Ocean and Coastal Management 210 (2021) 105715

Contents lists available at ScienceDirect

Ocean and Coastal Management

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

# Historical social relevance of ecosystem services related to long term land uses in a coastal arid aeolian sedimentary system in Lanzarote (Canary Islands, Spain)

Néstor Marrero-Rodríguez [a,*], Carolina Peña-Alonso [a], Leví García-Romero [a], María José Sánchez-García [b], Emma Pérez-Chacón Espino [a]

[a] Grupo de Geografía Física y Medio Ambiente, Instituto de Oceanografía y Cambio Global, IOCAG, Universidad de Las Palmas de Gran Canaria, ULPGC. Spain
[b] Grupo de Geología Aplicada y Regional, Instituto de Oceanografía y Cambio Global, IOCAG, Universidad de Las Palmas de Gran Canaria, ULPGC. Spain

ARTICLE INFO

*Keywords:*
Social relevance
Land use change
Ecosystem services
Historical information sources
Anthropic impacts

ABSTRACT

The loss of ecosystem services (ESs) is one of the main consequences of the inadequate management of natural environments. However, the drivers that shape the provision of ESs continue to be poorly characterized at local and regional scales, and their protection, generally, has not been a priority. This study analyzes the anthropic alteration process of an arid aeolian sedimentary system, the associated environmental consequences and changes in the social relevance of ESs for the local population. The social relevance of an ES was analyzed using historical sources (analysis of testimonies of travelers, press, government minutes, aerial photographs, field photographs and oral interviews, among others) for five land uses*: urbanization, aggregate extraction, grazing, cultivation* and *logging*. Using the available information, three criteria were selected to define their social relevance: *social sensitivity*, *economic* and *political*. Considering El Jable (Lanzarote, Canary Islands, Spain) as study area, the main results show that different historical land uses have generated different social reactions in relation to changes in the capacity of the ecosystem to provide its ESs. The ESs that directly benefitted the population (provision of food, fuel and raw materials, and the regulation of natural hazards) were found to have the greatest social relevance before 1960. However, since then, the change to the island's economic model has resulted in high levels of social relevance for ESs related to the promotion of tourism (cultural heritage, recreation and leisure, and aesthetic values), citizen security (regulation of natural hazards), wildlife (habitat preservation) and culture (cultural heritage). This type of analysis can provide information on the perception of society to changes in the local environment, the effects of such changes on people's lives, and the management response of the society in question.

## 1. Introduction

Arid coastal dunes are highly dynamic ecosystems that provide a wide range of ecosystem services (ESs) including, amongst others, food production and fuel or construction materials, as well as acting as a recreational space, a tourist attraction, a habitat for a large number of species, and a regulator of coastal erosion (Barbier et al., 2011; Everard et al., 2010).

Despite all these ESs, coastal dunes are among the most degraded and threatened ecosystems in the world due to human activities (Paskoff, 1993, 2001; Jackson and Nordstrom, 2011; Delgado-Fernandez et al., 2019b). Their degradation is commonly the result of traditional human activities such as cultivation, grazing or the use of vegetation as fuel (Tsoar and Blumberg, 2002; Kutiel et al., 2004; Levin and Ben-Dor, 2004; Provoost et al., 2011), as well as modern activities such as recreational uses, urbanization or the extraction of aggregates (Nordstrom, 1994, 2004; García-Romero et al., 2019; Marrero-Rodríguez et al., 2020b). In consequence, dune surface areas and sediment budgets have been reduced (Hernández-Cordero et al., 2018), changes in vegetation (Hernandez-Cordero et al., 2017; Delgado-Fernández et al., 2019a) and landforms (Tsoar and Blumberg, 2002) have taken place, and invasive species (used for grazing, as fuel, or for ornamental purposes) have

* Corresponding author.
*E-mail addresses:* nestor.marrero102@alu.ulpgc.es (N. Marrero-Rodríguez), carolina.pena@ulpgc.es (C. Peña-Alonso), levi.garcia@ulpgc.es (L. García-Romero), mariajose.sanchez@ulpgc.es (M.J. Sánchez-García), emma.perez-chacon@ulpgc.es (E. Pérez-Chacón Espino).

https://doi.org/10.1016/j.ocecoaman.2021.105715
Received 29 November 2020; Received in revised form 9 May 2021; Accepted 10 May 2021
Available online 2 June 2021
0964-5691/

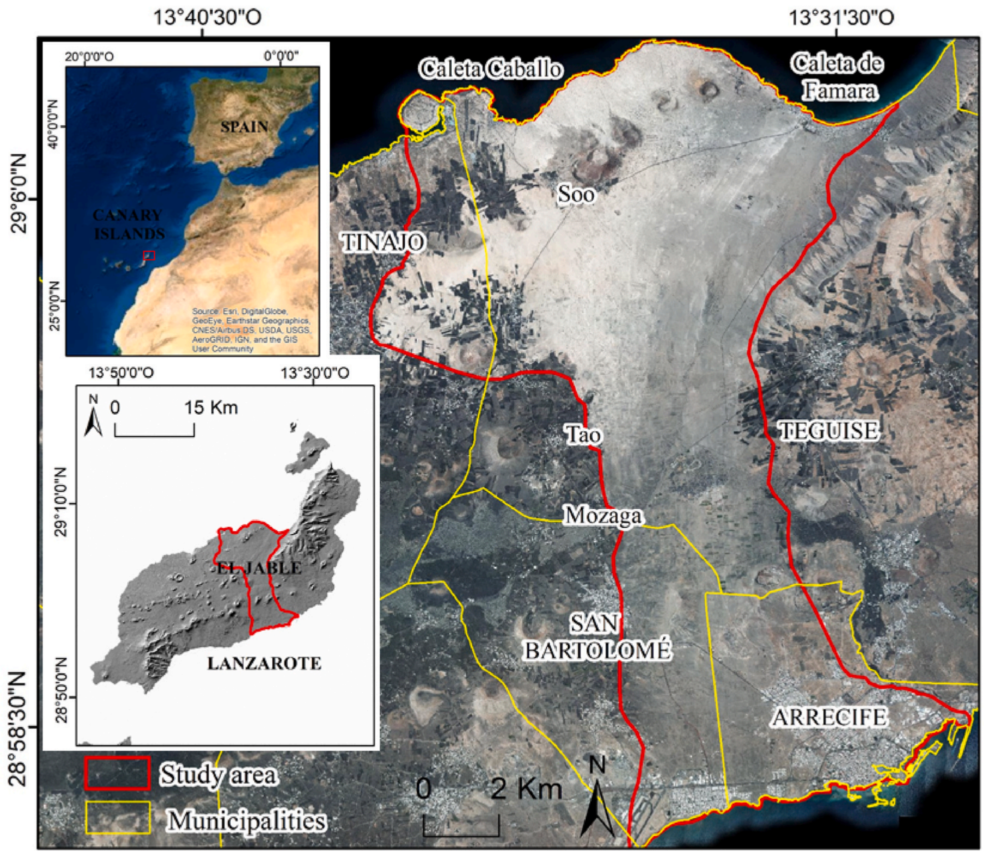


**Fig. 1.** Location and study area limits. Aerial photo source of Lanzarote: SDI Canarias (Canary Islands Regional Government-Grafcan S.A.).

successfully occupied large areas (Marchante et al., 2003; Esquivias et al., 2015; Parra-Tabla et al., 2018). Along with climate change (Clarke and Rendell, 1998; Tsoar et al., 2009), such degradation has compromised the capacity of ecosystems to provide services all over the world (Vilà et al., 2010; Van Oudenhoven et al., 2012; Walsh et al., 2016; Mehvar et al., 2019; Asmus et al., 2019; Weiskopf et al., 2020).

The reconstruction of historical management and the social relevance of ESs are described and analyzed in this paper through the methodological framework of historical ecology (Szabó, 2015), developed in recent decades as an important tool to: i) preserve cultural heritage linked to the exploitation of ecosystems, and understand the trajectory of the patterns, processes and behavior of landscapes (Bürgi and Gimmi, 2007) and species (Panzacchi et al., 2013; Morris and Rowe, 2014); ii) report past examples of ecosystem management (Bürgi and Gimmi, 2007); iii) test the effects of climate change (Vellend et al., 2013); iv) recognize the effects of different disturbances on ecosystem components (Dzwonko et al., 2002); v) plan management and restoration strategies (Fritsche, 2009; Trueman et al., 2013; Morgan et al., 2010; Dirkx, 2004); and vi) know the driving forces behind ecosystem degradation (Bürgi et al., 2010; Rohde and Hoffman, 2012).

In small islands, like those in the Canary Archipelago (Spain), the exploitation of resources is more significant than in continental environments (Mimura et al., 2007). Although human occupation of the archipelago took place less than 3000 years ago, meaning that the period of human intervention has been shorter than in many other ecosystems, anthropic intervention has been intense (mostly since the islands were colonized by the Spanish in the early-mid 15th century) and the number of sources is relatively large for the last few centuries.

Some studies have addressed in depth the effects that climate change (Petit and Prudent, 2010; Sauter et al., 2013), the reduction of sediment budget (Pye and Blott, 2012; Hernández-Calvento et al., 2014), changes in environmental conditions (Jackson and Cooper, 2011) and changes in land use (Marrero-Rodríguez et al., 2020) can have on aeolian sedimentary systems and, therefore, on the ESs they provide. However, there is a gap in the literature in relation to the evaluation of the extent to which changes in ecosystems have been relevant or not for the population that depended on or lived in that ecosystem. In this context, an analysis of the historical sources is carried out in the present study to know the evolution of the social relevance for the local population of the ESs provided by the arid aeolian sedimentary system of El Jable (Lanzarote, Canary Islands, Spain) (Fig. 1) between 1750 and 2018.

This type of analysis can provide information on how societies perceive such changes, how their lives are affected by changes in ecosystems and the management response of the society. With such knowledge, governments can take better and more informed decisions in terms of protection, restoration or regulatory measures. The aim of this work is to analyze the historical management of the aeolian system and to evaluate the social relevance for the local population of the ESs related to different land uses (urbanization, aggregate extraction, grazing, cultivation and logging).

