Vegueta. Anuario de la Facultad de Geografía e Historia
24 (2), 2024, 793-827
eISSN: 2341-1112
https://doi.org/10.51349/veg.2024.2.08

From Dunes to Forest: Historical Management of Coastal Dune Fields to Understand Their Changes Across Time: The Case of the Catalan Coast

De las dunas al bosque - gestión histórica de los campos dunares costeros para comprender sus cambios en el tiempo: el caso de la costa catalana

Carla Garcia-Lozano*
Universitat de Girona
Departament de Geografia
https://orcid.org/0000-0002-5071-1009
carla.garcia@udg.edu

Aarón Moisés Santana-Cordero
Universidad de Salamanca
Departamento de Geografía
https://orcid.org/0000-0003-2210-1980
aaron.santana@usal.es

Francesc-Xavier Roig-Munar
Universitat de Girona
Departament de Geografia
Laboratori d'Anàlisi i Gestió del Paisatge
https://orcid.org/0000-0002-9777-0938
xiscoroig@gmail.com

Josep Pintó
Universitat de Girona
Departament de Geografia
https://orcid.org/0000-0002-5693-393X
josep.pinto@udg.edu

Louis Gustavo Meira Barros
Universidade Federal do Norte do Tocantins
Departamento de Geografia
https://orcid.org/0009-0003-9427-7421
luiz.barros@ufnt.edu.br

Sueli Angelo Furlan
University of Sao Paulo
Departamento de Geografia
https://orcid.org/0000-0003-4699-5034
sucaangf@usp.br

Recibido: 04/05/2024; Revisado: 27/05/2024; Aceptado: 09/07/2024

Abstract

This work compares two dune fixation processes in Catalonia (Spain), the Montgrí and Begur massifs and the Llobregat delta, and disproves that both were undertaken to impede the advance of the sands. The fixation process in the Montgrí and Begur massifs is well documented and was planned in response to the need to stop sand advancement, whereas in the case of the Llobregat delta, the actions

* Corresponding author / *Autora de correspondencia.*

taken were spontaneous, took place over centuries and were aimed at mitigating health issues while at the same time gaining an economic benefit from the fruit and wood of the planted pine trees.

Keywords: Catalan Coast, Dune Fields, Dune Afforestation, Pine Forest, Landscape Changes.

Resumen

Este trabajo compara dos procesos de fijación de dunas en Cataluña (España), los macizos de Montgrí y Begur y el delta del Llobregat, y desmiente que ambos hayan sido llevados a cabo para detener el avance de las arenas. El proceso de fijación en los macizos de Montgrí y Begur está bien documentado y fue planeado en respuesta a la necesidad de detener el avance de las dunas, mientras que, en el caso del delta del Llobregat, las acciones tomadas fueron espontáneas, ocurrieron a lo largo de siglos y tenían como objetivo mitigar problemas de salud, al mismo tiempo que se obtenía beneficio económico de los frutos y la madera de los pinos plantados.

Palabras clave: Costa catalana, campos dunares, forestación dunar, pinares, cambios del paisaje.

1. INTRODUCTION

Humans have transformed ecosystems over millennia, leading to a global increase in ecosystem diversity (Western, 2001). These changes accelerated dramatically after the 18th century and continued through the mid-20th century, transitioning from primary ecosystems to more diverse and mixed systems (Martins *et al*., 2022). In the Anthropocene, coastal dunes act as a natural defence against sea level rise and storm surges while providing ecosystem services. Mobile dunes, as a primary ecosystem, were destabilised due to human activities such as deforestation in mountains (Pipió & Gelabert, 1999a) or local settlements in coastal zones (Sampath *et al*., 2023), causing social, economic and political problems because of the invasion of crops, urban areas and infrastructures that the movement of sands can trigger (Santana-Cordero *et al*. 2016b).

Attempts to prevent dune mobility were enacted in many parts of the world between the 18th and 20th centuries (Brémontier, 1797; Cerón, 1872; de Ferrer, 1895; Mira, 1903; Fernández de Castro, 1905; Fernández de Castro, 1917; Guadarrama Sosa, 2023; Halevy, 2023). While dune afforestation throughout history has been a natural process occurring over decades, hundreds or even thousands of years (Provoost *et al*., 2011), this article addresses artificial dune fixation through pine tree planting. The management of mobile coastal dunes represents a crucial global challenge due to their vulnerability to human activities and their intrinsic ecological value. This article examines dune management in two key regions of Catalonia (Spain): the Montgrí and Begur dune plains, and the Llobregat delta. The general aim is to illustrate and compare historical interventions in the stabilisation of these sandy formations, which is crucial to understand the current state and dynamics of the mentioned ecosystems. Particular objective is to determine if the artificial fixation of dunes was always done to avoid the sand movement towards inland or to obtain forestry resources. In this context, the case of Catalonia, with Montgrí and Begur, and the Llobregat delta as case studies,

offers a unique perspective on the differences in territorial and environmental management of mobile dune systems.

Around 30 historical documents were consulted for the present study, enabling a detailed comparison of the case studies and clarification, for the first time, as to how and why the most extensive dune fields of Catalonia were fixed and whether dune fixation by pine trees was always carried out to slow the advance of the sands.

2. STUDY AREAS

2.1. Plains of Alt and Baix Empordà (Montgrí and Begur)

The plains of the counties of Alt and Baix Empordà (Upper and Lower Empordà) in Catalonia are fed by 4 rivers: the Muga and the Fluvià in Alt Empordà and the Ter and the Daró in Baix Empordà. These rivers are relatively short but with a steep slope, which favours a considerable erosion and transport of sediment along their course until they flow into the sea. The high historical availability of sediments and the natural barrier to longitudinal transport created by the Montgrí and Begur massifs, respectively, have generated two independent sedimentary compartments or coastal cells: the Gulf of Roses and the Bay of Pals.

The tramontane, a predominantly N/NW wind which frequently blows across the lands of the Empordà region, is optimal for the movement of sands as it is strong and dry. However, the transversal W-E orientation of the drainage network as it crosses the Empordà plains slows down the N-S transport of sands driven by the tramontane and considerably hinders dune development. Furthermore, the direction of the prevailing winds with respect to the coastline (oblique from the land towards the sea) does not favour the formation of dunes on the beaches, as the sands of the dry beach are pushed out to sea again during windstorms.

Following the same trend as the deltas mentioned above, the coastal arcs of the Empordà have progressively gained ground from the sea over the last millennium (Fig. 1) (Rambaud, 2005). Changes in sea level, climate and land use in the headwaters of the mountains that supply sediment to the rivers have played an important role in filling the alluvial plains. Montaner (2010) noted how the successive lagoon environments and littoral strands of land towards the sea are living testimony to this progradation of the deltaic plains. The formation of these plains and bays has been the result of natural and anthropogenic factors. The progradation of the bays is the result of periods of large sedimentary inputs which caused avulsions and alluvion depending on the intensity of the floods (Rambaud, 2005). The most generous volume of sedimentary input occurred from the Medieval Climate Optimum (9th-14th c.) until the end of the 20th century, a period during which the clearance of forests took place for their conversion into meadows and pastures and for coal production or mining. More recently,

marshes and lagoons have been drained for conversion to arable land (Marqués & Julià, 2005).

It was precisely during the Medieval Climate Optimum when the development of the dune chains on the seafront began as a result of deforestation of the headwaters of the river basin (Marqués & Julià, 2005; Montaner, 2010). The inland dunes of the Empordà plains also originate from the 14th and subsequent centuries (Marqués & Julià, 2005), coinciding with the diversion of the Fluvià and Ter rivers and the Little Ice Age (14th-19th century). The gentle slope of the land in the lower section of the river favoured the creation of multiple branches in the old mouth located in the Gulf of Roses, where huge amounts of sediment were deposited. Also in the 18th century, the final straightening of the last stretch of the river Ter was approved in order to combat the constant flooding of the Empordà plains, at which point the remaining branches ceased to be functional. It was at this time that the wind once again transported the materials brought by the rivers of the old northern branch of the Ter and formed the great sand mountains of Foixà, Verges and Gualta (Cros & Serra, 1990, 1993).

The last transformation of the Empordà coast occurred in the middle of the past century, when the territory underwent accelerated change due to land use and land cover modifications, both in the mountain areas and on the coast (Montaner, 2010). Traditional forestry and grazing activities were abandoned due to an increasingly pronounced rural exodus. As a consequence, the headwaters of the rivers Ter, Muga and Fluvià were rapidly covered by forest masses, which soon led to a decrease in sediment transport downstream of the river courses. The second half of the 20th century also saw the implementation of reservoirs and water transfers that affected the river Ter and contributed to reducing flooding in the Empordà plain (Montaner, 2010), but also the contribution of sand to the river mouths. Likewise, the arrival of mass tourism on the Costa Brava drastically transformed the natural landscape of lagoons and marshes on the seafront. The construction of marinas and tourist complexes by the sea, with no application of criteria of sustainability with the environment and coastal areas, also contributed to the decline of the coast (ICC, 2010). Unlike deltas, however, the lesser exposure of gulfs and bays has kept them more sheltered from coastal erosion.

