the island (13.1km^2) is covered by aeolian sands. These are divided into two areas separated by a volcanic alignment: one is located north of the island (4.4km^2) and the other one south of it (8.7km^2).

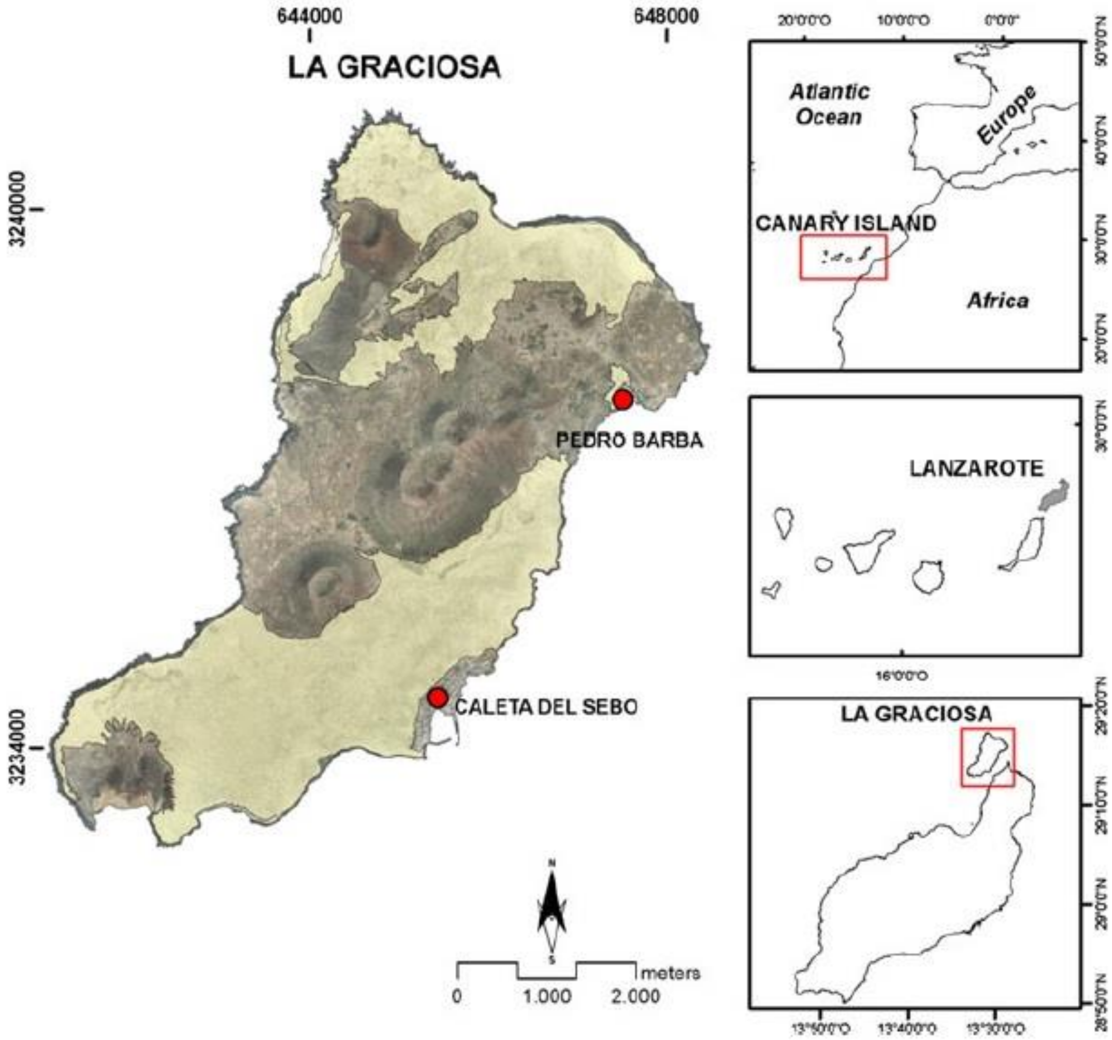

Fig. 13 La Graciosa location in the Canary Islands and its two villages, Caleta del Sebo and Pedro Barba.

The climate at La Graciosa is coastal desert with low rainfall rates (annual average of 116mm), mild average temperatures (19.7 °C) and prevailing winds from the north (trade winds), with an annual average speed of 18.3km/h. The vegetation consists of halophilic, psammophyte and xeric scrub species. Seasonal herbaceous species grow in association with occasional rain. Some of these species are *Ononis serrata* Forssk., *Reichardia tingitana* (L.) Roth, *Reseda lancerotae* Webb et Berth. ex Del., *Tragus racemosus* (L.) All., *Ifloga spicata* (Forssk.) Sch. Bip. and *Mairetis microsperma* (Boiss.) I. M. Johnst. (Flora Vascular de Canarias, 2015).

The island was not settled until the late 19th century, but its use as pasture by the inhabitants of Lanzarote started in the 18th century as evidenced by some references found in the archives (Ayuntamiento de Teguise, 1871; González Viera et al., 1996).

The methodology followed has been based on the application of different methods and tools, which have enabled us to work with various source types, analyse their information and integrate them in order to obtain a complete image of the system in each period studied.

Sources

In this research, five types of sources have been used (Figure 2), which are described in the following.

- Documentary sources: These are accessed from the National Historical Archive, the General Archive of the Administration, the National Library of Spain [Ministry of Education, Culture & Sport (Spanish Government)], the Provincial Archive of Las Palmas (Canarian Government), the Municipal Archive of Teguise (Teguise Town Hall), the FEDAC (2013) and the newspaper archive of the Museo Canario (dedicated from 1879 to the conservation of archaeological, ethnographic and anthropological heritage of the Canary Islands).
- Bibliographic references: Some monographic studies of interest that provide specific data on the study area have been consulted (Cabrera Socorro, 1997; de la Nuez et al., 1997; González Viera et al., 1996). Likewise, publications on methods (Bryman, 2012; Rumsey & Williams, 2002) have also been very useful.
- Oral sources: Interviews to ten people have been conducted, with the objective of gathering the witness of the inhabitants of the island, especially the elderly people. In general, the interviews were digitally recorded, with transcriptions carried out afterwards. Seven interviewed people were born between 1930 and 1937, the other two in the late 1950s and the last one in the late 1960s. Interviews were performed following the methodology of oral history (Benadiba, 2007); a model for an interview was established based on an open script as a conversation mode. This source has the ability to fill essential data gaps on some aspects of land use, especially during the decades of the 1940s and 1950s, and to compare and validate the information from other sources as well as from each interviewee.
- Aerial photographs (1954, 1977 and 1987) and orthophoto (2009): These have been used to get spatial data and to compare certain aspects of the information obtained through oral sources. Also, by comparison with a recent orthophoto (2009), an analysis was performed about the land cover changes (Table I).

- Field data: Field recognition was needed to locate some interesting historical landmarks, such as lime kilns, so intensively used in the island until the 1960s. Through several field works, the exact location of these landmarks was registered by GPS.

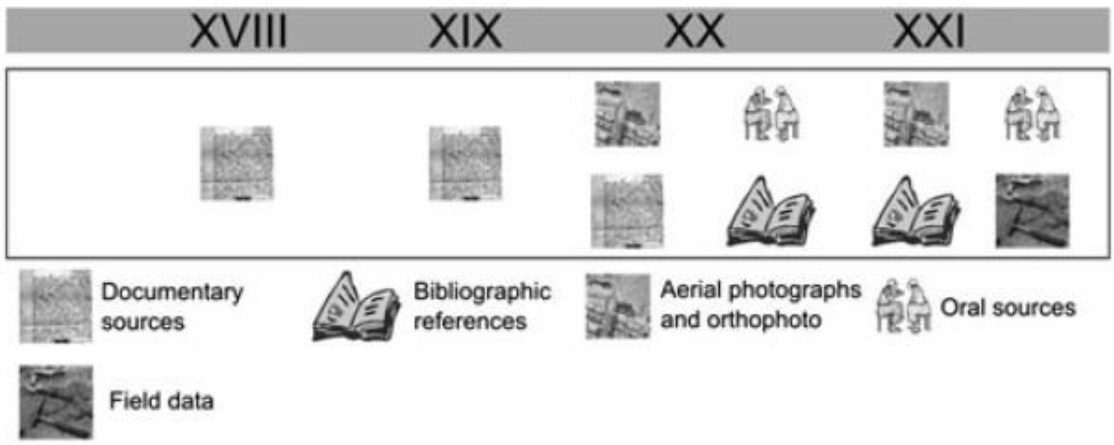

Fig. 2 Sources employed.

Table 1 Main characteristics of aerial photographs used.

Date	Source	RMS	Scale	Spatial resolution (m)
1954	Centro Cartográfico y Fotográfico (CECAF) (1954)	Ranging 1.05–2.01	1:5,000	1
1977	Consejería de Política Territorial (Gobiemo de Canarias)	*	1:25,000	*
1987	Consejería de Política Territorial (Gobiemo de Canarias)	*	1:5,000	*
2009	Organismo Autónomo Parques Nacionales (OAPN)	—	—	0.1

RMS, root mean square. Asterisks denote unknown data.

Data Analysis and Integration

A set of methods and tools has been used to analyse the data gathered in order to extract relevant information from the sources. Additionally, a GIS tool has been used to integrate the data. Table II contains key information about the methods/tools utilized, named documental analysis, photointerpretation, oral history, GIS and GPS.

All sources have been revised in order to extract information related to land use, land cover and their changes from the 1730s to the present. This has been useful in obtaining an important qualitative background and in producing cartographic documents that include data from different sources and also in suggesting conclusions to explain the changes in aeolian sedimentary dynamics. Similarly, for the last historical period (from 1954, when aerial photography is available) a GIS-based analysis of land cover changes was undertaken.

As shown in Table II, an integration of the data has been conducted through GIS. Modern spatial data are georeferenced from its production process and can be treated through GIS. Nonetheless, former spatial information (such as old aerial photographs) can be manually geo-referenced by a specific GIS tool. Additionally, non-spatial data (e.g. data about lime kilns and other landmarks) could be spatially located through oral history interviews and/or documentary sources and then geo-referenced by GPS through field work. The result of this process is to obtain a dataset where information derived from different sources is totally integrated. It allows us to do a basic visual analysis and to use several GIS tools in order to perform spatial analyses and to obtain spatial information from them such as distances, areas and so forth.

Land Use and Land Cover Classifications

Land use and land cover classifications have been established in relation to aeolian sedimentary dynamics. Our interest has been to consider land uses and covers that have affected this dynamics. Thus, land uses considered have been grazing, firewood (bush logging), lime kilns (sites where firewood was burned) and others (minor uses such as recent tourist use). On the other hand, land covers of interest have been farms abandoned from 1954 to 2009, farms abandoned before 1954, new ploughing fields between 1954 and 2009, active farms since 1954, new infrastructures, town expansion/edification expansion, quarry expansion and road network expansion.

Table 2 Methods and tools used in this research and their main characteristics.

Method/tool	References	Aim	Results
Documental analysis	a, b, c, d, e	Obtain a consistent background about the study area and the scientific context of this study	Qualitative data
Photo-interpretation	b, c, e	Extract important spatial data that help us to explain socio-environmental dynamics	Geographical data
Oral history interviews	b, d, f	Fill data gaps and validate information from other sources	Qualitative data
GIS	g, h, i	Spatial analysis and data integration	Spatial/cartographic data
GPS	j	Verify and specify spatial location of certain landmarks	Spatial data

GIS, geographic information systems. ‘References’ refers to a number of works that have used the exposed methods/tools and/or explained them. These works are the following: Bryman (2012) (a); Santana Cordero et al. (2014) (b); Domon & Bouchard (2007) (c); Gimmi & Bürgi (2007) (d); Bürgi & Gimmi (2007) (e); Fogerty (2005) (f); Hernández-Calvento et al. (2014) (g); Alphan (2012) (h); Rumsey & Williams (2002) (i); and de Mûelenaere et al. (2014) (j).