## 2. Study area

The El Jable coastal aeolian sedimentary system (Fig. 1) currently occupies an area of 90 km$^2$ and a width of between 10 km in its northern sector and 4 km in its southern sector. Sand transport is from the sediment entrance area (Caleta de Famara, N-NE) towards the leeward sector (Arrecife, S), crossing the central part of Lanzarote over an approximate 21 km length and covering areas belonging to four island municipalities (Tinajo, Teguise, San Bartolomé and Arrecife).

The substrate strip is made up of volcanic rocks (Miocene and Quaternary basaltic lava and pyroclasts) and sedimentary rocks (sandstones and quaternary conglomerates related to colluvial, alluvial and aeolian processes). The current aeolian sediments are interspersed at the edges of El Jable with alluvial and colluvial levels formed by lithoclasts (fragments of rock and basaltic minerals) and bioclasts (fragments of marine fauna and flora). The recognizable morphologies in this area are, generally, nebkhas formed from shrub individuals of *Traganum moquinii* in the foredune of the system (Caleta de Famara), which are replaced inland by individuals of *Launaea arborescens*. In addition to these aeolian landforms there are three isolated dunes of barchan morphology. The climate is arid with an average annual rainfall of around 110 mm and an average annual temperature of 20.7 °C (Cabrera-Vega, 2010). The dominant winds come from the first and fourth quadrants. Average wind speed is 20 km/h, but can reach as high as 60–70 km/h (Alonso et al., 2011). Currently, the coastal aeolian sedimentary system is delimited in the northern part by tourist urbanizations around Caleta Caballo and Caleta de Famara and in the southern part by Arrecife, the island's capital. Finally, part of the northern section of the arid aeolian sedimentary system has been designated as a protected area as part of the Natura 2000 program.

## 3. Methodology

Historical data sources were used to reconstruct the historical uses of the ecosystem and their environmental consequences and to analyze the evolution of the references of each ES and its historical social relevance.

### 3.1. Data sources

Data were collected from numerous historical documents of different origin for the purpose of a historical reconstruction of the study area. They were used to analyze: i) land uses and the historical evolution of the ecosystem; and ii) the recorded changes in ESs and their social relevance. In this respect, historical bibliographies and traveler testimonials were used (Torriani, 1959; Del Castillo, 1628; Glass, 1764; Ruiz-Cermeño, 1772; Caballero, 1776; Madoz, 1849; Álvarez-Rixo, 1866/1982; Greff, 1868; Stone, 1887; Hernández-Pacheco, 2002; Rumeu de Armas, 1981), as well as acts of the Lanzarote Island Government from the 17th century (Bruquetas De Castro, 1997) and minutes of the plenary sessions of Teguise City Council (1610–2006). In addition, the *Jable* search tool (jable.ulpgc.es) of the University of Las Palmas de Gran Canaria Library (first references from 1843) was used to find and then review relevant articles in the local and regional written newspapers and the Official Gazette of the Canary Islands Government. Various keywords related to landscape, toponyms and land uses were employed, and a total of 410 relevant articles were found. Six recorded interviews were also consulted, taken from the "Rescuing Life Stories" project of the Historical Heritage Service of the Cabildo de Lanzarote published in 2010. The interviewees were farmers who grew their crops in sandy fields and were born between 1920 and 1940. The field photographs (1950–2018) were obtained from the online collection of the Lanzarote Island Government (www.memoriadelanzarote.com), and the aerial photographs and orthophotos from GRAFCAN S.A, a company belonging to the Canary Islands Regional Government. Finally, the data on the evolution of the number of inhabitants was obtained from the Canary Institute of Statistics (1768–2019).

### 3.2. Evolution of land uses and the ecosystem

The reconstruction of land uses and the evolution of the aeolian sedimentary system was undertaken using the historical sources mentioned above. The information obtained was organized into three different periods: pre-1750, for which the sources are scarce and the information obtained is very limited; 1750–1960, when traditional land uses were the most important activity; 1960-present, when recreation and leisure activities have been predominant in the study area.

**Table 1**
Ecosystem services potentially supplied by El Jable, based on historical sources and ecosystem services literature.

| Ecosystem services | Description | References |
|---|---|---|
| **Provisioning services** | | |
| Food (F) | Wild food production [e.g. rabbits (invasive species), *M. crystallinum* plant species]<br>Meat production (goat and sheep grazing)<br>Miscellaneous crops (watermelons, sweet potatoes, onions, aloe vera, etc.)<br>Milk production (goat grazing) | Madoz (1849); Viera y Clavijo (1982) |
| Fuel (FU) | For lime kiln industry, bakeries, moonshine production, household heating, cooking, etc. (e.g. from: *L. arborecens* or *Lycicum intricatum*) | Hernández-Pacheco, 2002 |
| Raw materials (RM) | Wool and leather (goat and sheep grazing)<br>Construction materials (limestone and aggregates)<br>Glass (from the combustion of *M. crystallinum)*<br>Timber from *Tamarix canariensis* for tillage tools | Viera y Clavijo (1982) |
| Cosmetics (C) | Caustic soda (from the combustion of *M. crystallinum*), sand used in the manufacture of soaps, etc. | Madoz (1849); Viera y Clavijo (1982) |
| Industrial use (IU) | Installation of ports, factories, etc. | Ruiz-Cermeño (1772) |
| Genetic resources (GR) | The habitat of a high number of species of endemic flora and fauna | |
| Medicines or pharmaceuticals (MP) | For people (e.g. *Euphorbia paralias*, *Erodium hesperium*.) or animals (*L. arborescens*) | Madoz (1849); Viera y Clavijo (1982) |
| **Regulating services** | | |
| Natural hazards (NH) | Coastal defense for protection against storms and other extreme events<br>Vegetation acts as a control factor for sand storms | Hernández-Pacheco, 2002 |
| Climate regulation (CR) | Carbon sequestration | Everard et al. (2010); Barbier et al. (2011) |
| **Cultural services** | | |
| Cultural heritage (CH) | Archaeological sites (e.g. aboriginal deposits) and paleontological deposits<br>Historical fears about sand inundating villages<br>Ethnographic heritage: buried villages, cisterns, wells, tides, lime kilns, etc. | León-Hernández et al. (2016) |
| Recreation and leisure (RL) | Sand dunes as a major tourist attraction<br>Sports (sandboard, cycling and running) | Peña-Alonso et al. (2018) |
| Aesthetic value (AV) | | Everard et al. (2010); Barbier et al. (2011) |
| Inspiration for art (IA) | e.g. "Voices from the Badlands" | |
| Social relations (SR) | e.g. Jable Farmers' Association of Teguise or Viento del Jable Association | |
| Education and research (ER) | Educational activities for students, informative hiking, international scientific publications | Cabrera-Vega et al. (2013); Martín et al. (1996) |
| Supporting services | | |
| Soil formation (SF) | Common to most habitats | Everard et al. (2010); Barbier et al. (2011) |
| Nutrient cycling (NC) | | |

(continued on next page)

**Table 1** (*continued*)

| Ecosystem services | Description | References |
|---|---|---|
| Photosynthesis (P) | | |
| Pollination (PO) | | |
| Provision of habitat (PH) | The habitat of a high number of species of flora and fauna | Greff (1868); del Arco-Aguiar et al. (2010) |

### 3.3. *Social relevance of the ecosystem services*

To assess the social relevance of ESs, first we created a list of the ESs provided by El Jable based on other papers (Everard et al., 2010; Barbier et al., 2011) and historical sources (Table 1). The 21 ESs selected were classified into four different subgroups: i) *Provisioning*: food, fuel, raw materials, cosmetics, industrial use, genetic resource and medicines/pharmaceutics; ii) *Regulating*: of natural hazards and climate; iii) *Cultural*: cultural heritage, recreation and leisure, aesthetic value, inspiration for art, social relations, educational and research resource; and iv) Supporting: soil formation, nutrient cycling, photosynthesis, pollination and provision of habitat.

The social relevance of each ES loss or modification was analyzed using historical sources and in relation to five land uses*: urbanization, aggregate extraction, grazing, cultivation* and *logging*. Using the available information, three criteria were selected to define the degree of relevance: *social sensitivity*, *economic* and *political*. The three criteria were selected based on the evaluation in environmental planning proposed by McAllister (1982) and following the main driving forces (socioeconomic and political) of the changes in the aeolian sedimentary systems of the Canary Islands defined by Santana-Cordero et al. (2017).

For the *social sensitivity* criterion, four categories with corresponding scores were established (none, low, medium and high) to define the impact produced by the loss of an ES on the society, including the generation of social mobilization/protests (social response). The *economic* criterion was based on three categories (low, moderate and high) defining the monetary costs associated with the loss of an ES. Finally, for the *political* criterion, four categories were created (none, regulation, prohibition and restoration/protection) to evaluate whether local or regional governments have regulated or prohibited land uses to protect an ES or, if lost, whether they have developed restoration plans (Table 2).

The overall historical social relevance when a land use had an impact on an ES was then calculated as the sum of the scores awarded for each criterion (*social sensitivity, economic* and *political*) divided by the maximum score possible (9).

## 4. Results and discussion

To understand the social relevance of ESs it is necessary to first know the trends in the local economic model and the historical evolution of the land uses and the ecosystem. Thus, the reconstruction of the evolution of the landscape and the land uses is presented in the first part of this section and is followed by the analysis of the social relevance of the ESs.

### 4.1. *Evolution of land uses and the ecosystem*

The historical documents analyzed allowed reconstruction of the land uses in the El Jable aeolian sedimentary system, the alterations they have induced, their period of occurrence and the reasons why they have occurred (Table 3). The information was organized into three stages according to sediment mobility and vegetation cover. The results indicate that the first stage (until 1750) is unrelated to human activity given the small population registered. The second stage (1750–1960) shows evidence of sediment remobilization, which had different consequences for the economic system and infrastructure, due to traditional uses (exploitation of vegetation for use as food, fuel, and for grazing purposes). The third stage (1960 to the present) has seen the abandonment of traditional human uses and the beginning of new ones (urbanization and extraction of aggregates) which have generated environmental changes in the aeolian sedimentary system (spontaneous succession of vegetation and a consequent reduction in sediment mobility) (Fig. 2).