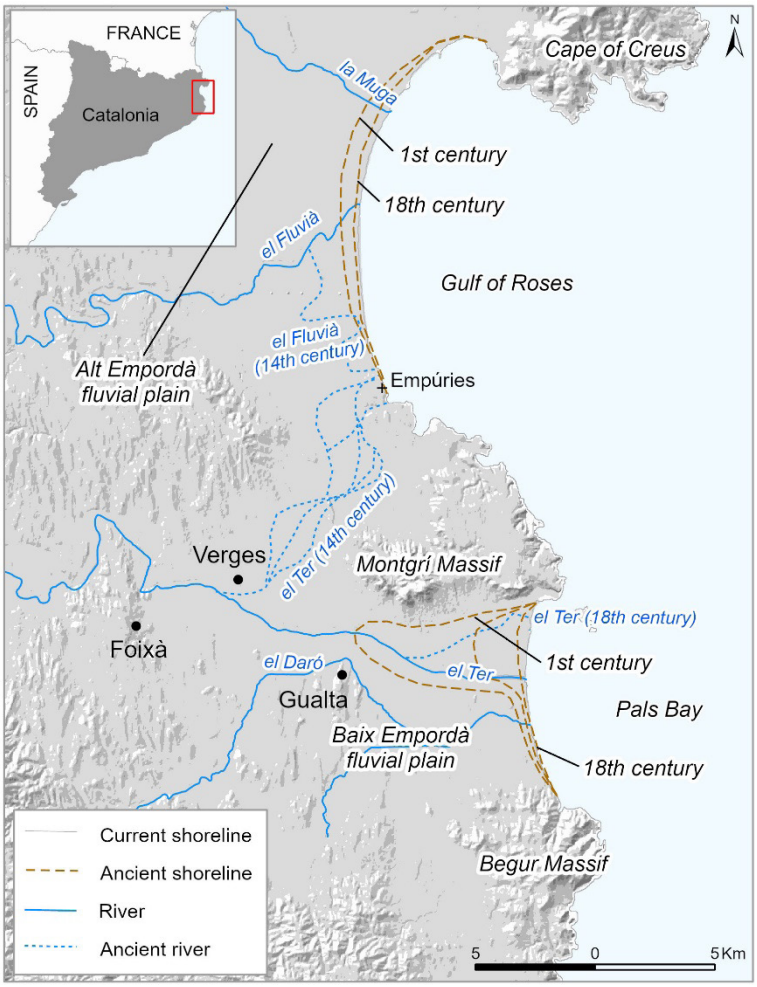

Figure 1. Evolution of the coastline and river courses in the deltaic plains of the Empordà.

2.2. Llobregat delta

The Llobregat delta covers an area of just under 100 km² and is surrounded by the hills and mountains of Serra de Collserola and Montjuïc to the north and the Garraf massif to the south. Its tidal regime varies between 20 and 5 cm (Marqués, 1984), and it is strongly influenced by SW and E/NE winds, generating coastal drift currents of approximately 30 cm/s (Puertos del Estado, 2023). It has a very low slope, only interrupted by dune ridges on the coastline, behind which lagoons and marshes form due to the lack of drainage towards the sea.

The river Llobregat rises in the Catalan Pre-Pyrenees, in the Serra del

Montgrony, and flows for more than 150 km before reaching the sea, forming a delta with a history of some 6,000 years (Gàmez *et al*., 2005; Marqués, 1984). The current delta sits on a set of ancient materials formed by Pleistocene sedimentation, whose front is located at a depth of 80 m and 12 km from the current coastline (Simó *et al*., 2005). Its most recent progradation began around 3,000 years ago, linked to the end of the Flandrian transgression and to human activity that increased the volume of sediments contributed by the river due to deforestation. The formation of successive dune and sand ridges has favoured the creation of extensive areas of lagoons and marshes throughout the delta.

Marqués (1984) analysed the historical evolution of the delta in depth and found that the first major expansion of the modern delta occurred between the 5th and 4th centuries BC (Fig. 2), coinciding with the onset of agricultural activities which increased sediment input. During the Visigoth period and the Early Middle Ages, the maximum volumes of sediment associated with the erosion of drainage basins due to forest clearance were recorded. These sediments formed sandy coastal bars parallel to the coast, confining areas of brackish ponds that were gradually filled by alluvial inputs. The progradation of the coast created new parallel bars, advancing the delta towards the sea. Roman remains indicate that the coastline in Roman times was between 2 and 3 km further inland than the present-day boundary (Marcos-Valiente, 1987).

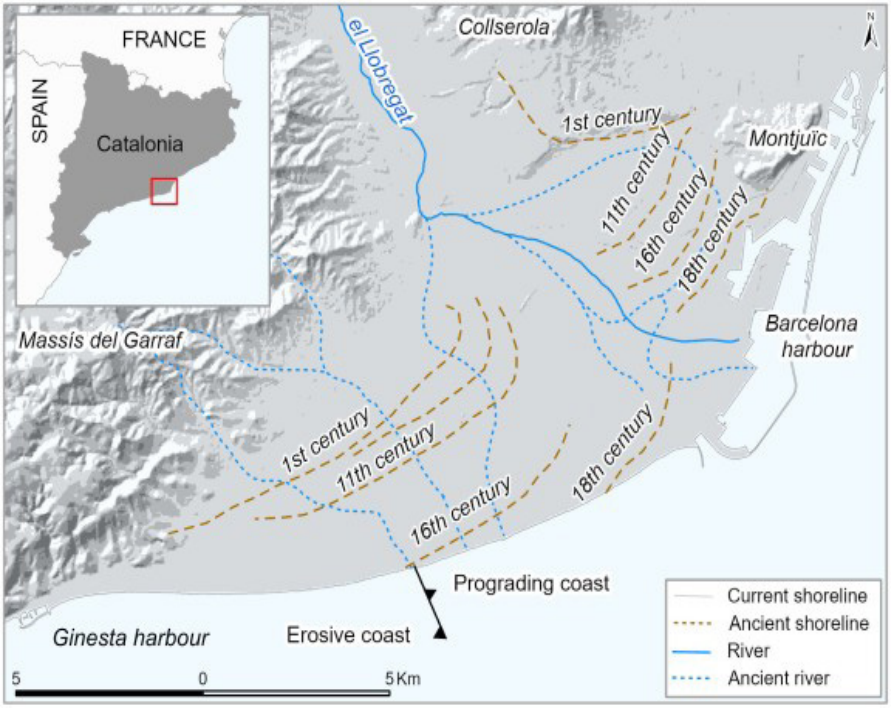

Figure 2. Evolution of the coastline of the Llobregat delta.
Source: adapted from Marquès (1984).

In recent decades, the Llobregat delta has suffered from settlement or subsidence of hydrostatic origin. Overexploitation of the delta aquifers caused subsidence of between 75 and 25 cm throughout the delta from the beginning of the 20th century until 1973 (Marqués, 1984). Despite the subsidence, the coastline shows areas of regression and progradation. The area between the mouth of the Llobregat river and the southern boundary of the municipality of Gavà is regressing due to construction of the port of Barcelona and canalisation of the final stretch of the Llobregat, which impede the longitudinal transport of sediments (Banchini *et al*., 2009; Marcos-Valiente, 1987; Marqués, 1984; McLachlan & Defeo, 2018). Shoreline erosion has also been attributed to construction of the Baells reservoir in 1976 as well as extractive activities along the river. According to Marcos-Valiente (1987), dune destruction linked to urban and tourism development is also a cause of coastal erosion.

Significant erosion of the beaches south of the port of Barcelona led to the Environmental Impact Declaration included in the Master Plan for the Port of Barcelona (BOE, 2005), which indicated the need for periodic artificial regeneration of the area (Perelló *et al*., 2019).

Llobregat, below the southern boundary of Gavà, is undergoing significant progradation (Banchini *et al*., 2009). The construction of the port of La Ginesta in 1986 has acted as a barrier to the longitudinal transport of sediment and has created a coastal cell between this port and the Port of Barcelona. The southern part of this cell receives a large amount of sediment transported by the drift current, which has resulted in a growth of between 20 and 25 m/year (Marcos-Valiente, 1987). According to Marcos-Valiente (1987) and Simó *et al*. (2005), the constant artificial regeneration of the beaches of Maresme and the continuous erosion caused by easterly storms could contribute positively to the sediment balance of the delta. The delta would no longer receive its main contribution of sediments from the river, but from a large part of these eroded sands from Maresme, which would end up overcoming the barrier of the Port of Barcelona and be deposited in the Llobregat delta.

3. Materials

For this research 29 historical sources were consulted (Supplementary Materials 1). They are divided into type of source as follows: technical or descriptive documents, cartography, vegetation or flora lists, photographs, and interviews. The most consulted type of source are the technical or descriptive documents, especially those from the *Montes* journal.

The *Montes* journal was created in 1868 and is one of the three oldest forestry journals in the world (https://www.revistamontes.net). Its papers were of fundamental importance as they allowed us to reconstruct the discourse about the mobile sand dunes of the Catalan coast and the details of the projects for fixing and reforesting them.

Authors of these papers talk about the threat of the sand dunes in terms of crop invasions and discuss the different plant species with which the fixation and afforestation might be done. They talk about similar experiences carried out in France, using them as a reference as dune fixation by pines in France was the first stabilisation of dunes known (Brémontier, 1797). Additionally, in some cases, they speak about dune measurements, the speed of annual movement and their distance from potentially invadable crops. Furthermore, in their discourses, economic profit is described as one of the motives for the actions taken, based on the potential for wood extraction and hence the conversion of unproductive lands (sand dunes) into productive ecosystems. Although many comments are made on dune afforestation, according to this source (period 1880-1908) no specific afforestation project took place. However, a report authored by Gil Sánchez & Pardos Carrión (2008: 138) states that the dunes of the Empordà were afforested in 1895.

Historic maps were also consulted, facilitating an overview of Llobregat delta coastal fringe land covers. The *Mapa Geológico y Topográfico de la Provincia de Barcelona* (Geological and topographic map of the Province of Barcelona) dates from 1891 and was created by Eduardo Brosa at a scale of 1:40000. The three other historical maps show the Castelldefels coast in 1926 (two maps at scales of 1:2000 and 1:5000) and 1930. These latter maps have topographic measures of the coastal dunes, as well as details of the crops behind them, confirming these two land covers for the indicated years.

4. METHODS

The aforementioned documents have served to georeference, through cartography, technical work, geographical descriptions and oral testimonies, the exact location of the dunes and their characteristics in the past and throughout history to the present day. This has allowed us to identify the chronology of the territorial transformation and its specific causes.

Following methodological resources described by Santana-Cordero (2021), historical sources were gathered for subsequent comparison with the current state and to generate new data. To this end, the historical documents consulted were subjected to a detailed examination through an analysis of the archival texts in order to integrate information that is not strictly spatial into the spatial plane. As far as the historical cartography is concerned, an interpretation was carried out using the legends and texts that accompanied these maps, when available.

The spatial data varies in several key dimensions: type (such as maps, aerial photographs, and satellite imagery), nature (including historical records and images), time frame (ranging from archaeological or prehistorical to contemporary), and thematic classification. Santana-Cordero (2021) described an integrated approach that addresses these variations. Primarily, the integration of temporal data is crucial for merging sources from different historical periods. This

integration is necessary to construct comprehensive timelines that facilitate the analysis of data over extended periods. This approach enables the identification of trends and trajectories in landscape changes spanning decades or even centuries. Additionally, the integration of multiple types of spatial data (such as historical maps, topographic maps, aerial photographs, and satellite imagery) is essential. This multi-type integration allows for the combination of a diverse array of documents, enriching the analysis and understanding of spatial data.