Results

Historical Evolution of Land Uses

From the information obtained through the aforementioned sources, the evolution of the relationship between human activities and the environment, especially regarding aeolian sedimentary dynamics, can be defined. This evolution experienced variations in its intensity depending on different historical circumstances. Despite this, it should be noted that sediment stability was always seen as a priority by local authorities (at least from 1834), legislating repeatedly against logging any kind of shrubs in order to avoid the remobilization of sandy sediments and thus the invasion of grassland areas and farms by the sand.

Considering the previous statements, we have defined up to six key historical periods in the island, based on important milestones related to the aeolian sedimentary dynamics. Each period shows significant changes with respect to the previous one, such as different relationships between human activities and the environment.

Before 1730

The island of La Graciosa was uninhabited, although it was used by the inhabitants of Lanzarote for the development of harvesting activities, shearwaters and rabbit hunting, fishing and shellfishing. Its seasonal grasses also had special relevance. In winter, cattle grazing consisting of goats, sheep, donkeys and camels from Lanzarote were moved to La Graciosa. They remained there until the summer, when water shortages forced them to move back to Lanzarote.

1730–1880

The island of La Graciosa was a strategic location for the animals of Lanzarote after the eruption of Timanfaya. Timanfaya, currently a national park, is a volcanic area of 5107 ha in Lanzarote island (located in its central part) (MAGRAMA, 2014). These eruptions (1730–1736) provoked the reduction of the grazing area. For that reason, a tank for collecting rainwater was built in La Graciosa, which enabled the permanence of cattle grazing throughout the year. Shepherds travelled with animals, thus constituting the first permanent presence on the island. Thus, the pressure on the environment increased markedly. A proof of this was the need to regulate several times (the last time in 1871) the use and exploitation of the island. The prohibitions and limitations contained in these regulations denote the use and abuse that some people performed over La Graciosa resources. Thus, a regime of permits and restrictions was established for any activity involving the use of resources of the island, while population settlements were forbidden, in the same manner as logging and burning bushes or cattle grazing entry without permission, among other issues.

These actions led to remobilization processes of sand, an issue that is reflected in the documentary sources:

> ‘…But even when the island of La Graciosa was capable of cultivation, we have the serious drawback for ploughing the sand and clearing of plants and shrubs, because growing up these on banks and promontories they stop the sand stream that would run impelled by the prevailing winds on our island. As experience teaches us in our own days, in the northern beaches these same nature headlands high on the surface, presented shrubs that contained the same kind of sea sand. As a consequence of their removal after the year 1730, to take advantage of the wood, burn lime kilns after planting and cultivation of the vines due to the lack of other kinds of wood, the same prevailing winds dragged and rose sand clouds that occupied and ruined, as stated above, many rich lands and towns across a

sand river from north to south and extending substantially from east to west. The City is currently taking steps to prevent such damage, limiting the portions of sand and leaving farming these plants and shrubs containing the current of this sand river…' (Report on the claim of D. Francisco de la Cruz Guerra at La Graciosa, minutes book, pp. 225–235, Ayuntamiento de Teguise, 26 November 1834, Archivo Histórico de la Villa de Teguise)

1880–1943

There was a gradual change in the occupation of the island. Starting from a very small population settlement, established in the beginning by about six houses, it reached a higher number of about 80 houses by 1943. Most of them were huts built with stone, mud and logs (Cabrera Socorro, 1997), whose construction should not pose a significant impact on the dynamics of the sands. However, the existence of this settlement on the island, which increased substantially during this period, also increases the exploitation of plant resources in the island. Some of the species used were *Mesembryanthemum nodiflorum* L. and *Mesembryanthemum crystallinum* L. They were used for construction (roofing), for ovens to make bread and, mainly, as a fuel in the home. We should add that in the 1930s the second village of the island, Pedro Barba, was also founded.

1943–1967

There is a substantial change in the relationship between the population of La Graciosa and its environment that marks a turning point in the sedimentary dynamics. The arrival of Capitán General García Escámez (Canarian Economic Command) to the island, in 1943, was a catalyst for the development of various infrastructures and represents the beginning of a population increase (Figure 3) and an increase in the number of houses. Thus, while between 1920 and 1940 the number of houses increased by 16, between 1940 and 1960, the new houses increased by 72: 63 in Caleta del Sebo and 9 in Pedro Barba (Cabrera Socorro, 1997).

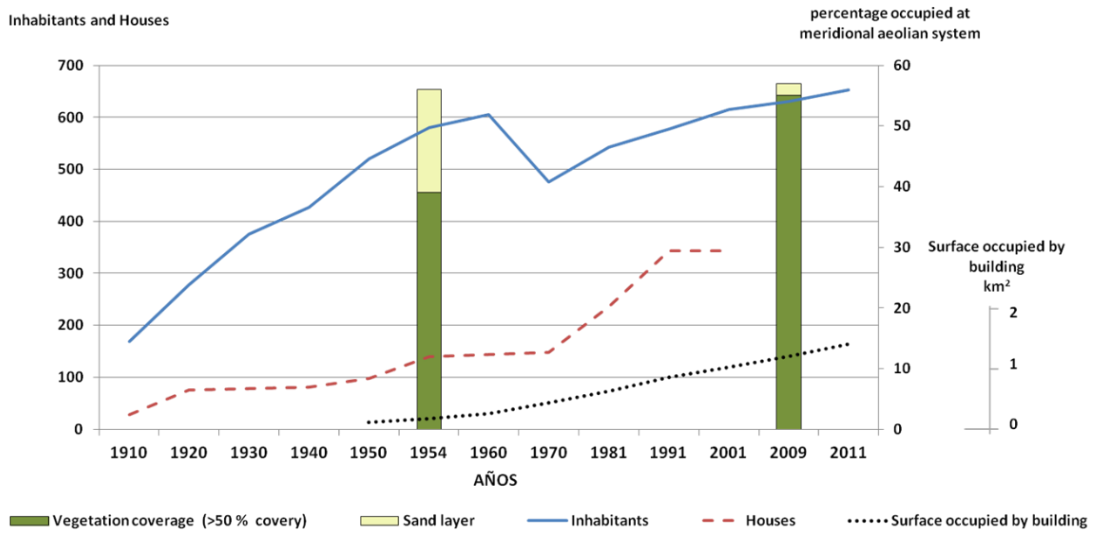

Fig. 3 Houses and inhabitants evolution at Caleta del Sebo from 1910 (Cabrera Socorro, 1997; González et al., 1996; and INE, 2013); evolution of the surface occupied by buildings at Caleta del Sebo (aerial photographs from 1954, 1977, 1987 and 2009); percentage distribution of vegetation coverage (>50% cover) and moving sand layer at meridional aeolian sedimentary system (aerial photographs from 1954 to 2009).

Additionally, in the aerial photography taken in 1954, the dense vegetation cover (>50% cover) occupies less than 40% of the sedimentary field at the southern area (which is closest to Caleta del Sebo), while mobile sand layers occupy about 17% of the surface of this same area (Figure 4).

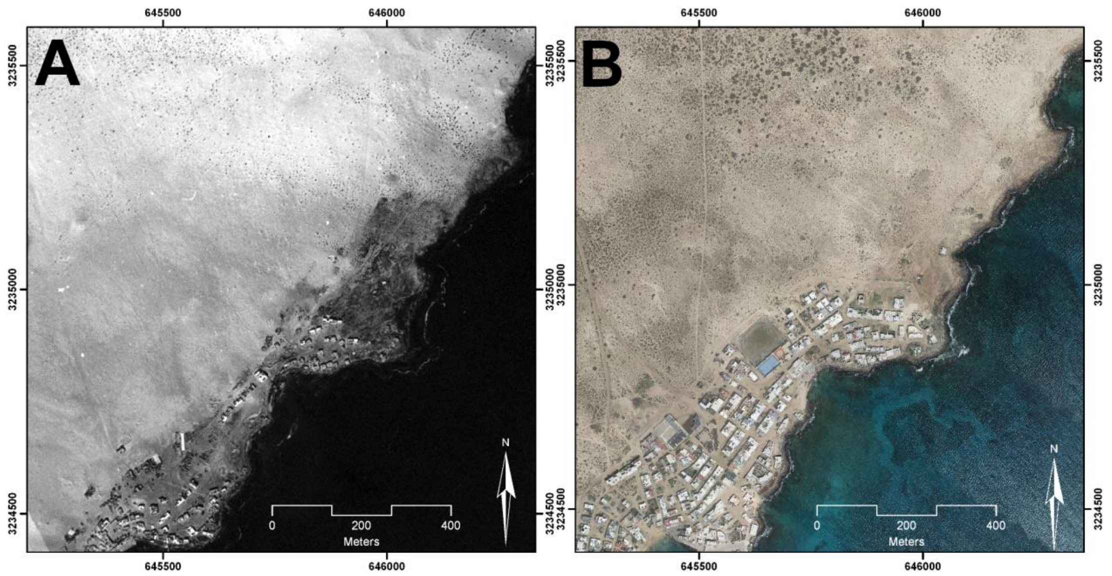

Fig. 4 State of vegetation around Caleta del Sebo from 1954 (A) to 2009 (B).

From the point of view of sediment stability, it is important to consider not only the increase in the number of houses but also the change in building materials. Thus, from the previous traditional buildings, they now build stronger houses, introducing the use of lime as mortar. This involves the cutting of bushes to feed the lime kilns. From the oral testimonies gathered, it appears that for the construction of a family home, the material produced by a lime kiln and half of another (three lime kilns for every two houses) were necessary. Each of these kilns' consumption implied '20 camel loads' (plant material) continuously burning 'over one night and two days'. Also keep in mind that, at this stage, there was not only an increase in the number of houses but also the renovation of the existing houses so far. Thus, during this period and until 1967, when according to oral sources the last lime kiln burning in the island occurred, at least 5100 camel loads should be required, only for the rehabilitation of existing houses and construction of new ones. Additional loads should be considered for the construction of public infrastructure (water tanks, school, cemetery and spring), funded by the Canarian Economic Command. In this sense, the fieldwork has identified 14 lime kilns in different states of preservation. Oral sources indicate the existence of some other in what today is the very core of Caleta del Sebo, but which disappeared after the current expansion of the buildings. According to these same sources, as a general rule, the location of the lime kilns was associated directly with the presence of rocky material, because of the two resources needed (calcareous sandstone and wood); rocks are the heaviest to transport. It is significant, however, that during the fieldwork we noticed the existence of some kilns not associated with the location of the rock material.

The wood was also a key resource in the homes of La Graciosa, not only for cooking but also for supplying small industries such as bakeries. According to oral sources, this wood was gathered initially around population centres, where it was forbidden to collect firewood for lime kilns. However, some witnesses have provided information on the collection of firewood in the north-western edge of the island, which could be indicative of resource depletion in the vicinity of these population centres for intensive use. These same reports indicate that the best wood for cooking was the thickest species (*Traganum moquinii* Webb ex Moq. in D. C. and *Nicotiana glauca* R. C. Graham), compared with thinner species used for lime kilns (*Launaea arborescens* (Batt.) Murb. being the species mostly used).

Another use of longer exploitation that had an impact on the stability of the sediment was grazing. The inhabitants of the island, although mostly devoted to fishing, complemented its resources with the farms. In this regard, the sources indicate that each family had about four livestock (goats), although some possessed a higher number. The dedication of the inhabitants of the island to fishing required the services of a community shepherd attending to livestock, leading to grazing all over the island.