#### 4.1.1. *Status of the arid aeolian sedimentary system before 1750*

According to the archaeological evidence found in the study area, El Jable was first settled in aboriginal times a (De León et al., 2016; Santana-Cabrera, 2017). However, there are no references to its natural dynamics until the 15th century. In general, reconstructing the characteristics of an ecosystem before 1800 is a complex task due to the lack of sources (Szabó and Hédl, 2011). In El Jable, in the 17th century the Bishop of Murga stated that the "accumulation of sand is so high that six men could sink into it". From the end of the 17th century, the cultivation of *Mesembryanthemum crystallinum* began to produce caustic soda and the manufacture of soaps, dyes and high quality glass in the north of the system.

In 1730, the eruption of the volcano Timanfaya covered a significant part of the island with lava, leaving that area with no grazing land, firewood or possibility of crop cultivation for a number of years. The eruption resulted in the burial of part of the ecosystem considered in the present study, damaging towns and villages in the system and disrupting

**Table 2**
Criteria selected to assess the historical social relevance of the loss of an ES related to crops, aggregate extraction, urbanization, logging and grazing, and the categories, score, description and sources used for each criterion.

| Criterion | | Category | Score | Description | Sources used |
|---|---|---|---|---|---|
| **Historical social relevance** | Social sensitivity | None | 0 | No mentions found. | Oral sources and written press |
| | | Low | 1 | Sporadic mentions (less than 5 references). | |
| | | Medium | 2 | People show sensitivity to loss, but no mobilizations recorded (5–10 references). | |
| | | High | 3 | People show sensitivity to loss or their lives were affected or there were protests, complaints, collections of signatures or strikes (10 or more references). | |
| | Economic | Low | 1 | The economic cost of the loss goes unnoticed (no references). | Written press, city council minutes, the Official Gazette of the province of Las Palmas de Gran Canaria, Official Gazette of the Canary Islands Government |
| | | Medium | 2 | The economic cost is discussed but is moderate (less than 5 references). | |
| | | High | 3 | The loss causes significant economic losses and is frequently referred to (5 or more references). | |
| | Political | None | 0 | Not discussed in government minutes at any political level. | City council minutes, the Official Gazette of the province of Las Palmas de Gran Canaria, Official Gazette of the Canary Islands government |
| | | Regulation | 1 | The government develops laws to regulate the land use. | |
| | | Prohibition | 2 | The government develops laws to ban the land use. | |
| | | Restoration/protection | 3 | The government starts to develop restoration measures or protection figures. | |

**Table 3**
Ecosystem evolution and effects of land uses on vegetation and landforms in El Jable from 1730 to the present.

| Ecosystem evolution | Period | Induced by | Source |
|---|---|---|---|
| **Vegetation** | | | |
| Deforestation | 1750–1960 | Firewood collection<br>Cleaning for cultivation | Historical documents (e.g. El Fénix newspaper, 15/07/1864) |
| Spontaneous recovery | From 1960 | Fossil fuel importation<br>Livestock reduction | Aerial photographs<br>Orthophotos |
| **Geomorphological** | | | |
| Partial burial of the system | 1730–1736 | Volcanic eruption | Romero (1991) |
| Sediment remobilization | 1750–1960 | Deforestation | Historical documents (e.g. El Fénix newspaper, 15/07/1864) |
| Sediment stabilization | From 1960 | Spontaneous recovery<br>Reduction in sediment input | Cabrera-Vega (2010) |
| Sand flows | Rare occurrence | Deforestation<br>Torrential rainfalls | Historical documents (e.g. Antena, 04/02/1958) |
| Beach progradation | 1750–1960 | Sediment remobilization<br>Torrential rainfalls | Greff (1868); Rumeu de Armas (1981) |
| Submarine sand bank enlargement | 1750–1960 | Sediment remobilization<br>Torrential rainfalls | Greff (1868); Rumeu de Armas, 1981 |
| Beach erosion | From 1980 | Sediment stabilization<br>Barriers to sand transport | Historical documents (e.g. La Voz de Lanzarote, 13/10/1989) |
| Dune size enlargement | Unknown −1960 | Sediment remobilization | Hernández-Pacheco, 2002 |
| Dune size reduction | From 2000 | Sediment stabilization<br>Reduction in sediment input<br>Barriers to sand transport | Cabrera-Vega (2010) |
| Aeolian landforms destruction | Unknown to present | Urbanization<br>Aggregate extraction | Aerial photographs<br>Orthophotos |
| **Direct human modifications** | | | |
| Changes in accumulation areas | Unknown to present | Barriers to sand transport<br>Vegetation changes | Aerial photographs<br>Orthophotos |
| Beach regeneration | From 1990 | Governmental administrative actions | Historical documents (e.g. La Voz de Lanzarote, 24/12/1994) |
| Reduction of sediment availability | From 1980 | Sand extraction | Cabrera-Vega (2010); aerial photographs; historical documents |

its economic activity. The flow that affected El Jable (located east of the eruption) covered a total of 3.86 km$^2$.

In this period, no references were found in the city council minutes or the historical documents that were consulted to problems caused by the transit of the sand. It is possible that the mobility of the ecosystem during this stage was much lower and that it only began to increase at a later stage with the rise in the number of inhabitants and the consequent increase in demand for vegetation as fuel. The existence of aboriginal settlements (León-Hernández et al., 2016; Santana-Cabrera, 2017) can be seen as evidence of low sediment mobility prior to the increase in the intensity of land uses. Working on the reasonable assumption that aboriginal societies and farmers would have had a good knowledge and awareness of their natural environment (Dekens, 2007), it seems unlikely that they would have settled in the center of a stream of sand with the ability to repeatedly bury their homes and crops.

#### 4.1.2. Deforestation and sand mobility (1750–1960)

At the beginning of this period, El Jable had about 10,000 inhabitants (Fig. 2) distributed in 11 towns and villages. The cultivation, grazing and exploitation of vegetation for use as fuel were the main activities. An important deforestation process began to take place for various purposes, including the burning of plant material to produce high alcohol content liquors and to generate tillable land for crop cultivation (Caballero-Mújica, 1991). The effects of the removal of vegetation to create fields for the cultivation of crops became evident. In this respect, numerous references were found from the years 1830–1840 to the problems being caused by sand (e.g. the burial of crops, infrastructure and houses) as the result of the cultivation of *M. crystallinum* and the use of vegetation as fuel.

The administration attempted to implement measures to slow down the progress of sand transport, as has also been reported for China (Qi and Luo, 2004; Qi and Wang, 2003; Wang, 2004). However, despite the implementation of an agreement for the planting of shrubs in 1842 and the publication by the Canary Islands Regional Government in the Official Gazette of 1843 that shrub removal was to be avoided, the situation would not change in the following years. However, the *M. crystallinum* trade would gradually diminish from this point on, as exportations to other countries began to decline.

The result of sand mobilization is similar to that found in other similar ecosystems in Israel (Tsoar and Blumberg, 2002; Kutiel et al., 2004). In El Jable, the erosion processes caused the partial or total burial of houses and forced migrations from San Bartolomé, Tao or Mozaga (towns in the interior of El Jable) (Madoz, 1849). Likewise, sand mobilization affected the remains of aboriginal villages and various infrastructures including a road that, according to travelers, was unusable due to the accumulation of sand. Frequent references can be found in press reports (1843–1864) and oral sources (1940).

It is possible that, because the aeolian sedimentary system discharges into the beaches of Arrecife, the historical land uses produced a progradation of the beaches or changes in the depth of the port area throughout the 19th century, forcing vessels to anchor at sea and use smaller boats to get to the island, as was reported by travelers (Álvarez-Rixo, 1866/1982; Stone, 1887). Such a process has also been observed in Jandía (Fuerteventura) due to the elimination of vegetation cover (Marrero-Rodríguez et al., 2020). This reduction in depth due to the accumulation in the port area of Arrecife, located on the south coast of the aeolian sedimentary system and described as one of the best ports in the archipelago (Glass, 1764; Ruiz-Cermeño, 1772; Caballero, 1776; Fritsch, 2006), raised concern that the port would be unusable within a few years. Greeff (1868) also reported that species present on the Arrecife coast had changed due to these modifications to the depth of the coast and the burial of coastal ecosystems.

Because of the need to adapt to this sand mobility, the inhabitants of El Jable developed a system based on the installation of bulky bales of rye which were positioned perpendicular to the wind to block its effects and the impact of sand on the crops. However, in years of poor harvests, the inhabitants were faced with the problem of having insufficient spare material for the construction of these protective barriers (Fig. 3B) against the burial of their crops by sediment. In such years, it is described in the press of the time how the crops were uprooted by the force of the wind and how the farmers had to strive manually to keep the crops clean of sand.

#### 4.1.3. Sand stabilization and erosion processes (1960-present)

Since 1960 there has been an important change in the economic model prevalent in the area, principally due to the emergence of tourism as an alternative to the traditional activities. The pressure of logging on the El Jable system for firewood collection purposes has ceased due to the rising importation of fossil fuels. However, there has been additional

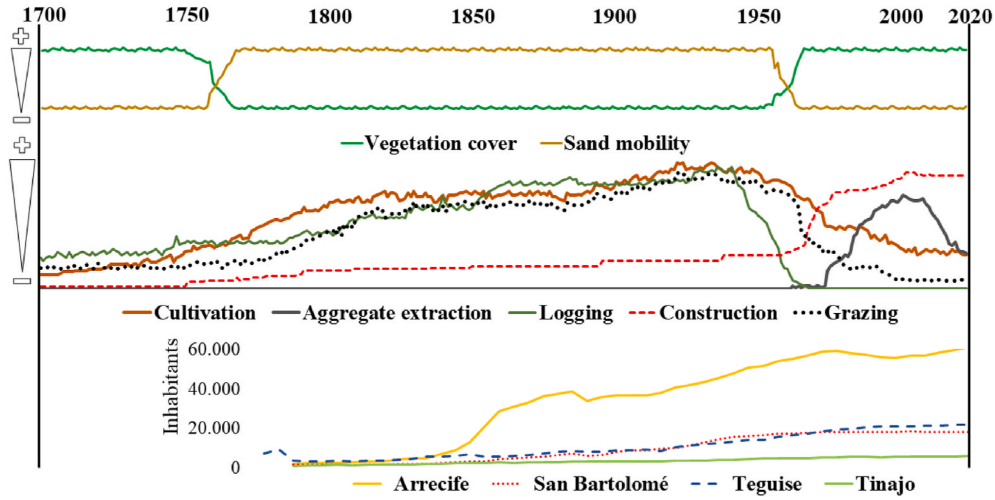


**Fig. 2.** Evolution of sand mobility, vegetation cover and land uses according to the sources used. Number of inhabitants (1768–2019) (San Bartolomé became a separate entity from Teguise in 1787 and Arrecife in 1798). (Source: Canary Institute of Statistics, based on data from Local Councils, Island Governments, Communities of Municipalities and the Spanish National Institute of Statistics).