5. RESULTS

5.1. Plains of Alt and Baix Empordà (Montgrí and Begur)

The Empordà area is home to the most extensive dune fields in Catalonia. These are the large climbing dunes of the Montgrí and Begur massifs, which in the past formed a mixture of mobile dune fields of parabolic and transgressive dunes. These sand mountains are the largest and best preserved dunes on the Catalan coast, which were stabilised with pine trees at the end of the 19th century to prevent their advance from covering villages and crops (Artigas, 1885; de Ferrer, 1895). The dunes of St. Martí d'Empúries (Fig. 3) were also stabilised in the same period to prevent their advance. The formation of these large dunes is due to the strong tramontane winds, which blew parallel to the coast and transported the sands brought by the river Ter for centuries, thus forming dunes over 100 m high.

In the 19th century, with vineyards already planted on part of the sands, the need arose to plant stone pine (*Pinus pinea*) and maritime pine (*Pinus pinaster*) on the 'flying sands' of the coast and Aleppo pine (*Pinus halepensis*) on the 'bare' slopes (Artigas, 1880). Along the same lines, Artigas (1885) highlights the following testimony: «Mr Quintana has fixed these dunes by means of marram grass (*Ammophila arenaria*) and sowings of maritime and stone pine». A large part of the dunes in question were privately owned, with Aleppo pine as the dominant species and maritime pine as a subordinate species in several places. To combat the movement of the sand, which threatened land and houses in the village of St. Martí d'Empúries, live hedges of tamarisk (*Tamarix gallica*) were planted, although they were not entirely effective.

Marram grass is the most abundant plant, and 40 years earlier (in 1840) it was used by the locals to stop the sand along with the century plant (*Agave americana*) and others, while on the top of the dune stone pine trees were planted. The road from Torroella to l'Estartit ran the same risk of being buried and would have been out of service if the dunes had not been replanted. The main plants in an inventory made in the dunes were: marram grass (*Ammophila arenaria*), sea daffodil (*Pancratium maritimum*), *Ononis antiquorum*, *Ononis natrix*, *Echinophora spinosa*, *Tenerium capitatum*, *Euphorbia paralias*, tamarisk (*Tamarix gallica*), sedge (*Ciperus schoenoides*), *Helichrysum stoechas*, sorrel (*Rumex acetosa*), *Microlonchus salmanticus*, *Sideritis hirsutus* and mugwort (*Artemisia glutinosa*) (Artigas, 1885).

The actions to be taken needed to be planned before repopulation. Holes

were dug into the sand, and decisions taken on which seeds to plant and how they should be placed, along with other materials that would help the plant grow. After 6 or 7 years, pine would dominate the area. The work to be undertaken was of some urgency given the closeness of some dunes to the Rexach plot (Artigas, 1885).

The threatened crops in the area were grapevine and olive on the outskirts of Torroella de Montgrí. The same sources indicate that these interventions would convert the coast into an area suitable for bathing all year round except when the strong NNW winds were blowing. These dunes were advancing at a rate of around 5 m/year. The roads from Begur to Pals, Regincós and Palafrugell could also have been affected by the movement of the sands (Artigas, 1896ab). The Torroella dunes were between 3.5 and 18.3 m high (Puig & Valls, 1897a).

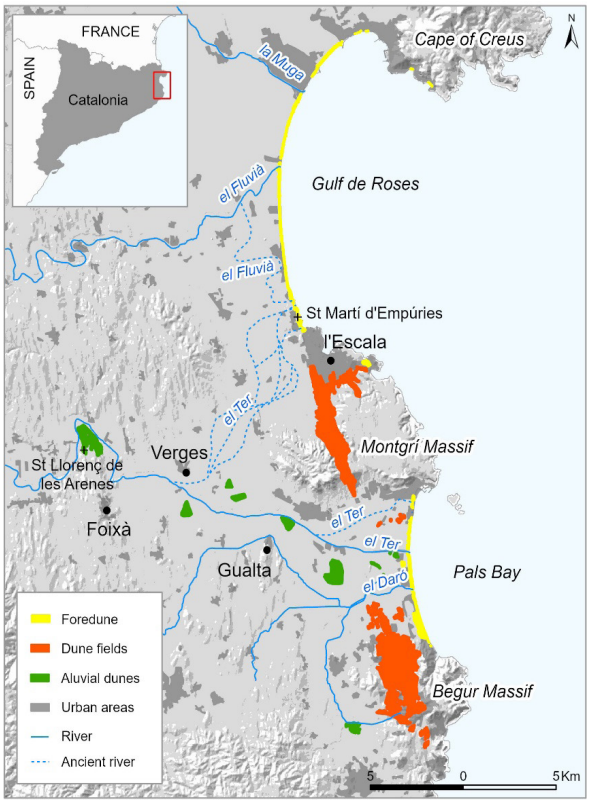

Figure 3. Dune systems in Empordà. Source: adapted from Cros (1987), Cros & Serra (1990, 1993), Marquès *et al*. (2011), and Sainz-Amor & Julià (1999).

5.1.1. The continental dune of the Montgrí Massif

The dunes in the interior of the Montgrí Massif start from the Greco-Roman settlement of St. Martí d'Empúries, from where they extend some 10 km

southwards until they reach the height of Torroella de Montgrí (Fig. 3). Along its course, the dunes had an average width of 500 m and reached their maximum width of 1 km on the northern slope of the massif, shortly before reaching the pass known as Coll de les Sorres.

The advance of the dunes buried fields, roads, fountains and houses, which led the government to fix it with vegetation.

The formation of the Montgrí continental dune took place starting in the 14th century and continued during the following centuries, coinciding with the diversion of the river Ter (1303) and the Fluvià (1740), with the lowering of sea levels during the Little Ice Age (14th-19th century) and with periods of intense deforestation in the river basins of the Alt and Baix Empordà plains (Marqués & Julià, 1983, 2005). The change in the position of the Ter towards the south of the Montgrí massif was a decisive element in the dune formation of the Empordà plains. According to Marqués *et al*. (2011), the disappearance of this sedimentological barrier would have activated the dune development that covered the Greek and Roman city of Empúries (currently, St. Martí d'Empúries).

Figure 4. Mobile dune field between St. Martí d'Empúries and Montgrí Massif at the end of the 19th century. Source: de Ferrer (1895).

The new trajectory of the lower reaches of the river courses (Fig. 4) was largely due to an increase in flow and sediment supply, as well as some anthropic channelling operations. The abundant sedimentation of past times in the lower reaches of the Ter and Fluvià rivers and the lowering of the sea level during the Little Ice Age once again favoured the tramontane in terms of activating the sands and forming dune fields of significant dimensions in the area (Marqués *et al*., 2011). The abandoned meanders of the river Ter provided sediment for the dune formations that developed thanks to the abrupt topography of mountainous areas in, for example, Montgrí, Begur and Foixà. Activation of the sands buried the old village of Sidillà and many of the buildings of Sant Llorenç de les Arenes (Fig. 3), both located in the municipality of Foixà (Cros, 1987; Marqués *et al*., 2011; Montaner, 2010).

The prevailing NNW winds, parallel to the coast, usually reach speeds of 100 km/h, although on some occasions they exceed 200 km/h (Meteocat, 2024). The transport or longitudinal current is from NNE to SSW (Puertos del Estado, 2023). Easterly storms are occasional and can occur with some virulence, contributing to the occasional replenishment of sand on the beaches. With these coastal dynamic conditions, it is unsurprising that the activation of wind transport towards the land was not effective with the transversal layout and the northern location within the coastal arc of the rivers Ter and Fluvià (Fig. 4).

The continental dune of Montgrí is still covered by a thick blanket of pine trees that makes it difficult to distinguish its original extent and morphologies with the naked eye.

The first documents that mention the issues caused by the sands date back to the 17th century, but it was not until the end of the 19th century that the need for action was raised. The first official news that states the problem of the advance of the sands and proposes stabilisation by means of pine trees was the report on a field trip carried out by third-year students of the Special School of Forestry Engineers (Pipió & Gelabert, 2008, 2013). This document was written in 1885 by Primitiu Artigas, the teacher in charge of the field trip, and was submitted to the Advisory Forestry Board, a body that rejected the proposal. Seven years later, in 1892, the Forestry District of Barcelona, Girona and the Balearic Islands took up Artigas' idea and commissioned a preliminary study of the dunes of the Gulf of Roses to the engineer Javier de Ferrer. The Montgrí dunes were fixed between 1896 and 1910, in what was to be the first major forestry engineering project in Spain. The Dunes Commission of the Province of Girona was created for this purpose, directed by the forestry engineer Andrés Llauradó. During this period, the responsibility for the fixation work alternated between different people and administrations. Over the course of the 14 years which the works took, Javier de Ferrer, Rafael Puig and José Reig coordinated the dune stabilization project which took place in an area that initially formed part of the Forestry District of Barcelona, Girona and the Balearic Islands and subsequently of the Hydrological-Forestry Division of the Lower Ebro Basin and the Eastern Pyrenees (Pipió & Gelabert, 1998, 1999b).

Javier de Ferrer was in charge of designing and directing the start of

the stabilisation, with the strategy to be employed and the actions to be taken published in a document in 1895 titled 'Proyecto de Fijación y Repoblación de las Dunas Procedentes del Golfo de Rosas' (Dune Fixation and Repopulation Project of the Gulf of Roses). The more than 11 km in length and 342 ha of surface area occupied by the dunes were classified by de Ferrer into four sectors according to their morphological characteristics and the tasks to be carried out.

Figure 5. Dune fixation work in St. Martí d'Empúries, l'Escala, around 1896. In the background, barchanoid morphologies perpendicular to the coast, caused by the tramontane, can be observed. Source: Josep Esquirol Collection, Municipal Archives of l'Escala.

The first sector stretched from St. Martí d'Empúries to l'Escala and consisted of uniform lines of dunes running parallel to the sea. These stretched between 50 and 200 m inland until reaching the farmland, which would have been much wider without the containment work carried out by the farmers themselves using reeds and tamarisk trees. This area was the first stretch of land to be worked on, and it was carried out through the artificial construction of counter-dunes designed to prevent the advance of the sands thanks to their arrangement parallel to the coast and their curved shape in the direction of the sea (Fig. 5). Once the artificial dune was established, it was stabilised by creating alignments perpendicular to the prevailing winds.