The clearing of vegetation should also occur for another reason: the growing of dry farms in areas of the island allowed by the soil quality. This agricultural use continuously developed during the decades of the 1940s and 1950s, being gradually abandoned since the 1960s.

The sand moved from north to south, accumulating in certain places. In this regard, some testimonies refer to the existence of three large dunes: one in the village itself of Caleta del Sebo, leaning on a home in those years located in the periphery of Caleta del Sebo (nowadays this house is inside the village); another one was located in El Salado (about 200m from the village to the south); and, finally, the largest dune was behind the cemetery (about 500m from the village, to the southwest), and it was used to aggregate extraction.

1967–1987

The pressure related to the agrarian mode of production is greatly reduced, and thus, a gradual natural regeneration of vegetation begins, which will contribute to the stabilization of sands. The causes that led to this change are basically three: first, the decline in the number of people living in La Graciosa, because many of them migrate to Lanzarote to work in tourism or in the harbour of the fishing industry, in Arrecife; second, the arrival of gas for domestic fuel and thereby the lower demand of wood for homes, joint with the availability of electricity for 12 h a day, from 1977, and the final electrical connection since 1985; and third, the termination of use of vegetation as fuel for lime kilns, because, according to testimonies gathered, this activity ended up in 1967.

The only use with an impact on aeolian dynamics that survives during this stage is farming, not having evidence of any variations in the number of cattle grazing during this stage.

From 1987

The island is declared as a natural park together with the rest of the northern islands of Lanzarote and the ridge of Famara as stated by the Law 12/1987, of 19 July, Declaration of Natural Sites in the Canary Islands. This statement confirmed the declaration made by the Canary Islands Government a year earlier (Decree 89/1986, of 9 May). From that moment, the whole island is classified as a protected rural land, except Caleta del Sebo. The direct consequence is a change in land use, which also involves the housing of livestock. These changes in traditional agricultural uses, which had led to the alteration of aeolian sedimentary dynamics, favors the gradual stabilization of the sands (Figure 5).

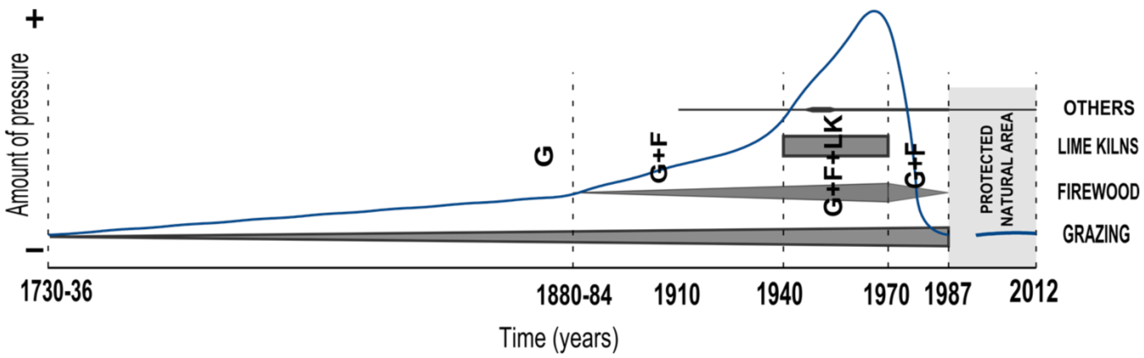

Fig. 5 Evolution of the land use from 1730 to 2012 and relative pressure over vegetation.

However, a new land use appears, which again alters this aeolian dynamics in a short period. Albeit generally less extensive, it is more intensive where it occurs. We refer to certain tourism-related activities, such as the extraction of aggregates for the building trade or track opening for the increasingly widespread use of motor vehicles, especially during the summer months.

Recent Evolution of Land Covers (1954–2009)

The aforementioned analysis is completed from the spatial point of view by comparing aerial photographs between 1954 and 2009 (Figure 6).

With respect to the farm fields, Table III shows the agricultural area in 1954 and 2009. In 1954, most of these lands were abandoned. Oral sources indicate that cereals were cultivated only in the years when it rained, collecting most of the time much grain, which was finally sold in Lanzarote. The trend of abandonment extends to the present day, when only 5.25 ha is cultivated.

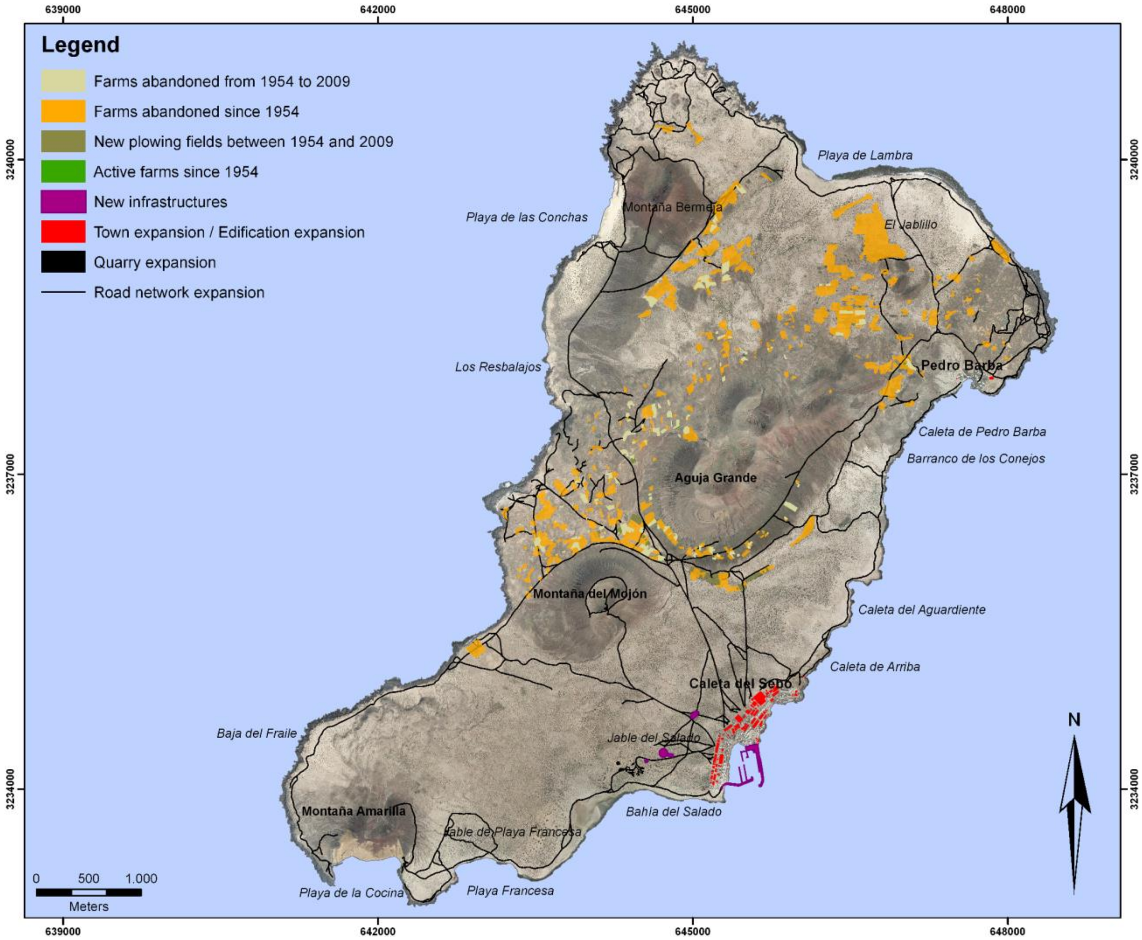

Fig. 6 Changes in land use from 1954 to 2009 (cartographic source: digital orthophoto from 2009, Canary Islands Government, production date: 2012).

Table 3 Active and inactive farm surface at 1954 and 2009.

Year	Active farm surface, ha (%)	Inactive farm surface, ha (%)
1954	19.87 (13.45)	127.88 (86.55)
2009	5.25 (3.55)	142.50 (96.45)

Changes along these decades have led to a transformation of the land use of these plots and thus the agricultural landscape of the island. At present, only some plots located in the central area of the island are in use, linked to the existence of a water tank. Today, these plots have a number of water irrigation hours a week, which has changed their use, as well as the products obtained. Thus, production has changed from cereal dry farming to orchards. While in the 1950s the crop was a complement to food and surpluses were sold at the markets, at present, this is practically a 'leisure' activity.

With respect to the urban side, it should be noted that the change in the main economic activity on the island, which is now based on tourism, represents a significant growth of Caleta del Sebo village, which almost doubled its surface area from 1977 to 2009 (Figure 7). Despite this increase in the surface occupied, the pressure on vegetation has decreased given the change in fuel use, running from the wood burning to fossil fuels.

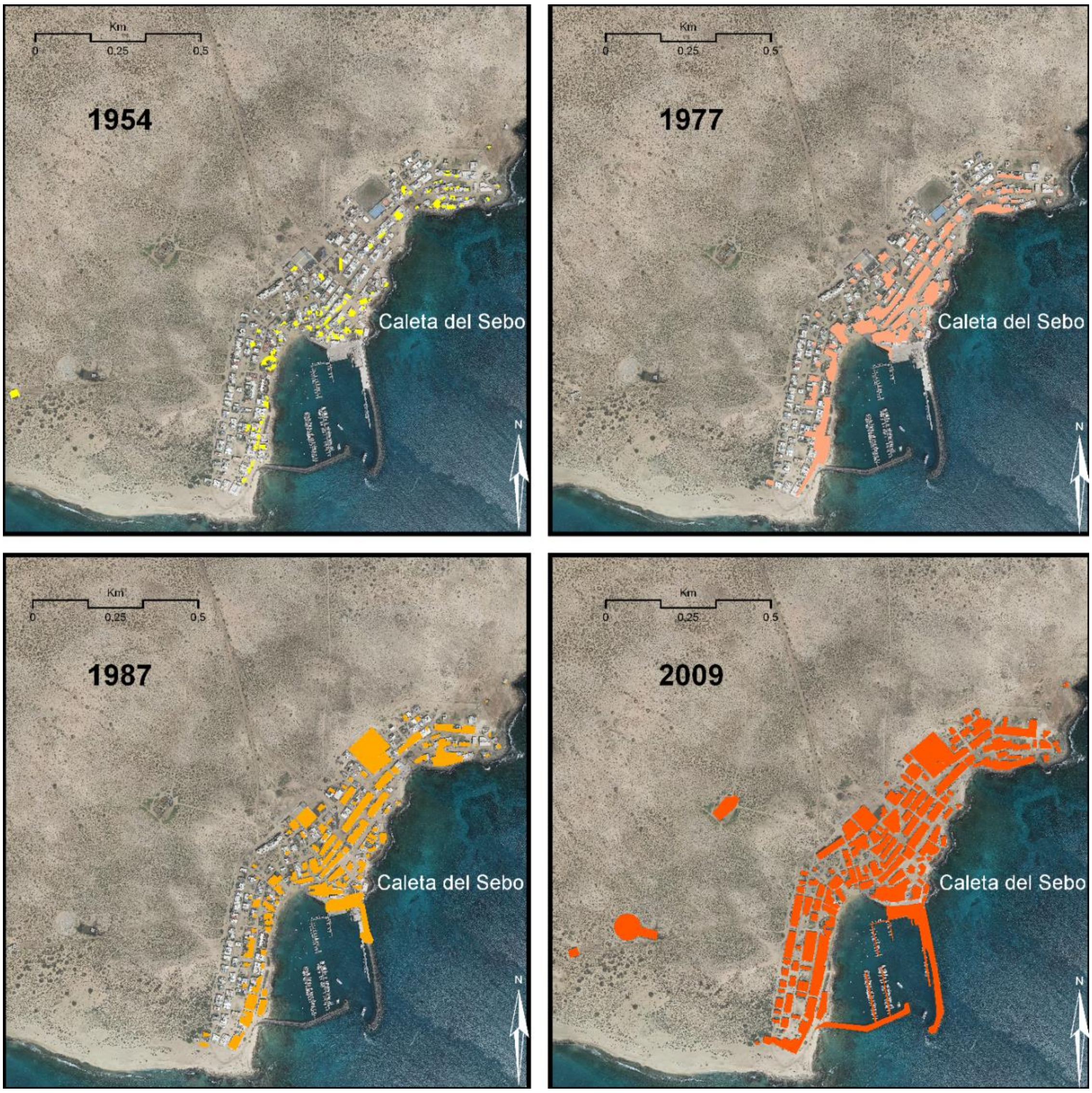

Fig. 7 Urban expansion at Caleta del Sebo from 1954 to 2009.