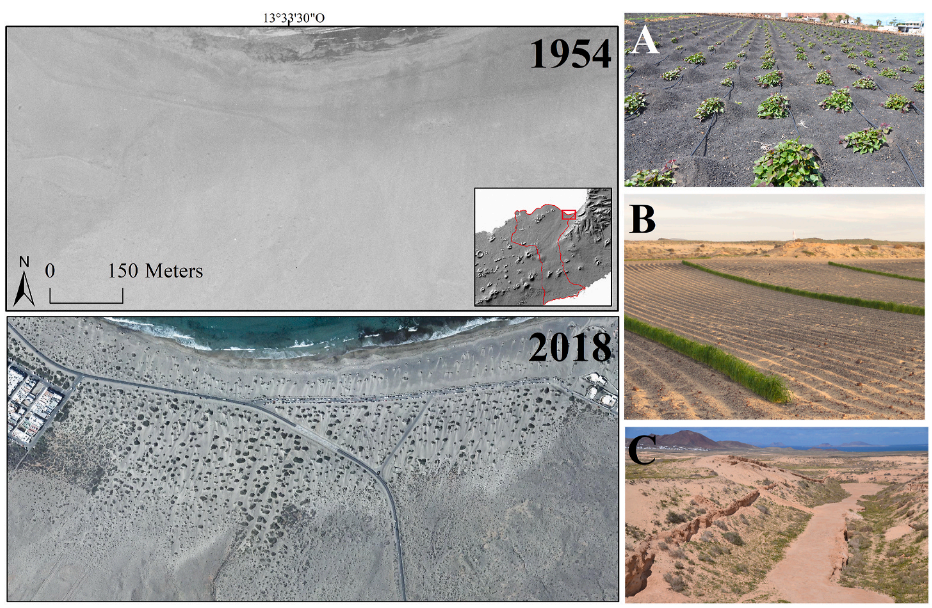


**Fig. 3.** Status of vegetation cover in 1954 and in 2018 (Source: Web Map Service of the Canary Spatial Data Infrastructure) **A)** crops grown in pyroclastic material. **B)** crops grown in sandy material with vegetation barriers to protect against wind and sediment. **C)** abandoned aggregate extraction area (Source: Juan M. Hernández-Auta. 2018).

pressure on the system due to the increased demand for aggregates for construction purposes and the different recreational uses that have appeared there. The abandonment of traditional uses and the cessation of deforestation have favored plant recolonization and the reappearance of nebkhas in Caleta de Famara (Fig. 3). However, the beaches of Arrecife have also been modified as the result of these erosion processes. This has forced the local administration to carry out actions to regenerate the beaches with sand from underwater quarries or the transfer of sediment from other beaches, sediment that is usually lost after episodes of sea storms. On the other hand, the capacity of the ports to receive large ships is slowly recovering due to the disappearance of the entry of sediment from El Jable. As stated above, the new development model of the island, now based on tourist activity, has generated new land uses on El Jable, such as the extraction of aggregates for construction, the urbanization of the coastline and the proliferation of recreational activities.

The traditional practice of crop cultivation, along with the use of land for grazing by a small number of goats and sheep, continues to be present in El Jable. There are two types of crop cultivation: the first is carried out using an artificially arranged layer of pyroclastic material (Fig. 3A), while the second is established directly on the sand (Fig. 3B). Even today, it can be seen how traditional practices are maintained to protect crops from the prevailing winds (using bales of rye or rows of *L. arborecens*).

By 2018, 9.35 $km^2$ of the sector had been urbanized, particularly in the area around the port of Arrecife and a few scattered built-up areas in the northern sector of the system. The buildings constructed across the sediment transport exit sector have acted as a barrier, isolating the beaches of this southern area. On the other hand, the constructions towards the north have acted as a barrier to the entry of sediment into the system and have consequently resulted in landform modifications (Cabrera-Vega et al., 2013), as also detected in other similar systems in

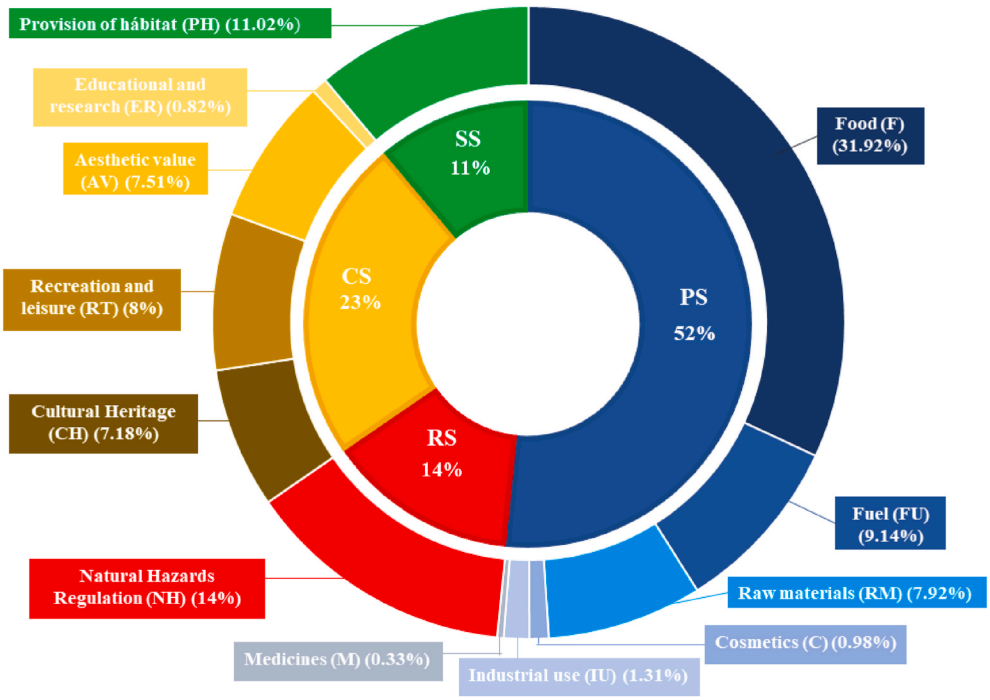


**Fig. 4.** Representation of ecosystem services in historical sources. PS: Provisioning services; RS: Regulating services; CS: Cultural services; SS: Supporting services.

the Canary Islands, including Maspalomas (Gran Canaria), Lambra and Jable Sur (La Graciosa) and Corralejo (Fuerteventura) (García-Romero et al., 2016).

The extraction of aggregates that began in 1980 in the study area has had two main purposes. Firstly, to supply the demand for materials for the construction and creation of infrastructure and, secondly, for the agricultural sector. However, in the case of the extraction of biogenic sands, its destination has mainly been for construction purposes. The extractions were carried out 24 h a day, and in many cases illegally. In response to various limitations imposed by governmental bodies, the industrial sector held strikes to allow the extractions to continue. The extractions often generated large quarries up to 8 m deep (Fig. 3C). The total affected area amounts to 6.48 $km^2$. The extractions have generated a deficit in the final sediment balance that can be transported and large traps that retain the sediments from the Caleta de Famara and Soo sectors.

### 4.2. Social relevance of ecosystem services

The representation of the different ESs in the historical sources varies depending on the type of service (Fig. 4). Thus, *provisioning* services are those that have the greatest weight in historical sources with 52% of the references (632 references), including most notably *Food* (31.92%), *Fuel* (9.14%) and *Raw materials* (7.92%). In the case of references to *regulating* services (14%), only references to *Natural hazard regulations* appear (169 references). For *cultural* services, there are a total of 288 references that are divided between *Cultural heritage* (7.18%), *Recreation and leisure* (8%), *Aesthetic value* (7.51%) and *Education and research* (0.82%). Finally, supporting services (136 references) only appear represented by *Provision of habitat* (11%).

How aeolian sedimentary systems are managed can have an impact on the provision of ESs (Everard et al., 2010). In this respect, Table 4 shows the qualitative impact that land uses recorded in the historical sources have had on the ESs provided by El Jable.

In general terms, ESs are significantly affected by the elimination of vegetation cover as this exerts an important control on the sedimentary dynamics (Hesp, 1981; Moreno-Casasola, 1986). Likewise, urbanization processes reduce the area available for wildlife habitats and affect the provision of other ESs (*Fuel, Raw materials, Photosynthesis* and *Pollination*, among others).

In El Jable, the effects on the *provisioning* services provided by the ecosystem between 1750 and 1960 were principally due to the problem of the transport of sediment burying crops. Livestock grazing and the need for fuel also resulted in modifications to plant communities, with some species seeing their populations considerably reduced or even becoming extinct, as also observed in other areas (Hunt, 2001). However, in El Jable, attempts were made by regional and local government authorities to control the overexploitation of plant resources and repair the damage caused by the sedimentary dynamics. In addition, the important ecological movement that has emerged on the island since 1970 has exerted considerable social pressure, acting as a driving force behind, firstly, a successful campaign to ensure the legal protection of at least part of the system and, later, the regulation of sand extraction for construction purposes.

As for the *regulating* services provided by the aeolian sedimentary dynamics, in the pre-1960 period an oversupply of sediments increased the capacity of the system to limit beach erosion in the southern sector. At the same time, the removal of vegetation cover and the resulting changes led to in an increase in the transport of sand that caused significant damage to crops, homes, port areas and roads. From 1960 onwards, sand-induced damage has diminished considerably due to the resurgence in vegetation cover, while beaches in the southern sector have suffered erosion processes due to both extreme meteorological and marine phenomena and the limited supply of sediment as the result of the previously mentioned reduction in sand transport and the urbanization processes that have isolated the beach.