The second sector stretched from the centre of l'Escala to Torre Ferrana and was characterised by a blanket of sand a few metres thick, partially covered by spontaneous vegetation and vines (Fig. 6), which alternated with rows of marram grass (*Ammophila arenaria*) aimed at fixing the dunes. Farmers had long

taken advantage of sand encroachment to grow crops, since if the sands were transported in the direction of the tramontane, the bedrock would be exposed and the land would be barren. Near Casa Nova (Fig. 7) stands a single parabolic dune morphology that occupied an area of more than 3 ha and was about 10 m high.

Figure 6. Dunes partially stabilised by shrub vegetation and vines near Torre Ferrana. Source: Municipal Archive Collection of Torroella de Montgrí (author and date unknown).

The third sector stretched from Torre Ferrana to Coll de les Sorres (Fig. 4), an area of public property where the sands moved freely without vine-based plant fixation (Fig. 7). On their ascent up the northern slope of the Montgrí Massif, the dunes were able to overcome rocky obstacles located more than 100 m above sea level. The rampant sands formed parabolic dunes that ranged in size from just over half a hectare to nearly 4 ha. The smallest were about 7 m high, and the tallest over 20 m.

Figure 7. Free parabolic dunes in the third sector before being fixed with pine trees. In the foreground, the beginning of fixation with *Ammophila arenaria* can be seen. Source: Municipal Archive Collection of Torroella de Montgrí (author and date unknown).

The fourth and final sector began at Coll de les Sorres, from where it descended the mountain until reaching the centre of Torroella de Montgrí (Fig. 4). In this sector, the whole of the dune formed a colossal crescent with a line of advance of almost 1 km and a maximum width of more than 500 m at the pass. This dune comprised several parabolic dunes that were advancing in the same direction. In this sector, the sand mountains are at their maximum, ranging from 10 m in the shallowest areas to 30 m in the deepest. Figure 8 shows the dune tongue advancing in a southerly direction from Coll de les Sorres.

Figure 8. View from Coll de les Sorres to the south, on the Baix Empordà plain. In the foreground, individual specimens of *Ammophila arenaria* can be seen growing on the sides of the parabolic dune, in the areas least exposed to wind erosion. Source: Municipal Archive Collection of Torroella de Montgrí (author and date unknown).

Each sector was semi-stabilised using marram grass (Fig. 9) which, once rooted, was replaced by shrub species in order to completely stabilise the mobile sand layer. For this purpose, stone pine (*Pinus pinea*) was used, which is well adapted to sandy soils, although Aleppo pine (*Pinus halepensis*) and maritime pine (*Pinus pinaster*) were also planted.

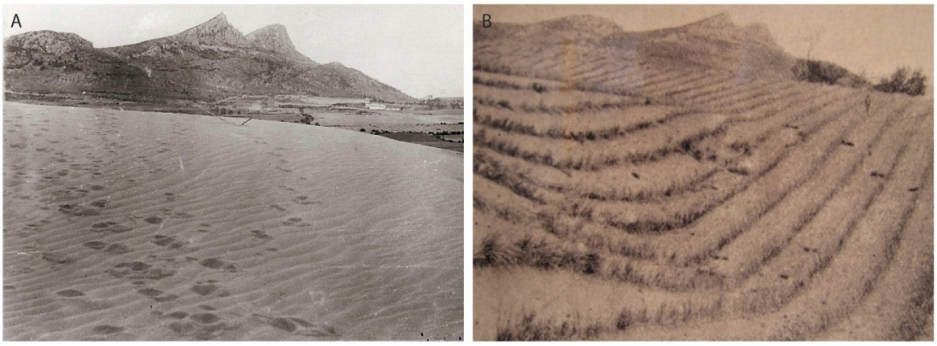

Figure 9. Dune fields on the southern slope of Montgrí Massif before (A) and after the fixation works (B). Source: Municipal Archive Collection of Torroella de Montgrí (author and date unknown).

5.2. Llobregat

Traditionally, the pine forests of the Llobregat delta have been considered to have a recent, artificial origin, with the supposed aim of preventing the movement of lands from burying the crops of the delta. Although everything suggests that the origin of the pine forests is artificial, Valverde (1998) compiled historical documents that contradict the recent planting of pine forests and attribute their existence exclusively to forestry exploitation and the improvement of sanitary conditions. The following paragraphs in this subsection on the Llobregat delta refer to the historical reconstruction carried out by Andrés Valverde in 1998 in an article published in the journal *Spartina* (Valverde, 1998), which gives an idea of the evolution of the stone pine (*Pinus pinea*) and Aleppo pine (*Pinus halepensis*) groves which largely grow on dune ridges and alluvial deposits in the delta.

The first references that corroborate the existence of a large pine forest in the delta date back to the 16th century in a cartographic representation of the old Barony of Eramprunyà (Fig. 10). Between the 16th and 19th centuries, numerous leases and court documents have been collected on disputes between settlers and landowners for the exploitation of pine forests that were spread over a large part of the delta and extended down close to the sea. In addition, the planting and logging of pine trees in the delta area is also recorded in corresponding calls for tenders, regulations, plans and censuses. These documents include the *Plan de la Gran Pineda* of 1746, the *Convocatoria de la Baronía de Eramprunyà* of 1755, the survey of Francisco de Zamora of 1789, and the *Diccionario Geográfico-Estadístico-Histórico de España y sus Posesiones de Ultramar*, by Pascual Madoz, drawn up between 1846 and 1850.

Figure 10. Reproduction of the map of the Barony of Eramprunyà from 1590. What are understood to be the limits of the pine forest are shown by the dashed red lines. Source: Collection of the Centre d'Estudis de Gavà.

During the 18th and 19th centuries, calls were made for the planting of pine trees to solve the health issues that the delta area presented in the interior of the extensive stretches of sand that separated the land from the sea. Also in the 19th century, land was ceded for cultivation, with the aim of drying out the land and combating malaria. In the same century, there is evidence of pine plantations on the first strip of coastline, when the forestry engineer Hilarión Ruiz Amado, in 1893, recommended in a publication in the journal *Montes* that pine trees should be planted there and that the sands of the surface dunes should be extracted and used for cultivation. The quantities of sand brought from the first strip of coastline to the marshes must have been such that loaders were even used, running on tracks fixed to the ground installed for that purpose. Amado's testimony is the only one that suggests the possibility that the cultivated land was buried by mobile sands, in the same way that, as he himself says, happened in Roses (Alt Empordà plain) and Bordeaux (Gascony heathlands). To prevent this from happening, he proposed the planting of pine trees after sand extraction. At this point, it should be noted that the invasion of crops by the dunes had not occurred. Dune fixation is only proposed as a preventive measure that would also serve for forestry exploitation.

At the end of the 19th century, there are also various references to the planting of pine trees on the dunes located at the inner end of the beach. The Medical Congress of 1888 and the publication of the book *El saneamiento del Llobregat* (The sanitation of Llobregat) bear witness to the need to use the sand from the dunes to fill in lagoons and marshes and thus combat malaria. The same texts suggest that pine trees should subsequently be planted in the sandbanks for forestry use, as it is warned that this would be the only possible activity with an economic return in the dune area. Finally, the 1868 Development Law encouraged the covering of marshland areas with sand and promoted the planting of pine and eucalyptus trees by landowners, who were exempted from taxes if they converted the land into woodland.

In none of these documentary sources has any official project been found that proposed or assumed the work of fixing the dunes with pine trees with the aim of preventing their advance inland. This suggests that the coastal dunes of the delta did not present relevant mobility problems that affected the interests of the local communities. Rather, the burial of the areas close to the dunes was promoted to eliminate the marshy areas and promote arable land. In the second decade of the 20th century, the Marshland Drainage Law (Gaceta de Madrid, no. 208, 27 July 1918), promoted by Francesc Cambó, resulted in the elimination of more than 2.5 km of marshland between Castelldefels and Sitges (Cambó, 1919). Marshland draining was considered a social good and, to promote its efficiency, the dried lands became the property of the promoter.

Despite the proven alteration of the dunes over the last few centuries, even at the end of the 19th century and well into the 20th century there were still large dune formations of over 10 m on the SW coast of the delta (Fig. 11). Pascual Madoz leaves a record of the dunes of Castelldefels when he refers in his Dictionary to the fact that «the land is of good quality except for the part near the sea, where

it is loose and sandy, on whose coast the strong winds that blow continuously have formed a range of sand mountains that seem to be marking the limits of the waters of the Mediterranean» (Madoz, 1847). In addition to this text, the geological map of the Province of Barcelona drawn up by Almera and Brossa (1891) shows precisely how the SW tip of the delta was occupied by an area of dunes at the end of the 19th century (Fig. 12). However, according to Chevalier (1928) and Sennen (1928), in the 1930s the dunes of the delta were large in size at its western tip, in Sitges (Fig. 11).

Figure 11. Dunes in the Llobregat delta at the beginning of the 20th century. Source: Institut Cartogràfic i Geològic de Catalunya (author and date unknown).

At the beginning of the 20th century, the Llobregat delta was anthropized through various land uses, including agriculture and forestry. Sources such as Madoz (1847) point to forestry as the main economic activity in the area. For its part, agricultural use, which had been going on for centuries, acquired greater importance with the passing of the aforementioned Marshland Drainage Law in 1918. It was in this context that the delta's deep aquifer system began to be exploited, with subsequent subsidence of the delta associated with aquifer overexploitation. However, according to Santana-Cordero *et al*. (2016), these anthropic transformations on the delta meant that in the years 1946-47 pine forests were the dominant land cover with an extension of 53.79% of the established study area (146,000 ha). During the same period, agricultural was responsible for 28.54% of the land cover.