Another significant change is the expansion of the port, and both the passenger and freight traffic through it. Meanwhile, the network of roads and trails is intensified, and also the number of people and vehicles on it. Although living conditions have improved and the island has secured a constant supply of water and energy, some environmental problems associated with this change in the economic model are detected: deterioration in some areas by the extraction of building trade materials and difficulties in the management of solid waste or wastewater discharges, among others. Some recent steps (closing of landfills, regulation of authorized roads, cleaning campaigns, etc.) have helped to reduce the environmental problems described previously.

Discussion

The evolution and current status of aeolian sedimentary systems depend directly on the existing environmental conditions around them, especially those related to climate (Jackson & Cooper, 2011). Similarly, such evolution depends on human activities that developed in them and/or around them (Jackson & Nordstrom, 2011). Aeolian sedimentary systems in La Graciosa are the result of special conditions that link these two sets of processes. So, first, we must attend to the arid nature, as performed with the rest of aeolian sedimentary systems in the Canary Islands (Cabrera-Vega et al., 2013). This determines a potential sand mobility greater than that produced in aeolian sedimentary systems at temperate regions. The xeric shrub vegetation stabilizes the soil, and occasionally, when it rains, seasonal herbaceous species grow for short periods. Second, there is a direct relationship between land uses developed on the island and the stability or instability of their aeolian sand fields. In this regard, the results of this research indicate that during the first third of the 18th century, the vegetation cover stabilized the sedimentary substrate. In fact, for that period, before 1730, there are not any documented evidences that suggest altering aeolian sedimentary dynamics by sand remobilization. Considering this information, we estimate that the pressure exerted on the environment was limited, as well as discontinuous in time. We therefore consider that during this period the stability of the sand should be significant in the island. However, human occupation of the island, from those dates, implemented activities of the traditional economic model (grazing, firewood extraction, etc.). So, during this stage (1730–1880), the pressure on the environment, although regulated and limited, surely affected the stability of the sediment, due to the permanence of a larger number of animals and shepherds than in the previous stage and throughout the year. In the next stage, this trend of increasing pressure over vegetation continues, so we can estimate that during this period (1880–1943), there was a significant increase in the remobilization of sands. This same trend has been confirmed for the next phase (1943–1967), when it can be assumed that at some point the vegetation has almost disappeared from large parts of the island, thus making possible the remobilization of sand by wind. In this regard, some oral testimonies indicate that the island became ‘totally bare’. This fact could be the result of the location of the last lime kilns, which were moved to ‘still non-exploited zones’ by the lack of vegetation in regular wood sources. Another important reason that led the island to that situation was an increment in the number of animals. Assuming an average of four heads of animals per house, between 1940 and 1970, the number of goats grazing on the island increased continuously from 368 (92 houses in 1940) to 680 (170 houses in 1970). To these, an unknown number of donkeys and camels, common animals in farming, must be added. Moreover, it has to be considered that also during this period there were sand mining, as this is a necessary resource for mixing mortar in buildings. Therefore, the consequence of these pressures of land use on vegetation and sand had to be the modification of aeolian sedimentary dynamics, producing sand remobilization and southward transport due to effective wind action. As one contemporary individual described, the island became ‘like a bald man head’. However, this trend was reversed after 1987, and it can be estimated that the pressure diminished to levels of 1730. Figure 5 shows the evolution of land uses as well as the relative pressure that they should have on the vegetation of the island and therefore on sedimentary dynamics.

Thus, as raised in the initial hypothesis of this study, the activities related with the use of woody plants are the main factors that produced the alteration of these systems. Nevertheless, in temperate regions where permanent or semi-permanent herbaceous cover stabilizes these systems, grazing is a major cause for destabilizing these systems (Granados Corona et al., 1988; Kutiel et al., 2004; Levin & Ben-Dor, 2004). In this case, this can be checked by facing the first stage, when only seasonal herbaceous are used, against the following stages, when there were permanent human settlements and thus a continuous use of woody plants. The increase of the population and, therefore, the pressure on the vegetation produced a greater intensity in the alteration of sedimentary stability. The system recovered as soon as the pressure on the vegetation ceased. Hence, the change of the economic model in La Graciosa, with its legal protection as a natural area, led to the disappearance of the primary activities involved in their aeolian sedimentary systems. The result was the recovery of the vegetation cover, hence stabilizing the sand again, a phenomenon also studied in other aeolian systems (Granados Corona et al., 1988; Kutiel et al., 2004; Levin & Ben-Dor, 2004; Hoffman & Rohde, 2007).

Regarding the methodology used, some issues that this work try to overcome must be addressed. First, historical sources generally impose temporary barriers because of the difficulty to work with pre-19th century documents. Therefore, most of the historical ecology studies span as much as the past 200 years (Szabó & Hédl, 2011). Nevertheless, this work has explored times previous to 1800, such as few other works, like for example Santana Cordero et al. (2014). Second, our methodology links oral history information and GIS in a successful way; this process has also been tackled by other studies, such as that of Trueman et al. (2013). Third, information integration has played a key role in the final interpretation of the results (Trueman et al., 2013).

Conclusions

From a historical perspective on traditional land uses, we consider that the alteration of arid aeolian sedimentary systems is mainly induced by the removal of woody vegetation that stabilizes the substrate. Thus, the main human exploitation activities that caused depletion of the vegetation cover are related to the extraction of wood for homes, bakeries and buildings (roofs and lime kilns). To these should be added the harsh weather conditions that make vegetation development difficult in arid environments.

However, in temperate regions, cattle grazing use eliminates herbaceous vegetation cover, which is what stabilizes the sandy substrate.

Acknowledgement

This work is a contribution to the projects CSO2010-18150 and CSO2013-43256-R funded by the R&D + I (innovation) Spanish National Programme, cofinanced with FEDER funds. It has been made possible by a contract of the Organismo Autónomo Parques Nacionales of Spain. Leví García Romero and Aarón Santana Cordero develop their research within the ULPGC Funding Programme. Authors would like to thank Antonio I. Hernandez-Cordero for his comments, especially on vegetation species in arid dune systems, and Lluís Gómez-Pujol and two other anonymous reviewers for their comments, which have allowed us to improve the manuscript. Likewise, we would like to thank the inhabitants of La Graciosa and an environmental agent involved in this research.

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Reconstruction of the land uses that led to the termination of an arid coastal dune system: The case of the Guanarteme dune system (Canary Islands, Spain), 1834–2012

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Land Use Policy (2016) 55:73–85

DOI 10.1016/j.landusepol.2016.02.021

Abstract

Coastal areas have been under pressure throughout history. Today these environments are occupied by a large portion of the world population and are dramatically affected by human activities. For a better understanding of the natural evolution of coastal ecosystems and their present state, historical studies are necessary. For this purpose researchers should apply methods that combine different historical sources, such as historic mapping and oral sources. In this paper we examine land uses that led to the disappearance of an arid coastal dune system, and the way to study it. Results reveal that each different land use had a different impact on the environment, and this was in correspondence with socio-economic needs. Finally, we discuss the results obtained and the methodology used.

Keywords: Arid coastal dune system; Land use history; Historical ecology; Historical sources; Historical analysis methods; Canary Islands.

Introduction

The coastal areas of the planet, as most natural ecosystems, have been affected from the changes caused by human activity during their history (Nordstrom, 1994). Especially in recent decades, these environments have been particularly affected, enduring much of the urban development and other important land changes (Jackson and Nordstrom, 2011). At global scale, currently almost 30 percent of the coastal areas are altered by development related to human activities, an area where 41% of the world population lives (Martínez et al., 2007). Bajocco et al. (2012) note that in recent decades there has been a significant “littoralization” of societies, which has led to a continuous degradation of the coast. This phenomenon has been observed across the Mediterranean, particularly in Spain, where urban development in the coastal area has intensified and accelerated in recent decades (Ariza, 2011). This has induced a permanent degradation of natural coastal systems, with a constant risk of losing vital ecological processes, as well as for the conservation of biota. In this scenario, many islands are particularly fragile as a result of intense development of urban and tourist infrastructure near their shorelines. Such is the case of the Canary Islands, where this development has exerted significant human pressure on both the ecosystems of high ecological value and some of their characteristic natural processes (Hernández et al., 2007; Hernández-Cordero et al., 2006; Otto et al., 2007).

In this context, coastal dune systems represent environmentally fragile and significantly changed areas, since various human activities that have an impact on their dynamics and natural elements are carried out on or near them. These impacts are particularly significant in Europe and North America where coastal dune systems are a diminishing resource (Jackson and Nordstrom, 2011; Paskoff, 1993; Pye and Tsoar, 1990). The primary cause of these changes is attributed to changes in land uses, both historical (grazing, agriculture, forestry and mining activities) and present uses, amongst which urban-touristic use is highlighted (Cooper and Alonso, 2006; Otto et al., 2007; Santana Cordero et al., 2015).

Most studies of coastal dunes have been conducted in temperate systems, while arid coastal dune systems have received much less attention, especially in terms of the geomorphological consequences resulting from human activities (Cabrera-Vega et al., 2013; Hernández-Calvento et al., 2014). Due to the arid climate that prevails in these environments, the impacts on landforms are evident within short periods of time compared with more humid environments (Cabrera-Vega et al., 2013).

To address the study of changes in an ecosystem, several lines of research focused on the changes experienced in the past are currently being developed in order to understand the present, predict future trends, and apply the results to improve the work of restoration and/or management (Anderson et al., 2006; Gimmi and Bürgi, 2007; Grossinger et al., 2007; McAllister, 2008; Robertson and McGee, 2003; Stein et al., 2010; Swetnam et al., 1999; Villagra et al., 2009). The information derived from these studies is particularly useful in systems that are still recoverable from an environmental perspective (Koster, 2009; Thomas and Wiggs, 2008). In systems which have disappeared or are dying out with no chance of recovery, the ultimate goal of these studies is the reconstruction of its environmental history, in order to better understand their ecoanthropic dynamics, since they can serve as a reference for other similar systems at different stages of development. In this line, studies that address changes in land use or land cover are of great interest, especially if they integrate both aspects. This type of analysis constitutes an effective way to characterize the current environmental situation and the ongoing changes of a natural system (e.g. Raj and Azeez, 2010; Ye and Fang, 2011).

In this point, the study of the causes of land change can shed light over the change process itself, allowing understand it better. So, describe the land-use changes, and analyzing the underlying driving forces—fundamental social processes that underpin proximate causes—and proximate causes—land visible changes—(Geist and Lambin, 2002) seems to be a correct procedure to examine this.