Less evidence of the loss of cultural services was found. In general, only a few losses related to cultural heritage (principally archaeological sites and wells) were detected. Local tourism and recreational activities were affected by sedimentary activity in the early 20th century due to damage to infrastructure such as roads and signage, although the number of visitors would have been low, and from 1960 onwards due to the effect on mobile sand areas of urbanization processes.

Finally, the supporting services have been affected by strong erosion and deforestation processes. The capacity of the system to serve as a wildlife habitat has been modified by anthropic land uses

**Table 4**
Changes and need for control induced by land uses in the ecosystem services recorded in historical sources. F: Food; FU: Fuel; RM: Raw materials; C: Cosmetics; IU: Industrial use; GR: Genetic resource; MP: Medicines or pharmaceutics; NH: Natural hazards; CR: Climate regulation; CH: Cultural heritage; RL: Recreation and leisure; AV: Aesthetic value; IA: Inspiration for art; SR: Social relations; ER: Educational and research resources; SF: Soil formation; NC: Nutrient cycling; P: Photosynthesis; PO: Pollination; PH: Provision of habitat.

| | **1750-1960** (Low vegetation cover / high sand mobility) | **1960 to present** (High vegetation cover / low sand mobility) |
|---|---|---|
| **Provisioning services** | | |
| F | Problems with the crops been buried | No references |
| FU | Resource shortage around mid-19th century | Abandoned |
| RM | Laws to control the exploitation of *M. crystallinum.* Numerous laws to control deforestation. | Aggregate extraction started to be controlled by government law |
| C | Laws to control the exploitation of *M. crystallinum* | Abandoned |
| IU | Silt accumulation in port area | Recovered |
| GR | Species in danger/lost via grazing/deforestation | Species in danger/lost via grazing/deforestation |
| MP | Species in danger/lost via grazing/deforestation | Species in danger/lost via grazing/deforestation |
| **Regulating services** | | |
| NH | Sand flows associated with torrential rainfall and frequent sandstorms | South coast erosion (Arrecife) through building acting as a barrier and vegetation recovery |
| CR | Lower carbon sequestration | Recovered |
| **Cultural services** | | |
| CH | Burial of archeological sites/high fear of sandstorms/development of crop system | Destruction and protection of archeological sites |
| RL | Infrastructure problems due to sediment accumulation (whole system). Municipal ordinances for road and port maintenance. | Infrastructure problems due to sediment accumulation (Famara) |
| AV | Changes in the visual aspect of the landscape through deforestation and sediment remobilization | Changes in the visual aspect of the landscape through urbanization, aggregate extraction, vegetation recovery and sediment stabilization |
| IA | No references | No references |
| SR | No references | No references |
| ER | No references | No references |
| **Supporting services** | | |
| SF | No references | No references |
| NC | No references | No references |
| P | No references | No references |
| PO | No references | No references |
| PH | Changes through sediment remobilization/introduction of invasive species/species lost through massive grazing | Favored by land protection laws/deteriorated through introduction of invasive species and urbanization processes |

| **Legend** | **High losses** | **Moderate losses** | **Increase** | **No change detected** |
|---|---|---|---|---|

(Hernández-Cordero et al., 2017, 2018; García-Romero et al., 2019). By way of example, underwater habitats were gradually buried, which resulted in modifications to the species (fauna and flora) found in the submerged area of Arrecife (Greff, 1868). This shows that there is an important link between the different ecosystems of the insular areas and that proper management is vital for their proper operation and conservation. Although, from 1987 onwards, new environmental laws protecting the system have contributed to conserving these services, the introduction of invasive species and the urbanization process that began with the emergence of tourism has had a negative impact on wildlife habitats.

In summary, it seems that the uses that have most influenced the alteration of ecosystem services are those related to the removal of vegetation cover (grazing and obtaining fuel) and the urbanization process (Table 4), the effects of which have also been analyzed for the Mediterranean coast (Carranza et al., 2019). In the case of El Jable, the ESs are conditioned by important changes in the sediment transport rate of the aeolian sedimentary system.

The social relevance of the ESs shows an important relationship with the land uses. Before 1960, the ESs with a high score in social relevance are generally related to the safety of the population, the provision of an economic income (e.g. *Fuel* or *Raw materials*), or the guarantee of food (*Food*) as they alleviate poverty (Shackleton et al., 2008). This is also related to the fact that some ESs can produce tangible resources, while the intangible nature of others makes them less relevant to the population. Changes in the social relevance of the ESs were observed in the information collected from the historical sources, starting around 1960 (when the transition to tourism begins). From that moment, *Aesthetic values, Local culture, Provision of habitat* and *Natural hazards* gain in importance. The increase in the social relevance of *Provision of habitat* is related to the appearance of pro-environmental movements in the island. The references to *Raw materials*, which until 1900 are related almost exclusively to the extraction of limestone and firewood, later, from 1980 onwards, give greater prominence to the extraction of

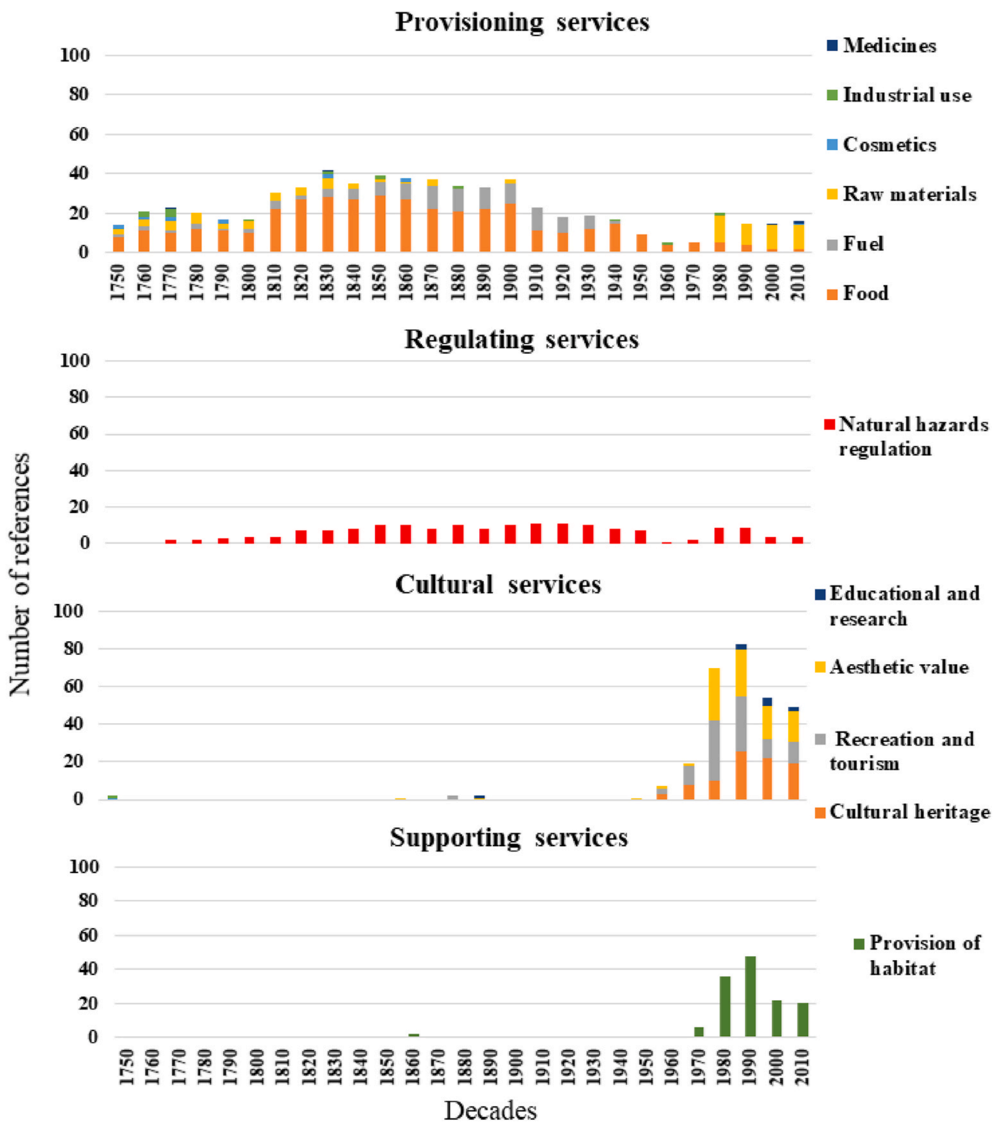


**Fig. 5.** Evolution of the number of references to ecosystem services in the historical sources consulted.

aggregates. Similarly, with respect to the *Natural hazards* regulating service, the references up to around 1950 speak of the problem of the massive aeolian transport of sand, whereas from 1980 onwards the problem of beach erosion because of marine storms is the main topic of discussion. However, the most important trend is the reduction of references to *Food* and *Fuel* and the increased number of references to questions related to *Cultural heritage*, *Aesthetic value*, *Recreation and leisure* and *Provision of habitat* (Fig. 5). This shows that there has been a profound change in the mentality of the population, who now depend on imported products from abroad (food and fuel), and in the main economic activity (from agriculture and livestock to tourism). It should be noted that some of the services considered in this section do not appear in the historical references. They are nevertheless included because of their punctual exploitation or because they are intangible services and the lack of scientific research on regulating and cultural (apart from recreation and leisure) services is mainly related to the complexity of assessing intangible values (Schaich et al., 2010). Rural society, and indeed in many cases society in general in the past, has traditionally not attached much importance to ESs such as *Genetic resource, Climate regulation, Inspiration for art, Social relations, Soil formation, Nutrient cycling, Photosynthesis* or *Pollination.*

The historical social relevance of changes to or the loss of an ES related to different land use is shown in Table 5. As can be seen, the effects of the urbanization process since 1960 generally resulted in low scores despite the loss of ESs. The *Natural hazards* regulating service obtained a high score (0.89), given the wide-ranging debate held about the buildings of the city of Arrecife creating a barrier to the arrival of sand and, therefore, an increased vulnerability to marine storms. Likewise, the *Provision of habitat* service (0.67) scored high due to the emergence of the ecological movement and the tourist urbanizations in the surroundings of Caleta de Famara.