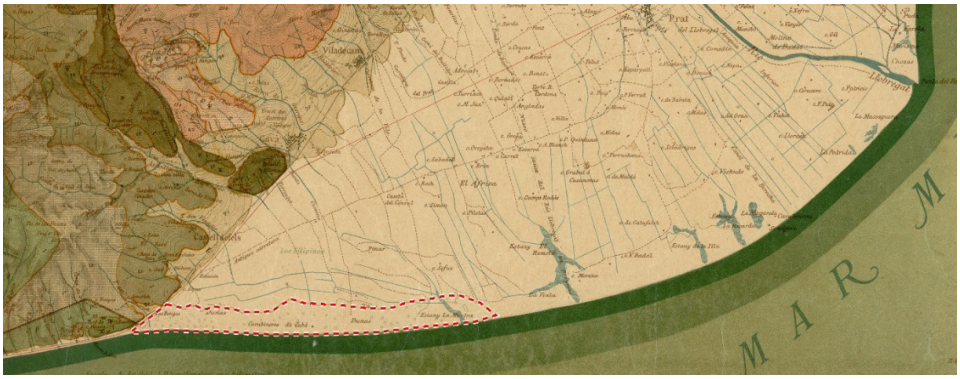

Figure 12. Part of the geological and topographical map of the Province of Barcelona showing a detailed outline of the capital. Within the dashed red lines is the section where the dunes located in the western part of the delta are mapped. Source: Almera i Brossa (1891).

During the 1930s, the possibility of establishing spas and places for leisure and recreation on the beaches of the Llobregat delta began to be considered. Urbanisation projects in this regard were put forward by the company Baños de Castelldefels S.A., which in the 1920s began to open roads towards the beach and build on the dunes (Fig. 13). This same company obtained the concession to build villas and single-family houses throughout the area following the diffuse urbanization model. From then until 1945, a significant part of the Castelldefels dune area disappeared and in its place rows of single-storey constructions were built (Fig. 14). This coincidence leads us to believe that much of the material used in the constructions may have been extracted from the large dune formations that the beach used to contain.

Figure 13. Castelldefels bathing area at the end of the 1930s. Permission for reproduction granted by Andrés Valverde.

Photographic documents from the company Sistemas Aéreos Comerciales Españoles (SACE) from 1960 show that by the second half of the last century this sector still had dunes of some considerable size (Fig. 14). In contrast, the Castelldefels sector was partially urbanised or dominated by pine forest.

Figure 14. Llobregat delta in July 1960. Source: Institut Cartogràfic i Geològic de Catalunya: SACE (Sistemas Aéreos Comerciales Españoles) photographic collection.

Although urbanized land in the mid-20th century is almost anecdotal in size (1.74%) compared to other land covers, its presence would subsequently increase exponentially along with population growth (Santana-Cordero *et al*., 2016). Up to this point, we can speak of the development of a pre-urban phase.

During the first half of the 20th century, we find bibliographic and cartographic references to the dunes still present in the south of Castelldefels. In his 1928 book *El paisaje de Cataluña* (The landscape of Catalonia), Marcel Chevalier reported that dunes were to be found in the Llobregat delta, to the south of Castelldefels, and considered them to be of some importance (Chevalier, 1928: 140). The Castelldefels dunes must have been a significant element for Chevalier given that he records them in a cartography of the Llobregat deltaic area that he himself drew up (Fig. 15).

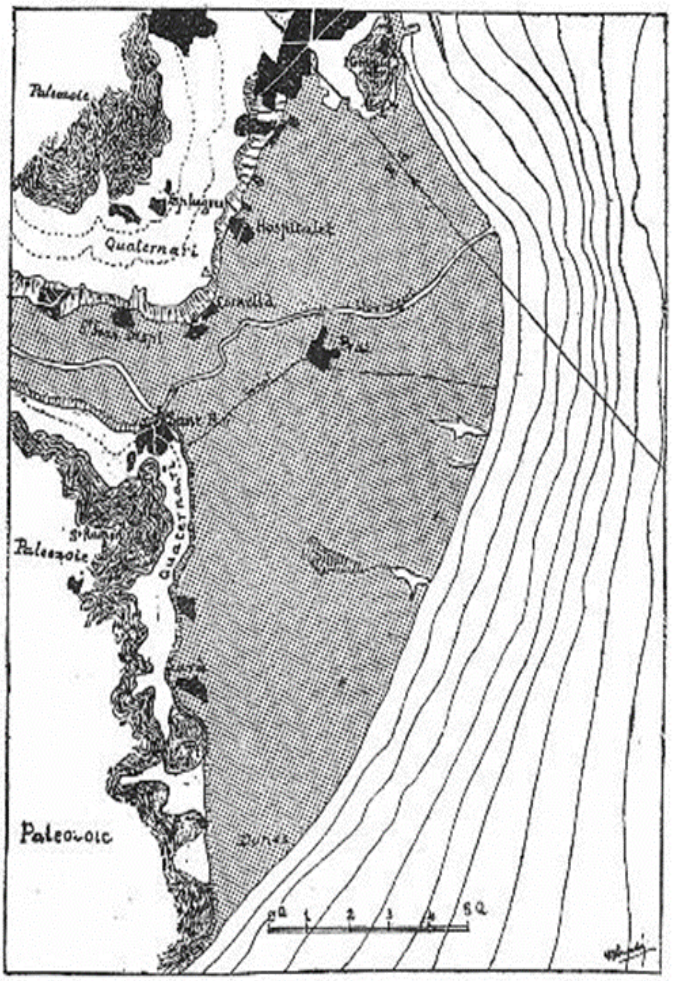

Figure 15. Geological map showing the existence of dunes in the westernmost part of the Llobregat delta. Source: Chevalier (1928).

In the same year, a publication by Sennen (Sennen, 1928) titled *La flora de la duna barcelonesa de Castelldefels* (The flora of the Barcelona dune of Castelldefels) also confirmed the existence of dunes in the municipality of Castelldefels. This author attributed a height of the dune morphologies of no more than 10 m and reported the presence of species typical of beach-dune systems. Sennen specified that beyond Castelldefels the beach sands did not form dunes and, furthermore, reported on the extraction of aggregates by train wagons which were continuously transporting beach sand inland for various uses and destinations.

Two years later, one of the plans dating from 1930 for the terracing of the maritime-terrestrial zone (Fig. 16) mapped a large area of dune ridges where the

contour lines give the highest mound a height of over 10 m. It was precisely this dune field that extended towards the Garraf massif, to the west, in the form of a climbing dune that reached the foot of Torre Barona, a building dating from 1583 and situated 50 m above sea level (Valverde, personal communications). The continuity that this dune should have had with the dune area of the beach had evidently been interrupted by the construction of the railway line that connected Barcelona city with Vilanova and Valls, inaugurated in 1881, and later by the extension of the connection from the Gran Vía de las Cortes Catalanas to Castelldefels, which took place in the 1930s.

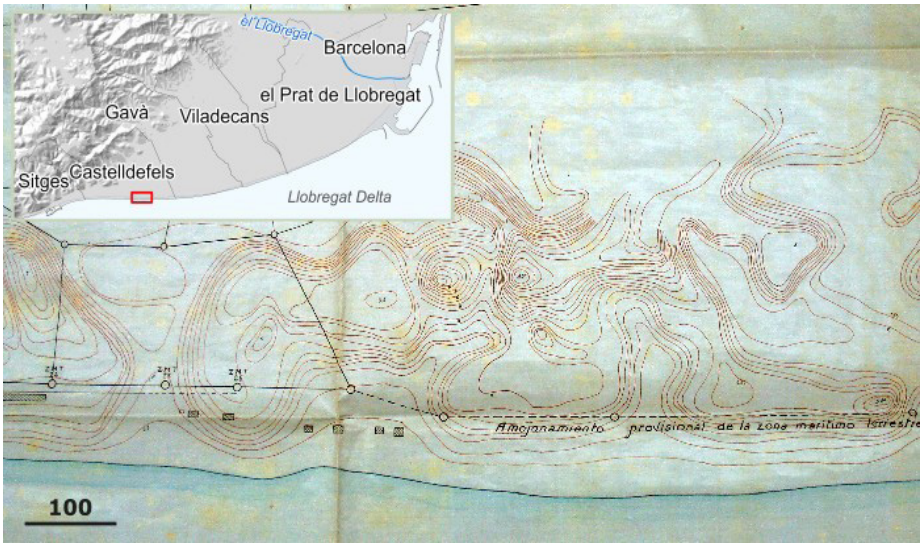

Figure 16. Part of the cartography made by Baños de Castelldefels S.A. as part of the 1930 Public Works file to delimit the maritime-terrestrial zone prior to the urbanization phase. Source: Baños de Castelldefels S.A. (1930).

It has not been possible in this study to date the exact moment when these large dunes disappeared from Castelldefels. However, two observations can be made in this respect: (1) no public works project fixed this area with pine trees; and (2) these dunes do not exist today as the site has an almost flat topographic profile. The most likely hypothesis suggests that these dunes would have been used as construction material for the urban expansion of Castelldefels beach. The construction of *Baños de Castelldefels* would have marked the beginning of the emergence of tourism in the municipality, and these buildings would mostly have been constructed on the natural space of the dunes. The builders could have used the sandy materials to carry out the project. In this sense, Ruiz Amado, already in 1893 suggested in a publication in the journal *Montes* that part of the sand from the dunes that was to be used to bury marshes should be reserved for the

construction of houses.

The coastal sediment dynamics were also altered by the construction of the ports of Barcelona and La Ginesta, located in the centre and west of the delta (Fig. 17), causing sediment accumulation to the north of the infrastructures and erosion to the south and destabilizing the dynamics of the coastline and the contribution of sediments to the beach-dune systems in the area.

In line with the extraction of aggregates, other oral testimonies show the use of dune sands as building materials. Andrés Valverde, a biologist and expert on the Llobregat delta, collected a number of testimonies that left a deep impression on him. The parish priest of Santa Maria de Castelldefels told Valverde that the church had been erected in 1909 thanks to the sands that made up the dunes of the same municipality. Another resident of the village also told him how, with her friends, she used to slide down the large dunes on the slope of the mountain that ascends to Torre Barona. Shortly afterwards, this climbing dune was fixed with pine trees to prevent it from advancing. The same biologist reported that at the end of the 20th century it was still possible to see the spectacular sight of the dunes under the pine trees. However, he also reported that when he visited the area a few years later he found only moving sands and uprooted trees. This coincided with the beginning of the construction of the Raconada flats and nearby buildings (Valverde: personal communications).