This paper presents an historical reconstruction of land uses in an arid transgressive coastal dune system that has already disappeared, the Guanarteme dune field (Gran Canaria, Canary Islands, Spain). Our general goal is to deepen our knowledge of the causes that led to its demise. To do so, the time period when those processes occurred is addressed. Thus, we begin the study in 1834, when we have a historical map showing that the system was working normally. The study concludes in 2012, when the entire surface of this dune system became urbanized, thereby blocking aeolian sediment transport between the input and output areas of this system.

Specific objectives of this research are the following: (1) to identify and characterize the land uses that occurred in the study period (1834–2012), as this is the period when human activities that led to the demise of this dune system were carried out; (2) to analyze the underlying socioeconomic forces that boosted the changes; and (3) to establish a consistent methodology able to work and integrate multi-source information.

Study area

The Guanarteme arid dune system was located in the northeast of the island of Gran Canaria (Canary Islands, Spain), covering the isthmus that connects the island of Gran Canaria with the volcanic complex of La Isleta, located to the NE. It had an area of 243.7 ha (2.44 km^2) and the dynamics of the dunes were conditioned by the prevailing winds in a NW-SE direction, resulting from changes in the direction of the trade winds, mainly from the NE, by the interposition of La Isleta (Fig. 1).

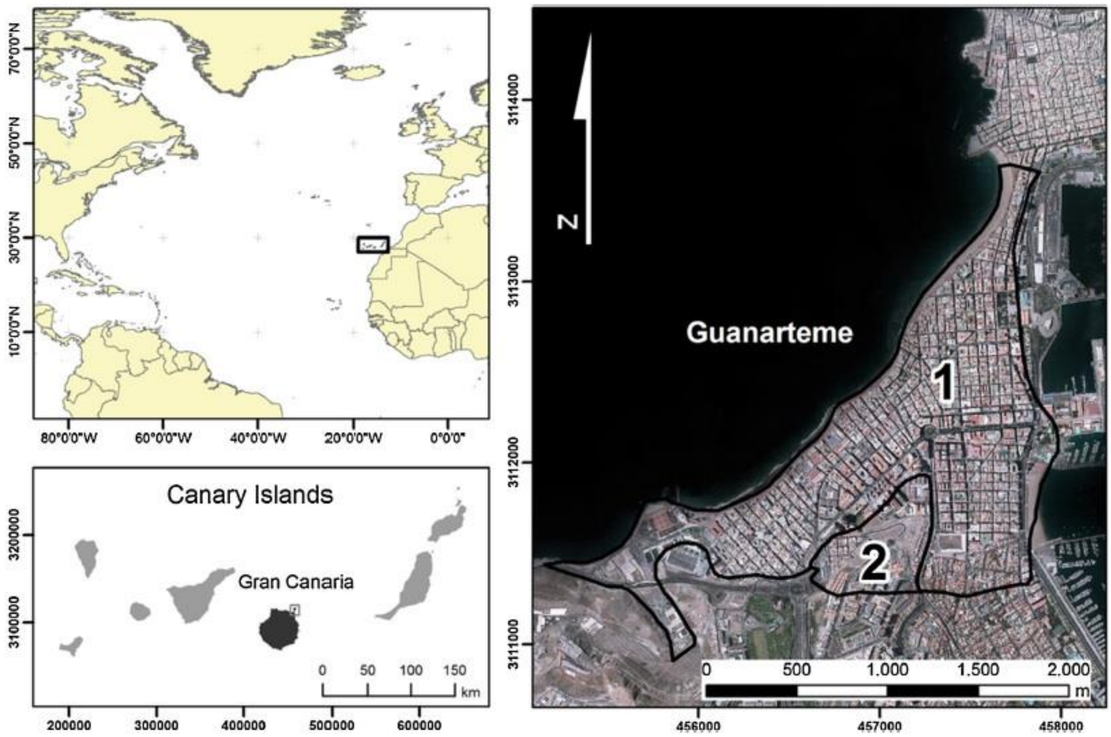

Fig. 14 Study area: 1) tombolo; 2) High sedimentary terrace.

The traveller Olivia Stone, who visited Gran Canaria between1883 and 1884, provides a description about this dune field as follows: 'the sand is disposed in hills, valleys, small tablelands, and plateaus, over which when one begins to walk their extent seems to be much greater than would be supposed from a distant view'(Stone, 1887).

The system consisted of two distinct areas from a topographical point of view: on the one hand, the tombolo (also known as the 'Guanarteme isthmus'), consisting of a flat surface formed by Pleistocene and Holocene sedimentary materials underlying the aeolian deposit; on the other hand, a Pleistocene wedge-shaped sedimentary terrace of about 50 meters height in the south. In terms of dynamics, it was an arid transgressive dune system, whose sand was sourced from the beach in the northwest (Las Canteras beach), crossed the tombolo as sand ridges and returned to the sea along the east coast (Las Alcaravaneras beach) (Santana Cordero et al., 2014).

Currently, the only one elements of this system that can still be observed are the sand input and output areas, the beaches of Las Canteras and Las Alcaravaneras, respectively. The rest of the dune field has been entirely occupied by the city of Las Palmas de Gran Canaria.

From an economic point of view the dune field was, until the late XIX century, an unproductive land, a marginal area regarding land use. Sometimes it was even a handicap to the development of the activities that took place around it. Thus, during high wind periods, sand invaded the agricultural fields located to the south of this aeolian sedimentary system. Anyway, this system represented a potential area of growth for Las Palmas de Gran Canaria, which developed its urban fabric from the mid-XIX to the mid-XX century, by spreading from the historic old town to join up with La Isleta.

Regarding the political context, changes in the national policy system throughout the study period had an effect on urban planning policies. From the 1830s to the Spanish Civil War (1936–1939), several legislative reforms affecting urban planning were introduced, promoted by various political regimes. Then, from 1939 to1975 during Franco’s regime, urban planning changed again. During the dictatorship, patronage and corruption dominated urban planning and in most Spanish cities urban development plans consisted of poor quality draft proposals, at least until the 1950s (Cardesín, 2015).

At the local scale it should be mentioned that the first urban plan for the city was made by Laureano Arroyo and dates back to 1898. This plan increased the available area for building, although at this moment the expansion of the city was already under way (Cáceres, 1983). Therefore, the city’s expansion was carried out in absence of rational urban planning nor, of course, any regulation in coastal management.

As a result, by 1940, the urban occupation of much of this territory was a fact:

> ‘This miracle of transformation of sand to orchard, of desert to one of the densest present-day urban agglomerations, has occurred and is still occurring right under our eyes. 40% of the urban extension of Las Palmas currently occupies land that belonged entirely to the domain of the sands and dunes until the last years of the last century’ (Miranda Guerra, 1940).

Materials and methods

Sources

In this study the following sources have been used:

Bibliographical references

Encompasses from scientific papers to local publications about the study area. These play a determining role in the entire paper, since they provide specific information about the landscape as well as the international scientific context.

Historical maps

9 historical maps from different dates were collected from various historical archives and digital platforms. The use of these documents has been of great interest because they show the different land uses developed in the study area and its environs over a century (from 1834 to 1938), when the system dynamics were natural and semi-natural (Fig. 2). Table 1 contains the details of all these maps.

Table 4 Basic data from historical maps collected. Abbreviations: Dir. Hidrografía: Dirección de Hidrografía; S.G. Madrid: Sociedad Geográfica de Madrid; BNE: Biblioteca Nacional de España; BNF: Bibliothèque Nationale de France; TNA: The National Archives (UK).

Date	Title	Approx. scale	Producer	Source
1834	Plano del Fondeadero de la Luz en la Gran Canaria	1:30800	Dir. Hidrografía	BNE
1853	Carta de la isla de la Gran Canaria	–	Dir. Hidrografía	–
1879	Plano de la Bahía de Las Palmas	1:20000	Dir. Hidrografía	BNE
1882	Baie de Las Palmas et Port de La Luz	–	Serres and Driencourt	–
1885	Plano de la Bahía de Las Palmas	1:20000	S.G. Madrid	BNF
1894	Las Palmas Bay	1:20312	S. Engineer's Plan	–
1896	Plano de la Bahía de Las Palmas	1:20400	Manuel Pérez y Rodríguez	BNE
1911	Plano de ensanche del Puerto de La Luz	1:5000	F. Navarro	–
1938	Defences of Las Palmas	1:20000	Spanish Government	TNA

Aerial photographs and orthophoto

These allow direct observation of the study area in the years 1949 and 1954. These images were obtained by the Air Force of Spain. The frames used in this research were acquired from the Centro Cartográfico y Fotográfico del Ejército del Aire de España (Cartography and Photography Centre of the Air Force of Spain) (CECAF, 1949, 1954). Their approximate scales are 1:1085 and 1:2650, and their spatial resolution 0.38 and 0.73 metres, respectively. Once the corresponding geometric adjustments were performed on these documents, it was possible to make accurate measurements. These documents have been particularly useful in identifying sand mining areas during the study period and the analysis of their evolution during the five years between the two flights.

Conventional photographs

These were obtained from the catalogue of the Fundación para la Etnografía y el Desarrollo de la Artesanía Canaria (Foundation for Ethnography and Development of Canarian Craft) (FEDAC). A set of 20 photographs was examined in order to identify certain elements in the territory and/or confirm their existence and characteristics according to the information from other sources.

Oral sources

These sources have been a key element of this study in the characterization of the use and exploitation of the study area in the second third of the XX century. Their application has been of great interest for the study of different aspects that have been addressed in this work. Moreover, oral sources are necessary to validate the information derived from other historical sources and/or fill gaps in the information (Robertson and McGee, 2003). The importance of oral sources in this study is motivated, in part, by the lack of information about the study area, it being an area that has attracted little economic interest, similar to what happened in other places (McAllister, 2008).

Oral sources have been constructed through interviews with 10 elderly people who still remember the Guanarteme dune system. Their average age is 82 years, ranging from 66 to 89 years. Each informant is identified by the letter I and a number, in the form I1, I2, etc. throughout the text. Interviews in this research were designed according to the definition of Fogerty (2005): 'a semi-structured conversation between two people' (the interviewer and narrator). A script that contains the topics of interest in the conversation, old photographs of the study area and pictures of plant species were used in order to correctly identify certain elements of the landscape.

Data analysis

Document analysis

This analysis has been conducted according to Bowen's conception: a procedure that 'entails finding, selecting, appraising (making sense of), and synthesising data contained in documents' with information of interest (Bowen, 2009). To do so, this analysis has involved, mainly, bibliographical and oral sources. On the one hand, scientific literature has been useful to put our investigation into an international scientific context regarding the situation of coastal environments of the world, to the studies of their human impacts, and to historical ecological research. On the other hand, some publications treating local issues and oral sources have constituted the material to obtain part of the results of this paper.

Cartographic analysis

Interpretation of historical maps has been made using drawing software, since the geometric characteristics of these documents do not allow us to treat them with GIS (see Section 5). However, these maps have spatial coherence, aside from the 1895 map which was excluded from the analysis. This fact has allowed us to detect landscape elements in the maps. Thus we have obtained 9 scenarios (one from each map) that show the changes in land uses from 1834 to 1938. The boundaries of the system (coastlines) are taken from the 1882 map; this is for two reasons: first, the accuracy of its coastlines and, second, because the rest of the maps fit quite well within these boundaries, which facilitates the superposition and change analysis.

On the other hand, the two aerial photographs have been analyzed with GIS, through which areas of aggregate extraction were identified for mapping. Additionally, the calculation of their extension in both aerial photographs available was carried out. Finally, the comparison between the latter aerial photograph (1954) and the current orthophoto (2012) has been made in order to illustrate the complete disappearance of the system.