With respect to aggregate extraction, high social relevance scores were only obtained for the services of *Cultural heritage* (0.78) and *Aesthetic value* (0.67).

The ESs from which the population benefits directly are those that have the greatest social relevance. As such, grazing scored high in the provisioning services of *Food* (0.89), *Fuel* (0.67) and *Raw materials* (0.67). Likewise, logging also produced several changes in the capacity of the ecosystem to provide its services with various problems related to the elimination of vegetation, as can be seen in the scores for *Food* (0.89), *Raw materials* (0.44) and *Fuel* (0.89). In this respect, most of the references come from a time when food, fuel and raw materials were produced in the immediate environment. Because these three uses were competing for the same resources, the capacity of the ecosystem to provide them was compromised. By way of example, with respect to the *Food* service, both agricultural farmers and shepherds/goatherders

**Table 5**
Social relevance of the change to or loss of an ecosystem service induced by land use. Horizontal axis: S: social sensitivity criterion; E: economic criterion; P: political criterion. Σav: Sum of all scores. Vertical axis: F: Food; FU: Fuel; RM: Raw materials; C: Cosmetics; O: Others; IU: Industrial use; GR: Genetic resource; MP: Medicines or pharmaceutics; OS: Ornamental source; NH: Natural hazards; CR: Climate regulation; CH: Cultural heritage; RL: Recreation and leisure; AV: Aesthetic value; IA: Inspiration for art; SR: Social relations; ER: Education and research; SF: Soil formation; NC: Nutrient cycling; P: Photosynthesis; PO: Pollination; PH: Provision of habitat.

| | Urbanization (1960-present) | | | | Aggregate extraction (1980-present) | | | | Grazing (Unknown-present) | | | | Cultivation (Unknown-present) | | | | Deforestation (Unknown-1960) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | E | P | Σav /9 | S | E | P | Σav /9 | S | E | P | Σav /9 | S | E | P | Σav /9 | S | E | P | Σav /9 |
| **Provisioning services** | | | | | | | | | | | | | | | | | | | | |
| F | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 3 | 2 | 2 | 0.89 | 3 | 1 | 0 | 0.44 | 3 | 3 | 2 | 0.89 |
| FU | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 2 | 2 | 2 | 0.67 | 2 | 1 | 0 | 0.33 | 1 | 1 | 2 | 0.44 |
| RM | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 2 | 2 | 2 | 0.67 | 2 | 1 | 0 | 0.33 | 3 | 3 | 2 | 0.89 |
| C | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| IU | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 1 | 3 | 1 | 0.56 |
| GR | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| MP | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| **Regulating services** | | | | | | | | | | | | | | | | | | | | |
| NH | 2 | 3 | 3 | 0.89 | 0 | 1 | 0 | 0.12 | 3 | 2 | 3 | 0.89 | 3 | 3 | 0 | 0.67 | 3 | 3 | 2 | 0.89 |
| CR | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| **Cultural services** | | | | | | | | | | | | | | | | | | | | |
| CH | 0 | 1 | 0 | 0.12 | 3 | 1 | 3 | 0.78 | 0 | 1 | 0 | 0.12 | 1 | 2 | 3 | 0.67 | 0 | 2 | 0 | 0.23 |
| RL | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 2 | 2 | 2 | 0.67 |
| AV | 0 | 1 | 0 | 0.12 | 3 | 2 | 1 | 0.67 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| IA | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| SR | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| ER | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| **Supporting services** | | | | | | | | | | | | | | | | | | | | |
| SF | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| NC | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| P | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| PO | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 | 0 | 1 | 0 | 0.12 |
| PH | 2 | 1 | 3 | 0.67 | 3 | 1 | 1 | 0.56 | 0 | 1 | 3 | 0.45 | 0 | 1 | 3 | 0.45 | 1 | 1 | 0 | 0.23 |
| Low social relevance | | | | | | | Moderate social relevance | | | | | | | High social relevance | | | | | | |

would have been competing for the same resource, which explains the high historical social relevance score due to the loss of/damage to both these land uses. This produced a conflict between the two types of user, as has also happened in other areas (Kovács et al., 2015).

Grazing, cultivation and logging scored high in the *Natural hazards* regulating service (grazing = 0.89; cultivation = 0.67; logging = 0.89), in this case highlighting the debate around the increase in wind transport and the significant damage that this exerted in the period 1750–1960 (as described above). From 1960 onwards, beach erosion due to marine storms is mainly attributable to the urbanization process that has isolated the beaches from the rest of the aeolian sedimentary system.

Interestingly, in general terms, no type of management or prohibition measure has been taken by the administrations if there has been no social relevance or mobilization. In other words, political actions are directly related to social sensitivity or vice versa (McClurg, 2006). The only case that might be considered an exception is the case of the *Provision of habitat* service for grazing and cultivation, for both of which protective and regulatory measures have been established despite the fact that both the extraction of aggregates and urbanization are more harmful to the provision of that service (García-Romero et al., 2019; Marrero-Rodríguez et al., 2020b). Finally, despite the potential damage of some land uses, some of the ESs scored low in terms of social relevance. Those with the lowest scores are intangible services (including *Inspiration for art*, *Social relations*, *Education and research*, *Soil formation*, *Nutrient cycling* or *Photosynthesis*), or have only been sporadically exploited (*Cosmetics*, *Genetic resource* and *Medicines or pharmaceutics*).

The methodology used in the present work has some limitations. The reconstruction of land uses and landscape has been widely carried out by numerous authors (e.g. Grossinger et al., 2007; Hoffman and Rohde, 2007), but the loss of ESs and the reaction that people and management entities have to such losses has not been studied in depth historically (Bálee. 2006). However, the relationship between ESs and land uses has been demonstrated in many studies (Su and Fu, 2013; Sun et al., 2019). It should be noted that the limitations of historical ecology for other works are also applicable to ours (Szabó, 2015). Nonetheless, the historical analysis carried out in the present work constitutes a tool to understand the driving forces behind the loss of a service, the reaction of society and political management. It should also be highlighted that many management measures are not applied until the moment when land uses have transformed or pushed the capacity of an ecosystem to provide an ES to its limit. In addition, this work shows the existence of conflicts for the exploitation of resources and the reaction of society to such conflicts through a methodology that integrates the social, political, environmental and economic dimensions using sources for a period of more than 200 years, which is commonly the limit of historical ecology studies (Szabó, 2015).

In terms of management, there is a tendency to integrate the physical and social sides under the framework of the integrated management of coastal areas (Scura et al., 1992; Thia-Eng, 1993; Post and Lundin, 1996) because society increasingly has more concerns about the environment and because management measures entail changes in the perception of users about the ecosystem (Pranzini et al., 2010). Therefore, this work offers an example of the monitoring of the reaction of societies to changes over an extensive period using the available sources. Works of this type can be useful in the decision-making process for societal integration in areas that depend heavily on a service sector-based economy, as well as in areas where traditional uses and subsistence economies are predominant. In both, planning, management and, later, monitoring (Micallef and Williams, 2002) are important to stop the degradation of ecosystems and, therefore, the loss of ESs.

In the present study, the aims of historical ecology as proposed by Bürgi and Gimmi (2007) have been taken into consideration in the reporting of the evolution of landscape management and how society has perceived the changes that have taken place. Knowledge of historical trends improves our understanding of the natural dynamics of landscapes and provides a framework for evaluating current patterns and present and future processes (Swetnam et al., 1999). Finally, this work can be of help to land managers who need to understand how management measures can provoke reactions in society or land custody entities, as well as to understand the reasons behind social reactions to changes in ecosystems and the services that they provide. Additionally, the reconstruction of land uses and their consequences for the natural dynamics of an ecosystem can help to understand the responses of that system to new environmental conditions, land uses or management measures (Swetnam et al., 1999; Berkes et al., 2000). In summary, the present work can help managers to plan the integrated management of coastal areas, using history as a tool to understand changes in the perception of society, the responses of ecosystem dynamics to land uses, and changes in ESs.

## 5. Conclusions

The methodology used to reconstruct historical social relevance related to the loss or modification of ecosystem services has shown the existence of a relationship with the different land uses that took place during varying timeframes of the study period. In this particular case study, environmental changes in El Jable (Lanzarote, Canary Islands) were found to have a social relevance in the past when the impacts were due to anthropogenic activities. Two main periods related to the loss of ecosystem services and environmental changes were identified: i) from 1750 to 1960, during which time traditional uses caused significant deforestation of the system and consequent sediment remobilization; ii) from 1960 to the present, during which time the abandonment of traditional uses has resulted in sediment stabilization due to the spontaneous re-emergence of vegetation. In both periods, the social relevance of the ecosystem services changed depending on the different land uses of each period. The analysis of historical sources reveals that the changes to or loss of ecosystem services which have had high social relevance are related to the social sensitivity, political or economic criteria that were considered, and that these depend to a large extent on the type of service provided (provisioning, regulating, cultural or supporting). The most direct and vital ecosystem services (the provision of food, fuel and raw materials, and the regulation of natural hazards) are those with the greatest historical social relevance until 1960. At this point in time, a change to the economic model involving the promotion of tourism resulted in other aspects (cultural heritage, recreation and leisure and aesthetic value) acquiring greater social relevance in terms of citizen safety (regulation of natural hazards), ecosystem conservation (provision of wildlife habitats) and culture (cultural heritage). This research also helps us understand that despite the fact that two ecosystem services may be lost due to the same land use, the social reaction may be different and, with it, the influence that society has had on the restoration, regulation and protection measures and on the political and economic decision-making processes. It additionally shows that most management measures are taken after the loss of an ecosystem service or after important modifications to the natural dynamics of the ecosystem.

## Declaration of competing interest

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

## Acknowledgements

This article is a contribution of the CSO2016-79673-R project funded by the Spanish Government's National Plan for R+D+i (innovation) and co-financed by the ERDF, and of the PLANCLIMAC project (MAC/3.5b/244), part of the INTERREG-MAC 2014–2020 cooperation program,. This article is a publication of the Océano y Clima Unit of the University of Las Palmas de Gran Canaria, an R&D&i CSIC-associate unit.