The pine groves of the delta occupy the first strip of the coastline of the municipalities of Prat de Llobregat, Viladecans, Gavà and Castelldefels and lie on dune morphologies and quaternary alluvial deposits, with a sandy texture and undulating orography. In fact, the pine groves are the last areas of the delta that remain unlevelled and conserve the original topography of the deltaic morphologies that constituted it. The urban growth of the second half of the 20th century eliminated a large part of the pine forests and fragmented the remaining ones (Fig. 14). Those that remain in the delta today on former dune morphologies have two distinct origins. While some areas have been planted with pine trees, as the aforementioned documents show, others have formed spontaneously in recent decades as a result of the expansion of the older inland pine forests. We are referring to some pine groves near the delta beaches, such as the pine grove on Remolar beach in Prat de Llobregat (Fig. 17).

With the arrival of the 21st century, the distribution of land cover has changed substantially, with artificial surfaces and forest and seminatural areas being the most representative according to Santana-Cordero *et al*. (2015, 2016) (47.54% and 31.55%, respectively). We can refer to this stage as the urban phase.

At the same time, natural protection has been incorporated into land use through the declaration of various protected status areas by the Government of Catalonia in 1997, which were subsequently incorporated into the Natura 2000 Network by the European Union in 2006 and currently constitute the Special Area of Conservation (SAC) Delta del Llobregat (ES0000146) with an area of 935.05 ha. A variety of important ecological values converge in this area which correspond to different habitats of Community interest such as stabilised and active dunes, coastal lagoons, and dunes with stone pine (*Pinus pinea*) and/or maritime pine

(*Pinus pinaster*), with the latter considered habitats of priority interest under the Habitats Directive (EEC, 1992).

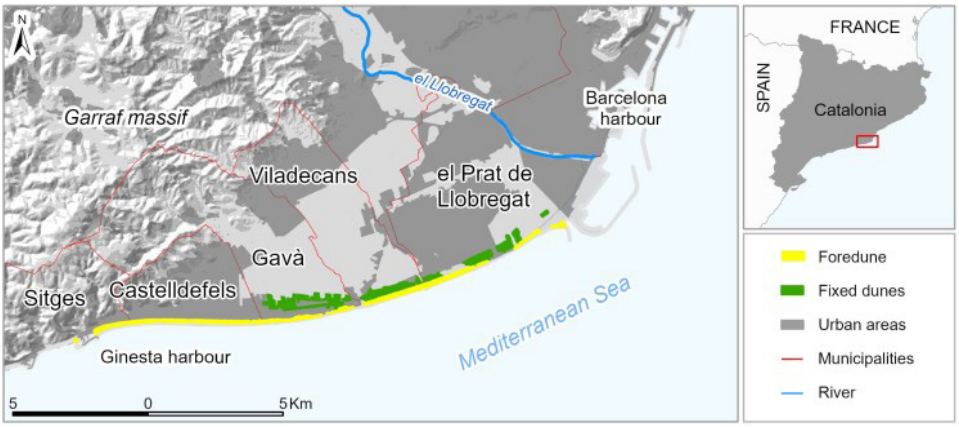

Figure 17. Present-day dunes in the Llobregat delta (Garcia-Lozano, 2019).

6. DISCUSSION

A case study is presented in this paper which shows that the appearance of pine trees on dune fields was the result of hundreds of years of management that responded to the differing economic and social interests of each moment rather than a single technocratic planning at a specific moment during that period, as generally occurs in most of the documented cases. The coastal dunes and sandy areas of the Llobregat delta have long been subjected to pine tree afforestation (Valverde, 1998). However, there is no evidence that the Llobregat delta pine trees were planted to halt the advance of dunes inland. In the Llobregat delta, unlike most of the pine tree plantations situated in sandy coastal areas, one of the intentions was to improve sanitation issues caused by marshland areas and, at the same time, extract an economic profit from the land. In fact, the large coastal dunes appear to have disappeared almost overnight, leaving no trace of their existence behind.

This case study contrasts notably with the other case study considered in this paper, namely the dune fields of Montgrí and Begur (Pipió & Gelabert, 1999a, 2013), as well as with other examples in Spain and other countries. Important dune fixation projects were enacted in Spain in, for example, the province of Cadiz, in Sanlúcar (Cerón, 1872) or Puerto de Santa María (Fernández de Castro, 1917), in Guardamar in the province of Alicante (Mira, 1903), in Portugal in the Leire region (Fernández de Castro 1905), and in France in the Gascony Moors region (Brémontier, 1797).

Today, the coastal dunes of the eastern flanks of the Montgrí and Begur dune fields have been completely built over and are now occupied by the urban centre

of l'Escala and the urbanizations that face seawards north of Begur massif (Fig. 4). In contrast, the large inland dunes have been fixed with pine trees. In the case of Montgrí, this dune fixation is extensively detailed in a technical report (de Ferrer, 1895), with the background to this case study described by Pipió and Gelabert (1998, 1999ab, 2008, 2013). However, in the case of the Begur dunes, no documents have been found in relation to a fixation project. The only valid documents in this case are two research works on their geomorphological formation or description (Cros & Serra 1990, 1993; Pallí & Roqué, 1990) and their landscape evolution (Pintó *et al*., 1997).

Other dune areas in Catalonia which were fixed with pine trees were eventually used to build second homes, golf courses or camp sites. These include Pals, Platja d'Aro (Castell-Platja d'Aro), Blanes, the Llobregat delta, Salou and Cambrils. The fixation actions were enacted in the first half of the last century to impede sand mobility. Unfortunately, no studies have been conducted on most of these systems and it is therefore impossible to comment on their origin and evolution. We will therefore concentrate on discussing the artificial origin of the pine groves on the dunes of the Llobregat delta, which this and previous works (Valverde, 1998) show to have a much earlier origin.

The stabilization of mobile dunes through tree planting was a widely used practice to impede the movement of sand inland (Dean & Delrymple, 2004; Klijn, 1990; Nordstrom, 2000; van Der Meulen & Salman, 1996) and to protect cropland from strong sea winds and the entrance of sand (Nordstrom, 2013). In this regard, the first major dune afforestation operation was undertaken at the end of the 18th century in the Gascony Moors region (Brémontier, 1797) to impede large transgressive dune fields invading lands in the southwest of France.

It should be noted that this problem (the invasion of anthropic installation by 'flying sands') has been seen in other parts of the Iberian Peninsula and indeed around the world. As reported by Cerón (1872), to deal with it, farmers in the province of Cadiz, in the coastal sector between Sanlúcar de Barrameda and Rota, tried planting in the dunes with great success. This practice, was carried out as described below (Cerón, 1872):

> The procedure is as follows. After forming a deep area of level ground enclosed and protected by a barrier built with the extracted sands, inside and all around a ditch with a depth that reaches the same level as the groundwater is dug. Sometimes other ditches can be made crossing the area of flat land, so that the water that originates from there and rainfall can flow through them. These waters flow and converge towards a common centre, which consists of a factory-made well, extending out from which, with the appropriate inclination, is a series of conduits which transport the waters to the sea from as high as 7 m. The most common thing is to leave the ditches uncovered, but sometimes they are filled with rubble or angular stones so that the water runs through the gaps between them.
>
> Despite the delicacy and care that these operations require, the so-called 'sand planters' have the knowledge that extensive experience has given them to develop their plot or plantations. Once these preparations have been concluded, the first thing to do is to secure the loose sands of the enclosure so that they do not collapse inwards, obstructing the ditches and raising the level of the ground again. For this purpose, they plant vines and fruit trees (peach, plum, peach, etc.) all along the

> outside of the enclosure right up to the top, and on the inside reeds and century plants, arranged neatly in parallel rows. In this way they not only secure the sands, but also produce a large quantity of varied and excellent fruit.
> After these preventive operations have been carried out, the inner surface of this newly generated plot is cultivated, necessarily varying depending on the nature of the land and other conditions. These plots, known as 'navazos' can be divided into three classes. The first comprises those which are influenced by the ebb and flow of the sea and are therefore called 'tidal navazos', the second those which are not affected in this way but which have drainage to the sea, and the third those which do not offer either of these two circumstances.

In the province of Cadiz, Fernández de Castro (1917) also claims that the city of Puerto de Santa María was being affected by the dune that appeared at the mouth of the river Guadalete. According to the same author, the municipality of Sanlúcar and a few jealous owners, after some careful deliberation, agreed to copy the example of the first 'sand planters', but this time planting with stone pine (*Pinus pinea*). They evidently chose the right moment to plant and in the perfect year, as the results apparently exceeded all expectations. According to Cueto (2001), in Cadiz province, hundreds of hectares of pine plantations were replaced a few decades after their planting with cropland, some illegally. The same author describes how, during the first half of the last century, efforts were made to make an economic profit from the plantations by harvesting the pine nuts or felling the trees for ship construction. The final transformation process, however, comprised the conversion of many acres of plantations into urbanized land which today still conserve scattered specimens between the constructions. Other stretches of sand, which previously had no vegetation, are today covered with pine trees, mastic trees, mock privets and other shrubs, and herbaceous plants which serve for livestock.

Another example can be found in the reports of Mira (1903) about the dune fields of Guardamar in the province of Alicante, between the headlands of Santa Pola and Cervera. According to this author, the inhabitants of Guardamar had been fighting since long into the previous century against the 'flying sands' of the 816 ha of dunes which had buried an entire block of houses and were «threatening to bury the entire village if appropriate actions were not taken rapidly».

In Portugal, an unbroken 127 km-long stretch of coastal sand with barely any vegetation was causing major problems in the region, as is clear from the following comments (Fernández de Castro, 1905):

> It is a true region of dunes, whose damaging action is felt from the very beginning, preventing the waters that flow from the interior to the ocean from exiting, invading the ancient lacustrine deposits and even extending as far as the ancient dunes of the quaternary period, on which the Leira pine forest sits.

According to Castro (1905), some 7,361 ha were stabilized by works which began in 1888.

Similar cases are recorded on the other side of the Atlantic. According to Guadarrama Sosa (2023), the dunes of the city of Veracruz (Mexico) were a coastal

ecosystem that had to be eliminated because of its barrenness and insalubrity (it was associated to the high rates of yellow fever) and because it was an obstacle to the city's modernization. In this case, the strategy was to construct walls to contain the sands (Guadarrama Sosa, 2023).

In another part of the world, it has been reported how the coastal sands of Gaza, during the period of British colonial rule, were subjected to afforestation and urbanization processes by the governmental authorities, while at the same time the traditional agricultural practices and territorial rights of the local population were ignored (Halevy, 2023).