With this information a map that identifies and integrates land uses for the XX century was made.

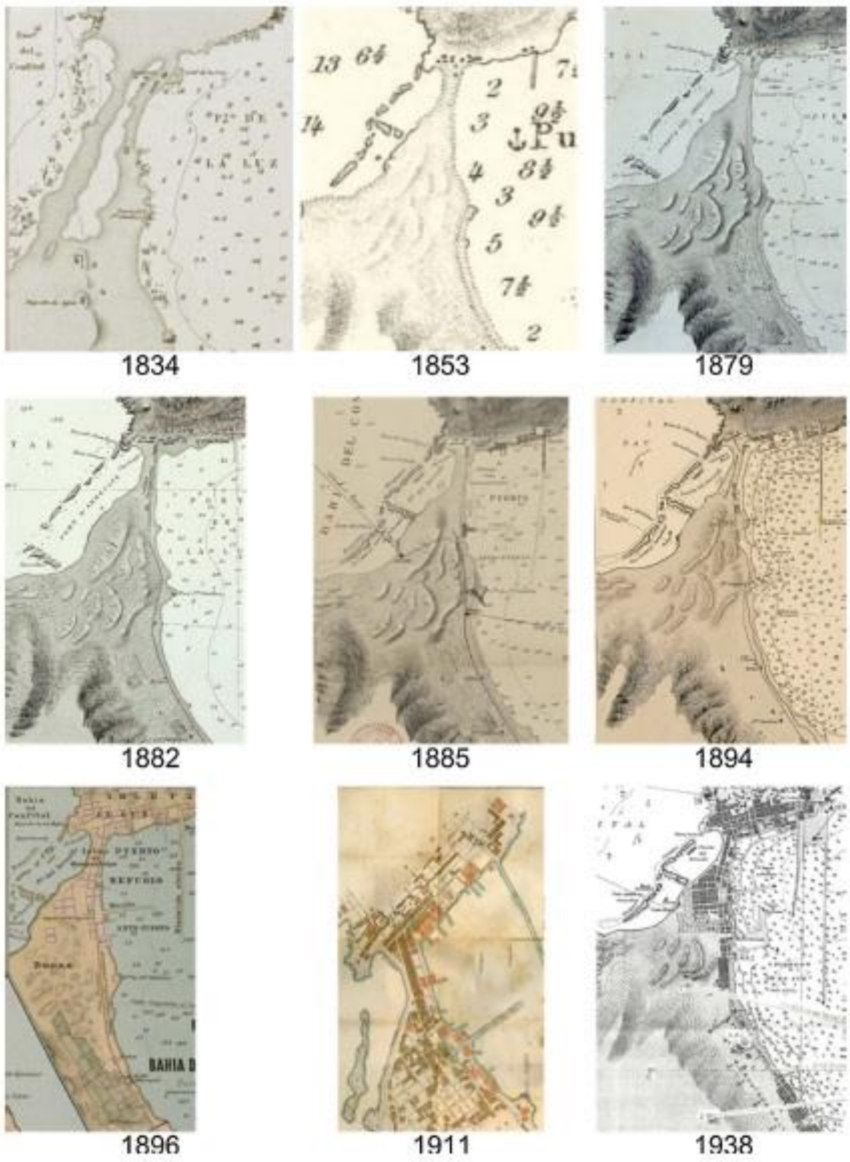

Fig. 2 Historical maps used.

Results

Before 1900

Agriculture

This use was located in the SE part of the dune system in the 1853 map. It constituted a quasi-rectangular parcel, or a group of parcels, that evolved through time changing in size and shape. It should be noted that this activity was developed along a sector of the east coast on active zones of the system. The type of crop was vegetables, generally on large plots, as some pictures show.

Urbanization

Settlements and related infrastructure were developed through the XIX century. In the 1834 map, the study area was free of human elements, excluding three unidentified landmarks. In the 1853 map a new settlement appears (La Isleta) (Fig. 3), although it is located outside of the sandy surface. In 1879, La Isleta grows and a new road parallel to the eastern coastline is constructed. Additionally, two groups of unidentified elements appear, one beside the crop parcels and another one where today the Guanarteme neighbourhood is found. In the period 1882–1885 La Isleta and the unidentified elements group of Guanarteme grew, with new features appearing: two telegraph houses (one close to each coastline) and new port infrastructures. The 1894 map does not represent all of the land uses that already existed (especially in the south of the area), but it shows the evolution of a road network and the growth related to the occupation of the eastern coast. Finally, the 1896 map clearly shows the establishment and advancement of an incipient urban fabric, that develops from north to south (Fig. 4).

From 1900

Agriculture

Agricultural land use continued to be located in the SE part of the dune system as evidenced by oral sources and aerial photographs. Nevertheless, this activity was reduced by the urbanization process; by the mid-XX century it was relegated to the Estadio Insular area and the northern part of Ciudad Jardín (see Fig. 3). In this regard, informant I2 talks about the existence of tomato farms in Ciudad Jardín, noting that 'there was no longer any sand.' The informant refers to an area where there were already marked plots for construction and/or cultivation, after the sand was removed.

On the other hand, in aerial photographs (especially in 1949) there is agricultural activity on the high sedimentary terrace, which had fallen into disuse, that is also referred to in the testimony of I1, who explains that 'all La Minilla was a farm'. This fact is confirmed by the current name 'Finca de La Minilla' (Farm of La Minilla) observable in the cartography regarding this area.

We conclude that this use was recessive during the period when the dune system disappeared. So, on the one hand, it seems that large extensions are lost in some areas, especially in the traditional farming areas; on the other hand, a small gain associated with new residential areas is produced.

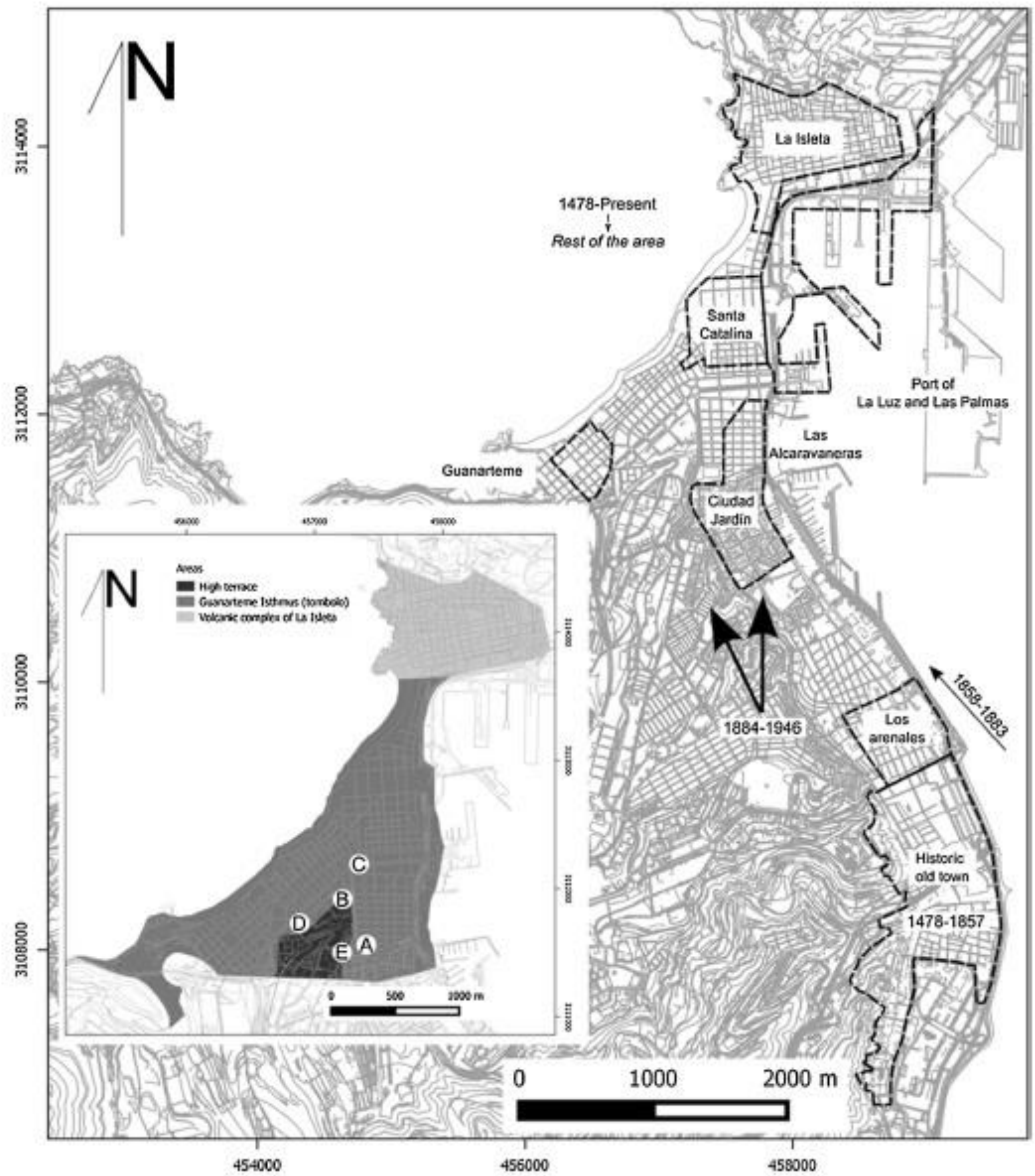

Fig. 3 Urban evolution of the city of Las Palmas. Sites and facilities of reference: A. Estadio Insular, B. headquarters, C. Bernardo de La Torre Street (end), D. Mesa y López High School, E. Loma del Ingeniero Salinas (Engineer Salinas' hill).

Urbanization

In this period the consolidation of the urban fabric can be observed, as well as the gradual disappearance of the dune field. Also, the port infrastructures are seen to expand into the dunes.

In addition to the urbanization, and according to some testimonies, some areas of the dune field at one time fulfilled the function of providing shelter to 'homeless' people. This is determined by the 'marginal' character of the dune field in the context of the city of Las Palmas. The period when this spontaneous settlement occurred has been identified by informant I1 in the 1950s.

In this regard, this informant remembers 'I saw the Moors living there. The Moors came [. . .] made their little houses and stayed there [. . .]. And poor people from here also lived there in shacks.' In this regard, informant I2 highlights the coexistence of groups of poor local people, economically disadvantaged, with groups of North Africans. They all had very poor living conditions in common: 'that settlement was an isolated thing there, where those people lived there. [. . .] Unfortunately I must say it. [. . .] That was a situation of terrible poverty, that area there [. . .]. Few were those who came out of there to go somewhere.' The informants I6, I7 and I8 comment that 'it was like another world, there was no relationship between the locals and the Moors who lived in the camp.'

From the previous two paragraphs we can highlight two fundamental ideas: first, the dune field was, during those times (coinciding with the end of its period of operation) and in specific areas (areas that had not been urbanized), a place with little economic value in agricultural terms; on the other hand, it was considered to be a marginal area from the social point of view. Still, it was a resource for the disadvantaged people who settled there.

Regarding the spatial distribution, these settlements have a certain clustering shape. On this last point, the informants identified several sites for these slums: occupying the western and central parts of the dune field (currently Mesa y López High School—Estadio Insular—Aviation Headquarters) (I1); at the end of the current Bernardo de La Torre street (I2 and I6); between the Santa Catalina and Guanarteme neighbourhoods (I2); at the confluence of the current Mesa y Lopez Avenue with Guanarteme (I2) and between the Estadio Insular and Central Market (I9) (Fig. 2).