## References

Alonso, I., Hernández, L., Alcántara-Carrió, J., Cabrera, L., Yanes, A., 2011. Los grandes campos de dunas actuales de Canarias. In: Sanjaume Saumell, E., Gracia Prieto, F.J. (Eds.), Las dunas en España. Sociedad Española de Geomorfología, Cádiz, pp. 467–496.
Álvarez-Rixo, J.A., 1866/1982. Historia del Puerto del Arrecife en la isla de Lanzarote. Una de las Canarias. Biblioteca Isleña, XV. Cabildo Insular de Tenerife.
Asmus, M.L., Nicolodi, J., Anello, L.S., Gianuca, K., 2019. The risk to lose ecosystem services due to climate change: a South American case. Ecol. Eng. 130, 233–241.
Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. Ecol. Monogr. 81 (2), 169–193. https://doi.org/10.1890/10-1510.1.
Berkes, F., Colding, J., Folke, C., 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecol. Appl. 10 (5), 1251–1262.
Bruquetas De Castro, F., 1997. Las actas del Cabildo de Lanzarote (siglo XVII).
Bürgi, M., Gimmi, U., 2007. Three objectives of historical ecology: the case of litter collecting in Central European forest. Landsc. Ecol. 22, 77–87. https://doi.org/10.1007/s10980-007-9128-0.
Bürgi, M., Straub, A., Gimmi, U., Salzmann, D., 2010. The recent landscape history of Limpach valley, Switzerland: considering three empirical hypotheses on driving forces of landscape change. Landsc. Ecol. 25, 287–297.
Caballero-Mújica, F. (Ed.), 1991. Compendio brebe y fasmosso, histórico y político, en que (se) contiene la cituazion, población, división, gobierno, produziones, fábricas y comercio que tiene la ysla de Lanzarote en el año de 1776. Ayuntamiento de Teguise. Teguise-Las Palmas.
Cabrera-Vega, L.L., 2010. Sedimentología, estratigrafía, dinámica sedimentaria y evolución de El Jable (Lanzarote). *Propuesta de gestión* (Doctoral dissertation).
Cabrera-Vega, L.L., Cruz-Avero, N., Hernández-Calvento, L., Hernández-Cordero, A., Fernández-Cabrera, E., 2013. Morphological changes in dunes as an indicator of anthropogenic interferences in arid dune fields. J. Coast Res. (65), 1271–1276.
Carranza, M.L., Drius, M., Marzialetti, F., Malavasi, M., de Francesco, M.C., Acosta, A.T., Stanisci, A., 2019. Urban expansion depletes cultural ecosystem services: an insight into a Mediterranean coastline. Rendiconti Lincei. Sci. Fis. Nat. 1–9.
Clarke, M.L., Rendell, H.M., 1998. Climate change impacts on sand supply and the formation of desert sand dunes in the south-west USA. J. Arid Environ. 39 (3), 517–531.
Dekens, J., 2007. Local Knowledge for Disaster Preparedness: A Literature Review. International Centre for Integrated Mountain Development (ICIMOD).
del Arco Aguilar, M.J., González-González, R., Garzón-Machado, V., Pizarro-Hernández, B., 2010. Actual and potential natural vegetation on the Canary Islands and its conservation status. Biodivers. Conserv. 19 (11), 3089–3140.
Delgado-Fernandez, I., O'Keeffe, N., Davidson-Arnott, R.G., 2019a. Natural and human controls on dune vegetation cover and disturbance. Sci. Total Environ. 672, 643–656.
Delgado-Fernandez, I., Davidson-Arnott, R., Hesp, P., 2019b. Is 're-mobilizaiton' nature restoration or nature destruction? A commentary. J. Coast Conserv. 23, 1093–1103.
Dirkx, J., 2004. Historical ecology of Dutch cultural landscapes: references for the integration of landscape planning and nature restoration in The Netherlands. In: Brandt, J., Vejre, H. (Eds.), Multifunctional Landscapes. I: Theory, Values and History. WIT Press, Southampton Boston, pp. 137–149.
Dzwonko, Z., Gawronski, S., 2002. Effect of litter removal on species richness and acidification of a mixed oak-pine woodland. Biol. Conserv. 106, 389–398.

Esquivias, M.P., Zunzunegui, M., Barradas, M.C.D., Álvarez-Cansino, L., 2015. Competitive effect of a native-invasive species on a threatened shrub in a Mediterranean dune system. Oecologia 177 (1), 133–146.

Everard, M., Jones, L., Watts, B., 2010. Have we neglected the societal importance of sand dunes? An ecosystem services perspective. Aquat. Conserv. Mar. Freshw. Ecosyst. 20 (4), 476–487. https://doi.org/10.1002/aqc.1114.

Fritsch, K.V., 2006. Las islas Canarias. Cuadros de Viaje. In: Traducción, Estudio Introductorio y Notas de José Juan Batista Rodríguez y Encarnación Tabares Plasencia. Taller de Historia, vol. 40. Centro de la Cultura Popular Canaria, p. 242.

Fritschle, J.A., 2009. Pre-EuroAmerican settlement forests in redwood national park, California, USA: a reconstruction using line summaries in historic land surveys. Landsc. Ecol. 24 (6), 833–847. https://doi.org/10.1007/s10980-009-9361-9.

García-Romero, L., Henández-Cordero, A., Fernandéz-Cabrera, E., Peña, C., Hernández-Calvento, L., Pérez-Chacón, E., 2016. Urban-touristic impacts on the aeolian sedimentary systems of the Canary Islands: conflict between development and conservation. Island Stud. J. 11 (1), 91–112.

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

Glass, G., 1764/1982. Descripción de las Islas Canarias 1764, vol. XX. Instituto de Estudios Canarios. Fontes Rerum Canariarum, La Laguna.

Greeff, R., 1868. Reise nach den Canarischen Inseln. (London, Lissabon, Madeira, Gran Canaria, Lanzarote, Marokko, Spanien. Mit popular-naturwissenschaftlichen Schilderungen. Max Cohen & Sohn, Bonn.

Grossinger, R.M., Striplen, C.J., Askevold, R.A., Brewster, E., Beller, E.E., 2007. Historical landscape ecology of an urbanized California valley: wetlands and woodlands in the Santa Clara Valley. Landsc. Ecol. 22 (1 Suppl. ment), 103–120.

Hesp, P.A., 1981. The formation of shadow dunes. J. Sediment. Petrol. 51 (1), 101–112.

Hernández-Calvento, L., Jackson, D.W.T., Medina, R., Hernández-Cordero, A.I., Cruz, N., Requejo, S., 2014. Downwind effects on an arid dunefield from an evolving urbanized area. Aeolian Res. 15, 301–309. https://doi.org/10.1016/j.aeolia.2014.06.007.

Hernández-Cordero, A.I., Hernández-Calvento, L., Espino, E.P.C., 2017. Vegetation changes as an indicator of impact from tourist development in an arid transgressive coastal dune field. Land Use Pol. 64, 479–491.

Hernández-Cordero, A.I., Hernández-Calvento, L., Hesp, P.A., Pérez-Chacón, E., 2018. Geomorphological changes in an arid transgressive coastal dune field due to natural processes and human impacts. Earth Surf. Process. Landforms 43 (10), 2167–2180. https://doi.org/10.1002/esp.4382.

Hernández-Pacheco, E., 2002. Por los campos de lava. Fundación César Manrique, p. 337.

Hoffman, M.T., Rohde, R.F., 2007. From pastoralism to tourism: the historical impact of changing land use practices in Namaqualand. J. Arid Environ. 70, 641–658.

Hunt, L.P., 2001. Heterogeneous grazing causes local extinction of edible perennial shrubs: a matrix analysis. J. Appl. Ecol. 38 (2), 238–252.

Jackson, D.W.T., Cooper, J.A.G., 2011. Coastal dune fields in Ireland: rapid regional response to climatic change. J. Coast Res. (64), 293–297.

Kovács, E., Kelemen, E., Kalóczkai, Á., Margóczi, K., Pataki, G., Gébert, J., et al., 2015. Understanding the links between ecosystem service trade-offs and conflicts in protected areas. Ecosyst. Serv. 12, 117–127.

Kutiel, P., Cohena, O., Shoshany, M., Shubb, M., 2004. Vegetation establishment on the southern Israeli coastal sand dunes between the years 1965 and 1999. Landsc. Urban Plann. 67, 141–156.

León-Hernández, J., Navarro-Mederos, J.F., Marrero Salas, E., Abreu-Hernández, I., Tejera-Tejera, M., García-Ávila, J.C., Perera-Betancort, M.A., 2016. La recuperación histórica de Fiquinineo-Peña de las cucharas (Teguise, Lanzarote). XXI Coloquio de Historia Canario-Americana. *2014)*, XXI-085. http://coloquioscanariasmerica.casadecolon.com/index.php/aea/article/view/9565.

Levin, N., Ben-Dor, E., 2004. Monitoring sand dune stabilization along coastal dunes of Ashdod-Nizanim, Israel, 1945-1999. J. Arid Environ. 58, 335–355.

Marchante, H., Marchante, E., Freitas, H., 2003. Invasion of the Portuguese dune ecosystems by the exotic species Acacia longifolia (Andrews) Willd.: effects at the community level. In: Plant invasions: ecological threats and management solutions, pp. 75–85.

Marrero-Rodríguez, N., García-Romero, L., Sánchez-García, M.J., Hernández-Calvento, L., Pérez-Chacón Espino, E., 2020. An historical ecological assessment of land-use evolution and observed landscape change in an arid aeolian sedimentary system. Sci. Total Environ. 716, 137087.

Martín, A., Nogales, M., Hernández, M.A., Lorenzo, J.A., Medina, F.M., Rando, J.C., 1996. Status, conservation and habitat selection of the houbara bustard chlamydotis undulata fuertaventurae on Lanzarote (canary islands). Bird. Conserv. Int. 6 (3), 229–239.

Madoz, P., 1849. Diccionario geográfico-estadístico-histórico de España y sus posesiones de ultramar: Madrid. Audiencia, provincia, intendencia, vicaría, partido y villa.

McClurg, S.D., 2006. The electoral relevance of political talk: examining disagreement and expertise effects in social networks on political participation. Am. J. Polit. Sci. 50 (3), 737–754.