It is fascinating to see how the perception of an area considered barren and threatening (burial of houses and cropland and malaria-ridden) could be changed by the management measure of afforestation. The economic exploitation of the planted trees and vegetation, which served to impede the advance of the sands, converted an unproductive area into a productive one, with the additional and unplanned consequence of generating what is today considered a space of high ecological value, often with protected status. Such landscape and ecosystem transformations have taken place in many coastal areas around the world.

For its part, the case of the Llobregat delta offers a clear example of historical reconstruction provided by documentary sources. In this regard, the bibliographic and cartographic historical sources are scarce and only refer to the best known and most highly developed dune systems, located, as indicated in this work, around river mouths. Books of the time written by travellers, geographers and explorers (Carreras Candi, 1908-1918; Chevalier, 1928; Vila, 1928-1936) only mention the large sand mountains located in the Montgrí and Begur massifs, in the Llobregat delta and at the cape of Salou. Apart from these dune formations, Chevalier (1928) also mentions dunes in Calafell and in the Ebro delta:

> In Catalonia [dunes] are found in the Llobregat delta, south of Castelldefels, where they are of some importance, in Calafell, and above all on the beaches of the cape of Salou, where they have taken over the trees and where some of these, half buried, only show the top. At the mouth of the Ebro there are also some dunes of minor importance, especially if we compare their surface area with that of the sediments of the delta.

There are also a number of parallels between the land uses discussed here and those that existed in the Guanarteme dune system (now extinct, Gran Canaria, Canary Islands, Spain), as sand was extracted for construction and children would roll down the dune slopes (Santana-Cordero *et al*., 2016). Likewise, in the last quarter of the 19th century, there were also plans to paralyse the Guanarteme dunes with a plantation of tamarisks (*Tamarix canariensis*) (Santana-Cordero *et al*., 2014).

This work cannot be completed without first talking about the impact of tourism and construction on the destruction of dune habitat. Although most of the pine forestation took place long before tourist activity, there is evidence that the last recorded dune disappearance is linked to construction. This happens especially in the Llobregat delta where construction by the company Baños de

Castelldefels S.A., which in the 1920s began to open roads towards the beach and build on the dunes (Fig. 13). This same company obtained the concession to build villas and single-family houses throughout the area following the diffuse urbanization model. From then until 1945, a significant part of the Castelldefels dune area disappeared and in its place rows of single-storey constructions were built (Fig. 14). This denotes a proto-tourism activity that would already lead to the disappearance of dunes where they were installed, this process being even older than what has been determined in previous studies (Garcia-Lozano *et al*., 2018ab).

7. CONCLUSIONS

The exhaustive study undertaken of the dune fields of Catalonia, and more specifically in the regions of Montgrí and Begur and the Llobregat delta, has revealed significant aspects of the geomorphological evolution of these landscapes and the anthropic interventions made in them. The implementation of dune stabilization techniques through the planting of different pine species since the end of the 19th century has been shown to be an effective strategy in preventing the advance of the dunes to inhabited and cropland areas. This measure not only protected farming and urban land, but also transformed previously barren areas into spaces of high ecological and productive value.

This study shows there were significant differences in dune management and stabilization practices between the two regions of Catalonia used as case studies: Montgrí and Begur, and the Llobregat delta. In the former region, dune stabilization was tackled through intensive afforestation with pine trees and other plant species adapted to sandy soils. This approach was the response to an urgent need to protect farmland and inhabited areas threatened by the advance of the dunes. From the end of the 19th century, these actions were meticulously documented and planned, revealing a proactive and structured approach to counteract soil erosion and its effects.

In contrast, the approach to the problems caused by the dunes of the Llobregat delta was more spontaneous and sustained over time, which explains the relative lack of official documents. Although afforestation practices were also applied, their fundamental aim was not to contain the dunes but rather to improve health conditions by transforming disease-ridden marshland areas into forested land, which indirectly helped to stabilize the dunes. However, the disappearance of the large coastal dune is directly linked to the urbanization of that area.

This study highlights the importance of historical interventions in the configuration of present-day landscapes and underlines the need to consider past practices and their long-term effects in modern environmental planning and management. These findings enrich our understanding of the interaction between human activities and natural systems.

8. ACKNOWLEDGEMENTS

This text has been translated into English with financial support from the Department of Geography at the University of Girona.

9. REFERENCES

Almera, J. & Brossa, E. (1891): *Mapa geológico y topográfico de la provincia de Barcelona: región primera ó de contornos de la capital detallada* [Mapa]. 1:40.000. Recuperat 27 juny 2016, de http://cartotecadigital.icc.cat/cdm/landingpage/collection/catalunya

Anónimo (1926): *Emplazamiento del caballón en proyecto - Castelldefels*. Scale: 1:2,000

Anónimo (1926): *Proyecto de caballón para defensa del cultivo - Castelldefels*. Scale: 1:5,000

Anónimo (1930): *Dunes platja de Castelldefels*. Unknown scale.

Artigas, P. (1880): «Bosquejo forestal de los alrededores de Bagur (Gerona)», *Revista Montes* 4 (77):145-151.

Artigas, P. (1885): «Memoria relativa á la excursión verificada por los alumnos de tercer año de la Escuela Especial de Ingenieros de Montes á los montes públicos, dunas y alcornocales de la provincia de Gerona por el verano de 1882», *Revista Montes* IX (desconocido)-número completo.

Artigas, P. (1896a): «Las dunas del golfo de Rosas», *Revista Montes* XX (476): 536-541.

Artigas, P. (1896b): «Las dunas del golfo de Rosas», *Revista de Montes* XIX (479): 9-15.

Artigas, P. (1908): «Fijación y repoblación de las dunas procedentes del Golfo de Rosas», *Revista Montes* XXXII (761): 750-755.

Banchini, S.; Chelleri, L.; Trujillo-Martínez, A. J.; Breton, F. (2009): «New Directions in Beach Management in the Barcelona Metropolitan Area Coastal Systems (Catalonia, Spain)», in A. T. Williams; A. Micallef (ed.), *Beach Management, Principles & Practice*, Sterling, Earthscan: 349-357.

Baños de Castelldefels, S.A. (1930): *Delimitació de la zona marítim-terrestre dins de l'expedient d'Obres Públiques previ a la fase d'urbanització [Plànol]*. Escala gràfica. Material cedit per l'Arxiu Municipal de Castelldefels.

BOE (2005): *Resolución de 5 de mayo de 2000, de la Secretaría General de Medio Ambiente, por la que se formula declaración de impacto ambiental sobre el Plan Director del puerto de Barcelona, de la Autoridad Portuaria de Barcelona*. España.

Brémontier, N. (1797): *Mémoire sur les dunes et particulièrement sur celles qui se trouvent entre Bayonne et la pointe de Grave, à l'embouchure de la Gironde*, L'imprimerie de la République, Paris.

Brosa, E. (1891): *Mapa geológico y topográfico de la provincia de Barcelona* (Geological and topographic map of Barcelona province). Scale: 1:40,000

Cros, L. (1987): *Estudi sedimentològic dels dipòsits eòlics del Baix Empordà*, Universitat de Barcelona.

Cros, L.; Serra, J. (1990): «Las formas dunares del Baix Empordà (Girona)», *Notes de Geografia Física*, 19: 45-56.

Cros, L.; Serra, J. (1993): «A complex dune system in Baix Empordà (Catalonia, Spain)», *Geological Society*, SI 72: 191-199.

Cambó, F. (1919): *Vuit mesos al Ministeri de Foment. Ma gestió ministerial*, Catalana, Barcelona.

Campmany i Guillot. J. (2003): «La colonització del delta occidental del Llobregat (Gavà i Castelldefels) al segle xviii: un fracàs econònimic i social», *Revista Pedralbes*, 23: 682-702.

Carandell, J. (1937): *El Bajo Ampurdán. Ensayo Geográfico*, Diputación Provincial de Gerona (1978), Girona.

Carreras Candi, F. (1908-1918): *Geografia General de Catalunya*, Alberto Martín, Barcelona.

Castro, M. M. de (1917): «Dunas de la provincia de Cádiz», *Revista Montes* XLI (961): 77-85.

Cerón, S. (1872): «Cultivo de arenas voladoras por medio de navazos», *Revista Forestal Económica y Agrícola*, 5: 321-325.

Chevalier, M. (1928): *El paisatge de Catalunya*, Barcino, Barcelona.

Convocatoria de la Baronía de Eramprunyà (1755): Unpublished.

Cueto Álvarez de Soto mayor, M. (2001): «Ordenaciones de pinares de pino piñonero en la provincia de Cádiz», *Cuadernos de la Sociedad Española de Ciencias Forestales*, 11: 125-134.

Dean, R. G.; Dalrymple, R. A. (2004): *Coastal Processes with Engineering Applications*, Cambridge University Press, Madrid.

EEC (1992): *Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora*, European Union.

European Comission (2000): *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy*, European Union.

Fernández de Castro A. (1900a): «Repoblación de dunas», *Revista Montes* XXIV (559): 225-232.

Fernández de Castro A. (1900b): «Repoblación de dunas», *Revista Montes* XXIV (561): 281-285.

Fernández de Castro A. (1900c): «Repoblación de dunas», *Revista Montes* XXIV (565): 395-400.

Fernández de Castro A. (1905): «Las dunas de Portugal», *Revista Montes* XXIX (688): 511-516.

Ferrer, J. de (1895): «Proyecto de fijación y repoblación de las dunas procedentes del golfo de Rosas», *Revista de Montes* XIX (432): 17-22.

Garcia-Lozano, C. (2019): *Els sistemes dunars de la costa catalana Evolució històrica, estat actual i potencial de restauración*, tesis doctoral, Universitat de Girona.

Garcia-Lozano, C.; Pintó, J. (2018a): «Current status and future restoration of coastal dune systems on the Catalan shoreline (Spain, NW Mediterranean Sea)», *Journal of Coastal Conservation*, 22: 519–532. https://doi.org/10.1007/s11852-017-0518-4

Garcia-Lozano, C.; Pintó, J.; Daunis-i-Estadella, P. (2018b): «Changes in coastal dune systems on the Catalan shoreline (Spain, NW Mediterranean Sea), Comparing dune landscapes between 1890 and 1960 with their current sytatus», *Estuarine, Coastal and Shelf Science*, 208: 235–247. https://doi.org/10.1016/j.ecss.2018.05.004.