It seems that this use did not have any influence on the disappearance of the Guanarteme dune field. Rather, it was a use 'adapted' to the mobility of the system itself, without permanent structures, so that settlements could move around according to the environmental conditions (Fig. 5).

Recreational use

According to the informants, the study area sustained some recreational activities. Firstly, the dunes were a very important place for the amusement of children. In this regard, informants I3, I4 and I5 describe how one of the main activities was to climb the dunes and then jump off them, then back up, and so on. There were other games, such as building small houses with ‘walls’ of sand or climbing a dune to see the train passing by (informant I4), which apparently was an attraction for children. They also played with wagons at the brickyard (informants I6, I7 and I8).

Secondly, this area was also used by poor families as a place to go on Sundays. Informant I3 remembers that, at least until the mid-1940s (1945–1946): ‘We went to the sands only on Sundays, because we did not have anything else. Nothing else [. . .]. We took off our shoes, we put them down, then climbed, climbed, jumped and threw ourselves up and down . . .’

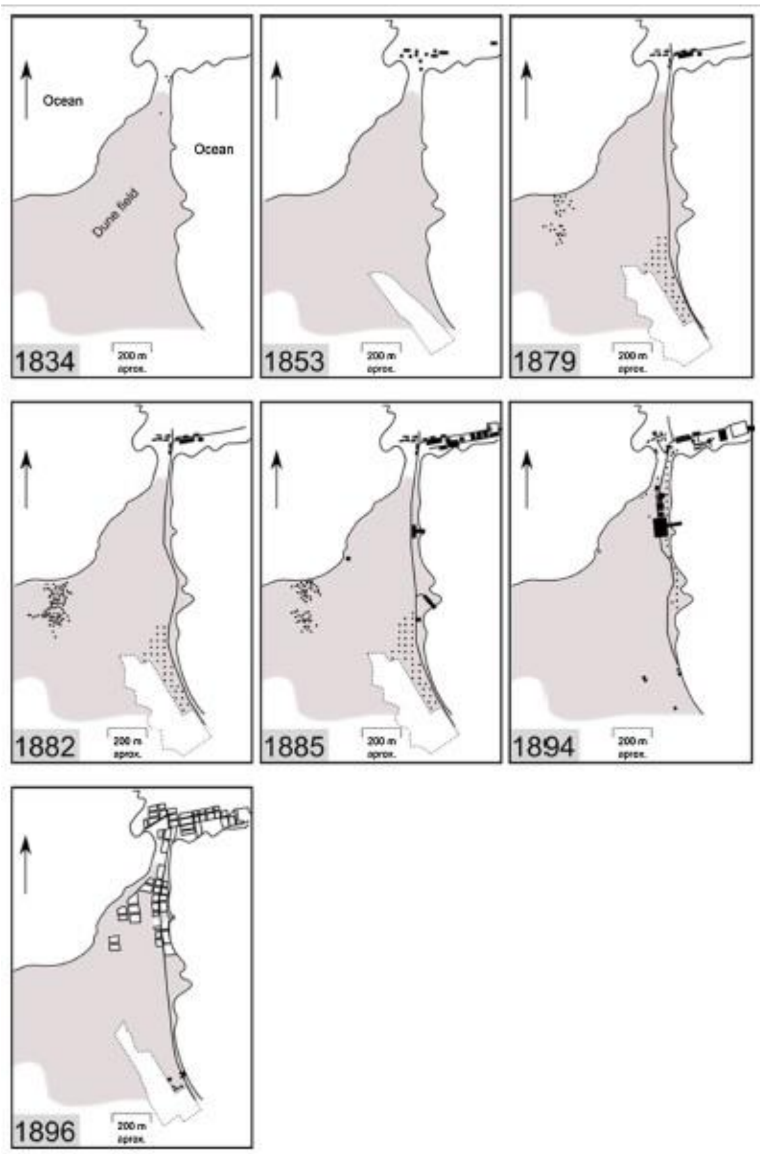

Fig. 4 Land uses evolution during the XIX century. These maps show agricultural parcels (dotted lines), buildings (black/white-filled polygons), roads (lines) and unknown elements (dots). The grey shaded area corresponds to the dune system extension.

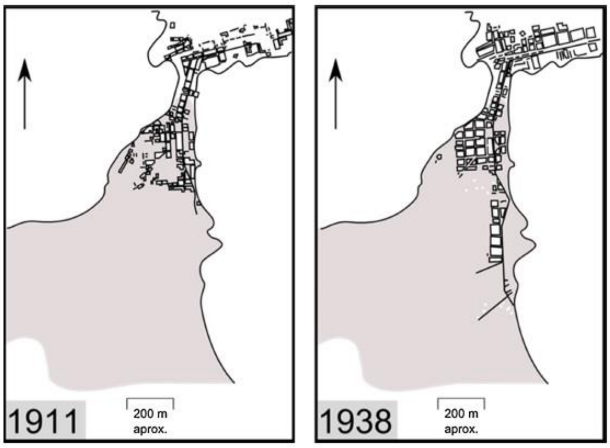

Fig. 15 Land uses evolution in the first third of the XX century. These maps show buildings (white and black-filled squares) and roads (lines).

Third and finally, it is worth mentioning that the last existing dune in this system was supported on the Engineer Salinas' hill associated with the high terrace. It also had recreational use, since there were people who accessed to the top of the dune to see football matches at the Estadio Insular which was just below. On this question, informant I2 said that this was a military zone and that the military granted access to the dune in order to allow them to see the football games. Then he says: '. . . I remember going there in the 1950s to see football games, just sitting there in the sand [. . .]' (Fig. 6).

Fig. 16 Children playing in the dunes (left); the dune used as a stand to see the football matches (right) (Vittet, 1966 (left), unknown author and date (right), FEDAC, 2015).

Aggregate extraction

We estimate that this activity was developed massively from 1883, with the operations to build the Port of La Luz, given that the construction of this infrastructure required material as a filler. The port construction and its subsequent operation stimulated various economic activities of relevance in the context of the Archipelago. The port became a center of attraction, around which workers took up residence (Martín Galán, 1984). As a result of this transformation, the 1949 and 1954 images depict a 'colonized' system that is clearly altered by urbanization. The fact that there is no longer any continuity between the beach and the inner system indicates that by this date aeolian processes had become marginal.

Some oral sources highlight the intensity with which sand was extracted during the beginning of the expansion of the city, while others focus on activities related to theft of the sand. In this regard, we include here some comments from the informants: informant I1 tells us that 'everyone built up Guanarteme with that sand', citing the amount of material that was extracted through this activity; on the same topic, informant I2 says that 'the amount extracted was outrageous' and according to him, the extraction activity was developed from north to south and 'in a systematic manner'; informant I9 says that 'extraction ended because they used up all the sand'. On the other hand, informant I3 talks about the theft of the sand: 'they went to the beach at night, with trolleys, gathered sand from the beach, and took it to build the houses. [. . .] That would be in the (year) 1936. [. . .] I heard they said: they go to the beach and steal sand to build their houses. [. . .] Everyone was stealing sand to build houses.' According to this same informant the way to construct the houses was by filling small wooden boxes of sand to build the walls.

With respect to the major observed sand extractions, we proceeded to their identification in 1949 and 1954 (Figs. 7 and 8), based on aerial photographs for those years. This allows us to estimate how the extraction rate increased in those years. Over a period of 5 years the area occupied by the extractions nearly doubled from 2.09 ha (20870 m^2) to 3.79 ha (37935 m^2), numbers that yield an average growth rate of 0.34 ha per year (3412 m^2 per year).

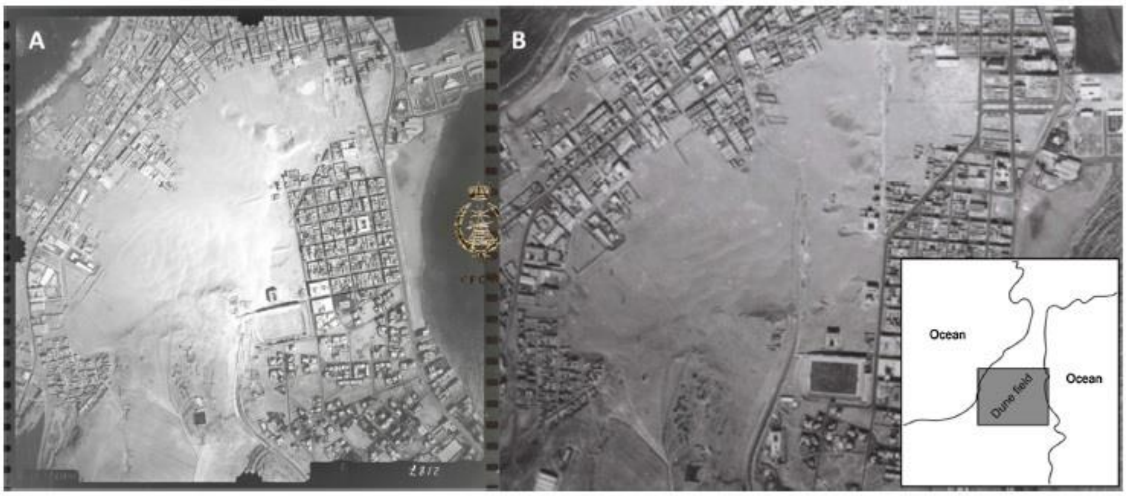

Fig. 17 Aerial photographs where part of the dune field can be seen. A: 1949; B: 1954.

Much of the sand that was removed for the construction of housing and infrastructure was transformed into bricks at the Eufemiano Fuentes Cabrera factory, which operated in the city from 1924 (Fig. 9). This company not only used sand for making bricks, but also had two lime kilns and a factory for the production hydraulic tiles (Florido Castro, 2000). Similarly, a transport network was set up that enabled the carrying of sand from the mining areas to the places where it was to be used (for instance, the port, in its various stages of construction, or the brick factory). Amongst the various means of transport, wooden carts pulled by mules, trucks and a small train that ran across the system have been identified.

Considering the above, it is clear that the extraction of sand for the construction of facilities, infrastructure and, above all, housing, is the main activity that led to the disappearance of the dune system. This process occurred by destroying the characteristic landforms of the aeolian sediment dynamics, i.e. the dunes. In the last period this process develops quickly and massively, together with the urban expansion of the city of Las Palmas de Gran Canaria, which occupied the area without any mobile dune. The only area free of urbanization is a part of the high sedimentary terrace, which currently constitutes a degraded area and where there are no dunes or sand surfaces.