McAllister, D.M., 1982. Evaluation in Environmental Planning: Assessing Environmental, Social, Economic, and Political Trade-Offs. Mit Press.

Mehvar, S., Filatova, T., Sarker, M.H., Dastgheib, A., Ranasinghe, R., 2019. Climate change-driven losses in ecosystem services of coastal wetlands: a case study in the West coast of Bangladesh. Ocean Coast Manag. 169, 273–283.

Micallef, A., Williams, A.T., 2002. Theoretical strategy considerations for beach management. Ocean Coast Manag. 45 (4–5), 261–275.

Mimura, N., Nurse, L., McLean, R., Agard, J., Briguglio, L., Lefale, P., et al., 2007. Small islands. Clim. Chang. 16, 687–716.

Moreno-Casasola, P., 1986. Sand movement as a factor in the distribution of plant communities in a coastal dune system. Vegetatio 65, 67–76.

Morgan, J.L., Gergel, S.E., Coops, N.C., 2010. Aerial photography: a rapidly evolving tool for ecological management. Bioscience 60, 47–59.

Morris, L.R., Rowe, R.J., 2014. Historical land use and altered habitats in the Great Basin. J. Mammal. 95, 1144–1156.

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

Nordstrom, K.F., 2004. Beaches and Dunes of Developed Coasts. Cambridge University Press.

Paskoff, R., 1993. Côtes en danger. *Practiques de la Géographie*, Masson, París, p. 247.

Paskoff, R., 2001. Dune management on the Atlantic coast of France: a case study. In: Houston, J.A., Edmondson, S.E., Rooney, P.J. (Eds.), Coastal Dune Management. Shared Experience of European Conservation Practice. Proceedings of the European Symposium Coastal Dunes of the Atlantic Biogeographical Region, Southport, NW England, September 1998. Liverpool University Press, pp. 34–40.

Panzacchi, M., Van Moorter, B., Jordhøy, P., Strand, O., 2013. Learning from the past to predict the future: using archaeological findings and GPS data to quantify reindeer sensitivity to anthropogenic disturbance in Norway. Landsc. Ecol. 28 (5), 847–859.

Parra-Tabla, V., Albor-Pinto, C., Tun-Garrido, J., Angulo-Pérez, D., Barajas, C., Silveira, R., et al., 2018. Spatial patterns of species diversity in sand dune plant communities in Yucatan, Mexico: importance of invasive species for species dominance patterns. Plant Ecol. Divers. 11 (2), 157–172.

Peña-Alonso, C., Ariza, E., Hernández-Calvento, L., Pérez-Chacón, E., 2018. Exploring multi-dimensional recreational quality of beach socio-ecological systems in the Canary Islands (Spain). Tourism Manag. 64, 303–313.

Petit, J., Prudent, G., 2010. Climate Change and Biodiversity in the European Union Overseas Entities. IUCN, Gland, Switzerland and Brussels, Belgium, p. 178.

Pranzini, E., Simonetti, D., Vitale, G., 2010. Sand colour rating and chromatic compatibility of borrow sediments. J. Coast Res. 26 (5), 798–808, 265.

Provoost, S., Jones, M.L.M., Edmondson, S.E., 2011. Changes in landscape and vegetation of coastal dunes in northwest Europe: a review. J. Coast Conserv. 15 (1), 207–226.

Post, J.C., Lundin, C.G., 1996. Guidelines for Integrated Coastal Zone Management.

Pye, K., Blott, S.J., 2012. A geomorphological survey of Welsh dune systems to determine best methods of dune rejuvenation. CCW Science Report No. 1002.

Qi, S., Luo, F., 2004. Desertification and sustainable development of the Heihe River Basin in arid northwestern China. Chin. J. Pop. Res. Environ. 2 (4), 25–27.

Qi, S., Wang, T., 2003. Current status and causes of sandy desertification land in the middle and lower reaches of Heihe River Basin, northwestern China. J. Soil Water Conserv. 17 (4), 98–101.

Rohde, R.F., Hoffman, M.T., 2012. The historical ecology of Namibian rangelands: vegetation change since 1876 in response to local and global drivers. Sci. Total Environ. 416, 276–288.

Romero, C., 1991. Las manifestaciones volcánicas históricas del Archipiélago Canario. In: Consejería de Política territorial. Gobierno de Canarias, p. 695.

Ruiz-Cermeño, J., 1772/1981. Previa noticia de la ysla de Lanzarote, su situación, lugares, número de vecinos, ganados, comercio, etc., con una exacta descripción de sus fortalezas, costas y puertos, inclusos los reparos de que necesitan, con cálculo de su costo. In: Rumeu de Armas, A. (Ed.), Estructura socioeconómica de Lanzarote y Fuerteventura en la segunda mitad del siglo XVIII. Anuario de Estudios Atlánticos, pp. 425–456, 27.

Rumeu de Armas, A., 1981. Estructura socioeconómica de Lanzarote y Fuerteventura en la segunda mitad del siglo XVIII. Anu. Estud. Atl. (27), 425–456.

Santana-Cabrera, J.A., Moreno-Benítez, M.A., Suárez-Medina, I., Mendoza-Medina, F. y, Alberto-Barroso, V., 2017. Zonzamas: un yacimiento singular en la isla de Lanzarote. Nuevos datos arqueológicos, vol. XXII. Coloquio de Historia Canario-Americana. *2016)*, XXII-135. http://coloquioscanariasmerica.casadecolon.com/index.php/aea/article/view/10072.

Santana-Cordero, A.M., Bürgi, M., Hersperger, A.M., Hernández-Calvento, L., Monteiro-Quintana, M.L., 2017. A century of change in coastal sedimentary landscapes in the Canary Islands (Spain)—change, processes, and driving forces. Land Use Pol. 68, 107–116.

Sauter, R., Ten Brink, P., Withana, S., Mazza, L., Pondichie, F., , et al.Clinton, J., Lopes, A., Bego, K., 2013. Impacts of Climate Change on All European Islands. Report by Institute for European Environmental Policy (IEEP) for the Greens/EFA of the European Parliament. Final Report. Brussels.

Schaich, H., Bieling, C., Plieninger, T., 2010. Linking ecosystem services with cultural landscape research. Gaia-Ecol. Perspect. Sci. Soc. 19 (4), 269–277. https://doi.org/10.14512/gaia.19.4.9.

Shackleton, C., Shackleton, S., Gambiza, J., Nel, E., Rowntree, K., Urquhart, P., 2008. Links between Ecosystem Services and Poverty Alleviation. *Situation Analysis for Arid and Semi-arid Lands in Southern Africa*.

Scura, L.F., Chua, T.E., Pido, M.D., Paw, J.N., 1992. Lessons for integrated coastal zone management: the ASEAN experience. In: Regional Workshop on Coastal Zone Planning and Management in ASEAN Lessons Learned, Bandar Seri Begawan (Brunei Darussalam), 28-30 Apr 1992. ICLARM.

Stone, O., 1887. Tenerife and its Six Satellites or the Canary Islands Past and Present. Marcus Ward & Co, London.

Su, C., Fu, B., 2013. Evolution of ecosystem services in the Chinese Loess Plateau under climatic and land use changes. Global Planet. Change 101, 119–128.

Sun, Y., Liu, S., Dong, Y., An, Y., Shi, F., Dong, S., Liu, G., 2019. Spatio-temporal evolution scenarios and the coupling analysis of ecosystem services with land use change in China. Sci. Total Environ. 681, 211–225.

Swetnam, T.W., Allen, C.D., Betancourt, J.L., 1999. Applied historical ecology: using the past to manage for the future. Ecol. Appl. 9 (4), 1189–1206.
Szabó, P., 2015. Historical ecology: past, present and future. Biol. Rev. 90 (4), 997–1014.
Szabó, P., Hédl, R., 2011. Advancing the integration of history and ecology for conservation. Conserv. Biol. 25 (4), 680–687.
Thia-Eng, C., 1993. Essential elements of integrated coastal zone management. Ocean Coast Manag. 21 (1–3), 81–108.
Torriani, L., 1959. Descripción e historia del reino de las Islas Canarias antes Afortunadas, con el parecer de sus fortificaciones, vol. 2. Goya Ediciones.
Trueman, M., Hobbs, R.J., van Niel, K., 2013. Interdisciplinary historical vegetation mapping for ecological restoration in Galapagos. Landsc. Ecol. 28, 519–532.
Tsoar, H., Blumberg, D.G., 2002. Formation of parabolic dunes from barchan and transverse dunes along Israel's Mediterranean coast. Earth Surf. Process. Landforms 27 (11), 1147–1161.
Tsoar, H., Levin, N., Porat, N., Maia, L.P., Herrmann, H.J., Tatumi, S.H., Claudino-Sales, V., 2009. The effect of climate change on the mobility and stability of coastal sand dunes in Ceará State (NE Brazil). Quat. Res. 71 (2), 217–226.
Van Oudenhoven, A.P., Petz, K., Alkemade, R., Hein, L., de Groot, R.S., 2012. Framework for systematic indicator selection to assess effects of land management on ecosystem services. Ecol. Indicat. 21, 110–122.
Vellend, M., Brown, C., Kharouba, H.M., McCune, J.L., Myers-Smith, I.H., 2013. Historical ecology: using unconventional data sources to test for effects of global environmental change. Am. J. Bot. 100, 1294–1305.
Viera y Clavijo, J.D., 1982. Diccionario de historia natural de las Islas Canarias. Cabildo Insular de Gran Canaria, *Las Palmas*.
Vilà, M., Basnou, C., Pyšek, P., Josefsson, M., Genovesi, P., Gollasch, S., et al., 2010. How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. Front. Ecol. Environ. 8 (3), 135–144.
Walsh, J.R., Carpenter, S.R., Vander Zanden, M.J., 2016. Invasive species triggers a massive loss of ecosystem services through a trophic cascade. Proc. Natl. Acad. Sci. Unit. States Am. 113 (15), 4081–4085.
Wang, T., 2004. Progress in sandy desertification research of China. J. Chin. Geogr. 14 (4), 387–400.
Weiskopf, S.R., Rubenstein, M.A., Crozier, L.G., Gaichas, S., Griffis, R., Halofsky, J.E., et al., 2020. Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. Sci. Total Environ., 137782