Gàmez, D.; Simó, J.; Vàzquez-Suñé, E.; Salvany, J. M.; Carrera, J. (2005): «Variación de las tasas de sedimentación en el Complejo Detrítico Superior del Delta del Llobregat (Barcelona): su relación con causas eustáticas, climáticas y antrópicas», *Geogaceta*, 38 (2): 175-178.

Gil Sánchez, L.; Pardos Carrión J. A. (2008): *Pinares y rodenales la diversidad que no se ve*, Real Academia de Ingeniería, Spain.

Guadarrama Sosa, A. (2023): «"¡Abajo los médanos!": orígenes del conflicto entre dunas costeras y humanos en la ciudad de Veracruz (siglos xvi-xix)», *LLull* 46 (93): 33-64. https://doi.org/10.47101/llull.2023.46.93.guadarrama

Halevy, D. D. (2023): «Sand and the City: On Colonial Development and its Evasive Enemies in Twentieth-Century Palestine», *Environment and history*, 29 (4) : 537-564. https://doi.org/10.3197/096734022X16384451127302

ICC (2010): *Llibre Verd: Estat de la zona costanera a Catalunya*, U. P. de B. i C. I. d'Investigació dels R. Costaners (ed.), Institut Cartogràfic de Catalunya i Generalitat de Catalunya, Barcelona.

Klijn, J. A. (1990): «The younger dunes in The Netherlands; chronology and causation», *Catena Supplement*, 18 : 89-100.

Madoz, P. (1846-1850): *Diccionario geográfico-estadístico-histórico de España y sus posesiones de ultramar*, la Ilustración, Madrid.

Mapa de les marinas de la baronía d'Eramprunyà (1590): Unpublished map.

Marcos-Valiente, Ò. (1987): «Canvis recents a la línia de costa del delta del Llobregat», *Treballs de la Societat Catalana de Geografia*, X (39): 45-72.

Marqués, M. A. (1984): *Les formacions quaternàries del delta del Llobregat*, Institut d'Estudis Catalans, Barcelona.

Marqués, M. A.; Julià, R.; Montaner, J. (2011): «Las dunas de la costa norte catalana», in E. Sanjaume; F. J. Gracia (eds.), *Las dunas en España*, Sociedad Española de Geomorfología, Cádiz: 187-203.

Marqués, M. A.; Julià, R. (1983): «Características geomorfológicas y evolución del medio litoral de la zona de Empuries (Girona)», *Cadernos do Laboratorio Xeolóxico de Laxe*, 5: 155-164.

Marqués, M. A.; Julià, R. (2005): «Evolución de la zona litoral del Empordà durante el último milenio», in *Geomorfologia Litoral i Quaternari. Homenatge a Vicenç M. Roselló i Verger*, Universitat de València, València: 259-272.

Martins, I. S.; Dornelas, M.; Vellend, M.; Thomas, C. D. (2022): «A millennium of increasing diversity of ecosystems until the mid-20th century», *Global Change Biology*, 28 (20): 5945-5955. https://doi.org/10.1111/gcb.16335

McLachlan, A.; Defeo, O. (2018): *The Ecology of Sandy Shores*, Academic Press. https://doi.org/10.1016/C2015-0-04773-6

Meteocat (2024): Accessed: 17/01/2024; Available at: https://www.meteo.cat/wpweb/serveis/cataleg-de-serveis/serveis-oberts/dades-obertes/

Ministerio de Fomento (27 de julio de 1918): *Leyes*, Gaceta de Madrid, https://www.boe.es/gazeta/dias/1918/07/27/pdfs/GMD-1918-208.pdf

Mira, F. (1903): «Reseña de las dunas de Guardamar», *Revista Montes* XXVII (635): 361-366.

Montaner, J. (2010): *El flux hidrològic de la plana litoral del Baix Ter*, Càtedra d'Ecosistemes Litorals Mediterranis.

Nordstrom, K. F. (2013): *Developed Coasts*. *Treatise on Geomorphology*, vol. 10, Elsevier Ltd. https://doi.org/10.1016/B978-0-12-374739-6.00292-X

Pallí, L.; Roqué, C. (1990): *Mapa litomorfológico del Massís de Begur*. Escala 1:25.000, Ed. Unitat de Geologia, Est. General de Girona.

Perelló, M. X.; Durán, R.; Valero Montesa, L.; Guillén, J. (2019): «Evolución geomorfológica de la costa del delta del Llobregat mediante datos LIDAR (2008-2017)», in R. Durán; J. Guillén; G. Simarro (eds.), *X Jornadas de Geomorfología Litoral*, Castelldefels: 177-180.

Pintó, J.; Panareda, J. M.; Mas, R.; Carbó, S. (1997): «Evolución del paisaje dunar en el Macizo de Begur», in *Dinámica litoral-Interior: Actas del XV Congreso de Geógrafos Españoles*, vol. 1, Asociación de Geógrafos Españoles, Santiago de Compostela: 221-234.

Pipió i Gelabert, H. (1998): «Les dunes empordaneses», in *Llibre de la festa major de Torroella de Montgrí*, Ajuntament de Torroella de Montgrí, Torroella de Montgrí: 111-120.

Pipió i Gelabert, H. (1999a): «Ressenya històrica del procés de fixació de les dunes empordaneses», in *Sorra i Vent. Les dunes 100 anys després*, Museu de la Mediterrània: 26-41.

Pipió i Gelabert, H. (1999b): «Ressenya històrica del procés de fixació de les dunes empordaneses», *Papers del Montgrí*, 17 (Sorra i Vent. Les dunes 100 anys després.): 26-41.

Pipió i Gelabert, H. (2008): «Reseña histórica sobre las dunas del golfo de Roses», *Montes*, 95: 27-32.

Pipió i Gelabert, H. (2013): «Els Treballs De Fixació De Les Dunes», *Dossiers Agraris*, 16: 191-199. https://doi.org/10.2436/20.1503.02.60.

Plan de la Gran Pineda (1746): Unpublished.

Provoost, S.; Laurence, M.; Jones, M.; Edmondson, S.E. (2011): «Changes in landscape and vegetation of coastal dunes in northwest Europe: a review», *Journal of Coastal Conservation*, 15: 207-226. https://link.springer.com/article/10.1007/s11852-009-0068-5

Puertos del Estado (2023): Accessed: 15/11/2023; Available at: https://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx

Puig i Valls, R. (1897a): «Causas de la humedad existente en las dunas de Torroella de Montgrí», *Revista Montes* XXI (496): 461-470.

Puig i Valls, R. (1897b): «Causas de la humedad existente en las dunas de Torroella de Montgrí», *Revista Montes* XXI (497): 497-501.

Raeburn, G. (2022): «The repercussions of the Culbin Sands disaster of 1694: the emotional impacts of a shifting landscape in North-East Scotland», *Landscape History*, 43 (2): 5-21. https://doi.org/10.1080/01433768.2022.2143151

Rambaud, F. (2005): «Reconstrucción de la línia de costa en el entorno de Ampurias», *Empúries*, 54: 59-70.

SACE (Sistemas Aéreos Comerciales Españoles) (1960 - 1986): Colecció fotogràfica SACE. Recuperat 15 setembre 2015, de http://cartotecadigital.icc.cat/cdm/landingpage/%0Acollection/fsace

Sainz-Amor, E.; Julià, R. (1999): «Utilización de la mineralogia de arenas en la interpretación paleoambiental de las llanuras aluviales costeras: El Emporda, NE de la Península Ibérica», *Acta Geologica Hispanica*, 31 (4): 55-65.

Sampath, D. M. R.; Beattie, J.; de Freitas, J. G. (2023): «Managing Coastal Sand Drift in the Anthropocene: A Case Study of the Manawatū-Whanganui Dune Field, New Zealand, 1800s-2020s», *Nomadic Peoples*, 29 (3): 422–448. https://doi.org/10.3197/096734021X16328497562933

Santana-Cordero, A. M.; Monteiro-Quintana, M. L.; Calvento-Hernández, L. (2014): «Reconstructing the environmental conditions of extinct coastal dune systems using historical sources: the case of the Guanarteme dune field (Canary Islands, Spain)», *Journal of Coastal Conservation*, 18: 323-337. https://doi.org/10.1007/s11852-014-0320-5

Santana Cordero, A. M.; Ariza, E.; Romagosa, F. (2015): «Evolución histórica de los servicios del ecosistema y su aplicación en la gestión integrada de zonas costeras: el caso del Delta del Llobregat (Barcelona, España)», *Geo-Temas*, 15: 161-164.

Santana-Cordero, A. M.; Ariza, E.; Romagosa, F. (2016a): «Studying the historical evolution of ecosystem services to inform management policies for developed shorelines», *Environmental Science and Policy*, 64: 18-29. http://dx.doi.org/10.1016/j.envsci.2016.06.002

Santana-Cordero, A. M.; Monteiro-Quintana, M. L.; Calvento-Hernández, L. (2016b): «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», *Land Use Policy*, 55: 73-85. http://dx.doi.org/10.1016/j.landusepol.2016.02.021

Santana-Cordero A. M. (2021): «Geographic information science in historical landscape studies», *GeoFocus, Revista Internacional de Ciencia y Tecnología de la Información Geográfica*, 28: 121-133. http://dx.doi.org/10.21138/GF.736

Sennen, F. (1928): «La flora de la duna barcelonesa de Castelldefels», *Memorias de la Real Academia de Ciencias y Artes de Barcelona*, XX (14): 457-466.

Simó, J. A.; Gàmez, D.; Salvany, J. M.; Vàzquez-Suñe, E.; Carrera, J.; Barnolas, A.; Alcalà, F. J. (2005): «Arquitectura de facies de los deltas cuaternarios del río», *Geogaceta*, 38 (1): 171-174.

Valverde, A. (1998): «Evolución histórica: origen y significación de la pineda litoral del delta del Llobregat. I (siglos xvi-xix)», *Spartina. Butlletí naturalista del delta del Llobregat*, 3: 63–101.

Vila, P. (1928-1936): *Resum de la Geografia de Catalunya*, Barcino, Barcelona.

Western, D. (2001): «Human-modified ecosystems and future evolution», *PNAS*, 98 (10): 5458-5465. https://doi.org/10.1073/pnas.101093598

Zamora, F. (1787): *Diario de los viajes hechos en Cataluña*. Manuscrito.

Zamora, F. (1784-1799): *Respuestas al cuestionario de Francisco Zamora*. Manuscrito.