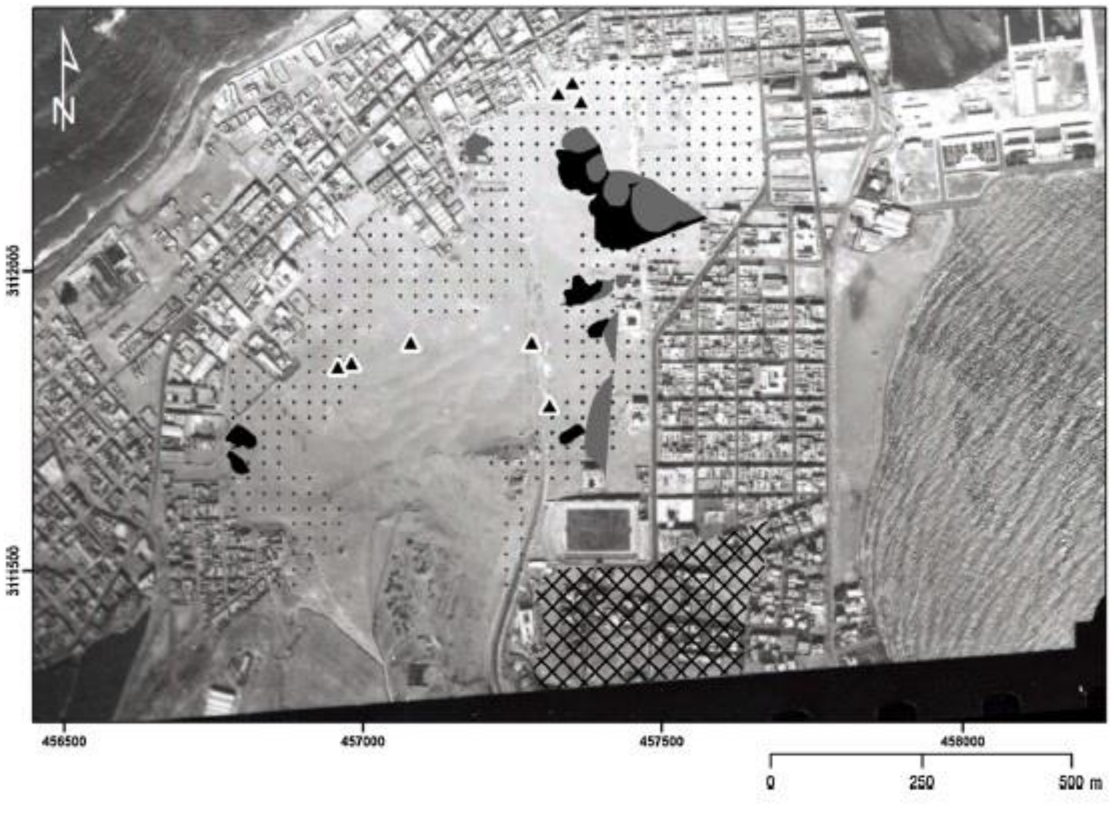

Fig. 18 Map of the first half of the twentieth century land uses. This map integrates agricultural (gridded area), residential (black triangles) and recreational uses (dotted areas), identified through historical sources, with sand mining in the years 1949 (grey areas) and 1954 (black areas), identified through photo interpretation.

Fig. 19 Church of El Pino (center of the photo) and the brick factory (at the right hand side) (Miranda Armas, 1932; FEDAC, 2015).

Underlying driving forces and proximate causes

The most important underlying driving force is the political decision to construct the new harbor which has become in the current Port of La Luz and Las Palmas (Fig. 2).

Once the ports of the Canary Islands had become hubs of intercontinental communications at the end of the XIX century, and their main cities had attracted considerable foreign investment, which was mainly British in Las Palmas de Gran Canaria, these cities started to develop new administrative, service-related and business functions, which brought with them the growth of urban areas. In the city of Las Palmas de Gran Canaria, this accelerated the aggregate extraction process, allowing the growth of the urban fabric. Meanwhile, banana cultivation provided a new product to trade, which moreover could be exported to Europe by means of the good maritime communications that had been established (Cáceres, 1983). In this sense, the Port of La Luz and Las Palmas was the principal proximate cause in the development process of the city of Las Palmas de Gran Canaria (Noreña and Pérez, 1992).

Consequently, the selling of many plots of land along the road that communicated the city with the port—which crossed the former dune system from south to north near the eastern coast—were executed, and some scattered population settlements appeared. This landscape change process constitutes the definitive step to the occupation of the system.

In this scenario, workers from the rural areas of Gran Canaria and from the islands of

Lanzarote and Fuerteventura moved to the city of Las Palmas de Gran Canaria, engaged in the construction of the port, dwellings, and urban facilities. Likewise, infrastructure that foreign capital needed for investment purposes, and also the services and activities generated by the development of the port and the agricultural trade sector were significant attractors. All of this provided access to housing and improvement of the employment.

Discussion

Results obtained in this investigation provide important knowledge to 'build' the history of this landscape, since land uses are identified and characterized. However, the land uses identified did not have the same impact on the system. Whereas agriculture, recreation and temporary settlements could simply alter certain aeolian processes (cutting of vegetation, establishment of anthropic obstacles), the aggregate extraction directly removed large amounts of sand, thus destroying the system.

Furthermore, the results reveal human-related processes over a natural system, which are in correspondence with those that occurred in other parts of the world. Thus, infrastructure development along the coast that has affected coastal dune environments can be seen in northwest Europe, in the Mediterranean region, in the USA and in Japan (Bertacchi and Lombardi, 2014; Provoost et al., 2011). Of particular interest is the case of the city of San Francisco (USA), which was built over a massive coastal dune field (Nordstrom, 1994). Another example can be found on the coast of Belgium, where almost 50% of dune landscapes have been lost due to urban development (buildings, gardens and roads) during the XX century (Doody, 2013).

In our study, we found that the political decision to construct the new harbor in the XIX century was the most important underlying driving force, and the harbor itself the first proximate cause. Therefore, it observes that an important political decision is at the origin of a great landscape change process.

On the other hand, the dryness present in the studied dune system is an important factor due to the fact that it intensifies the geomorphic processes. From this point of view, the remobilization of sediments is much higher than in dune systems with higher humidity. Thus, as plants (scattered bushes) are removed, a significant volume of sediment is transported by the wind, invading the next humanized areas. This idea fits well with the data that shows the dune field dynamics. They show that for the XIX century and probably for the first third of the XX century, there was a large volume of sediment movement in the form of transverse ridges several meters high. This process prevented the establishment of any permanent agricultural activity in the tombolo and explains the land occupation process.

The need to stabilize the dunes is evident, but is limited by environmental aridity:

stabilizing one of these systems is almost impossible using traditional techniques such as reforestation. Eliminating the whole system is more effective. From this point of view the results obtained in this study are of relevance to other arid dune systems, where human pressures exist, especially those located in the Canary Islands, such as Maspalomas (Gran Canaria), Corralejo (Fuerteventura) and El Jable (Lanzarote). The sand has been exploited in all these systems in recent decades, for the development of resorts, residential urban infrastructure and tourist facilities, which has impacted on the sedimentary dynamics (Cabrera-Vega et al., 2013; Hernández-Calvento et al., 2014). These impacts are also observed in the Cape Verde archipelago, especially on the islands of Sal and Boa Vista, where tourism-related development also exploits these sand systems (Hernández and Suárez, 2006). Hence, the causes for the disappearance of this dune system are the same as those that jeopardize other similar systems today.

Methodological issues

In the historical ecological-related literature various methods used in several parts of the world and in studies with different aims can be found. However, the integrated treatment of multiple source types and their analyses still constitutes an important challenge today. Thus, after a brief review of the methods and techniques employed in this kind of research, we have adopted a number of sources and methods to carry out this study. In this sense, we have explored cartographic and visual analyses in order to apply them.

To do so, we have tried to analyse historical maps using GIS, which constitutes a widely accepted analysis method in the field of landscape change over historical periods (Haase et al., 2007; Rumsey and Williams, 2002; San-Antonio-Gómez et al., 2014). Nonetheless, we have found that in the geo-referencing operation of historical maps, they result in deformed forms, which constitutes a clear and definitive drawback regarding a correct analysis. Deformations change the shape and size of landscape elements, thus preventing us from obtaining valid measurements. Therefore, we have briefly explored the available scientific literature on this topic, but have not found any alternative method that satisfactorily meets our requirements. The closest methods in this regard are those of aerial photograph interpretation, but we consider that these techniques do not adequately combine with historic map analysis (Morgan et al., 2010). Likewise, we explored visual analysis of photography and video. This seemed to be a priori appropriate, although these methods have also been developed in disciplines out of the scope of this paper, such us sociology of knowledge, semiotics or history of the art (Bohnsack, 2008).

On the other hand, we have encountered several limitations, imposed by the characteristics of the sources. This was the case for some of the historical maps, whose interpretation was difficult. The scale (e.g., the 1853 map) and low quality of the symbology of certain elements constrained our analyses. This fact has led us to treat certain landmarks as 'unknown elements', especially in the nineteenth century maps. Nevertheless, we suspect that many of these landmarks were probably small buildings used for habitation.

Furthermore, these sources have a set of characteristics that mark their own limits when analyzing. The aim of the maps, technical skills of their authors or their scale may condition their performance. For example, the maps that have been analyzed here contain some inconsistencies, since they show some elements of the landscape that are omitted in later maps (e.g., the 1885 and 1894 maps). Likewise, while some show 'future' infrastructure constructions (in dashed or solid lines), others do not show this (e.g., the 1882 and 1885 maps). Although this latter point can be due to the different dates, as it shows infrastructure representation from a specific year, it could signify that during the former dates this infrastructure had not yet been planned. Also, the coastlines on different maps (especially the west coast) draw attention, since some of them seem to be copies of the immediately preceding maps. This fact is evidenced in the 1853, 1879, 1882, 1885, 1894 and 1938 maps. Finally, spatial resolution is another limiting factor, especially in the early maps, in the extraction of relevant information. Low spatial resolution conditions the detail of some of the elements, which hampers their interpretation, leaving us to treat them as unknown elements.

Conclusions

Results indicate that amongst the different land uses that occurred with the progressive occupation of the dune area, aggregate extraction had the most serious consequences for the disappearance of the aeolian sedimentary system, by the surface affected, the intensity it developed and the impact it generated. This use continued an upward trend over the years which resulted in a notable impact.

Furthermore, it observes that an important political decision of the construction of a key communication infrastructure (a new harbor in the XIX century) is at the origin of a major landscape change process.

On the other hand, this study provides a history of the destruction of a coastal dune system which can be used as a reference for other similar systems in the world that are in danger of disappearance.

Acknowledgements

This paper is a contribution of CSO2010-18150 and CSO2013-43256-R projects of the Spanish National Plan for R + D + i (innovation), co-financed with ERDF funds. Aarón M. Santana-Cordero develops his research within the ULPGC Funding Programme.

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4. Conclusions and prospects

Conclusion 1: Sources and methods.

Conclusion 1.1: this dissertation makes a methodological contribution to the assessment of the reliability of sources. The method developed consists of an application of a source critical approach on the basis of the assessment of their characteristics and their contribution to the study. The variables chosen for this evaluation are: 1) the type of source, 2) the detail level and/or resolution of the information provided, and 3) the analyses that could be applied.

Conclusion 1.2: the consolidation of the oral sources in the development of this dissertation has been a key question. Thanks to these sources, we are able to better describe and analyze the physical features of these systems, as well as the social reality that exists in and around them.

Conclusion 2: Important findings.

Conclusion 2.1: from a historical perspective on traditional land uses, we consider that the alteration of arid aeolian sedimentary systems is mainly induced by the removal of woody vegetation that stabilizes the substrate. This activity has the capacity to change the dynamics of the systems. This is the case that we observe in the sedimentary systems of La Graciosa island.

Conclusion 2.2: aggregate extraction (sand mining) had the most serious consequences for the disappearance of the Guanarteme dune system, by the surface affected, the intensity it developed, and the impact it generated.

Conclusion 2.3: we find that an important political decision on the construction of a key communication infrastructure (a new harbor in the XIX century) is the origin of the major landscape change process that occurred at Guanarteme.

Prospects

Prospect 1: the creation of an archive of environmental memory for the Canary Islands. This will be based on our knowledge of the immediate past of our territory, involving citizens’ roles as “memory donors”, and will influence scientific progress in the Canary Islands. This archive will be constructed from oral sources, pictures and videos, and their interpretations, about the physical features and social realities of our ecosystems and landscapes.

Prospect 2: the creation of an historical GIS online platform, through a geoportal or a Spatial Data Infrastructure, which will hold all of our historical knowledge about our ecosystems and landscapes that could be accessed and enriched by the population in general.

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