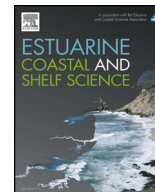




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Changes in coastal dune systems on the Catalan shoreline (Spain, NW Mediterranean Sea). Comparing dune landscapes between 1890 and 1960 with their current status

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ABSTRACT

The aim of this paper is to assess the changes that have occurred in coastal dune landscapes in Catalonia (Spain, NW Mediterranean Sea) over the last decades. Data from photographic, cartographic, and documentary sources between 1890 and 1960 have been examined and contrasted with the current status of dunes. Our analysis measures the historical transformation of the coastal dune system according to type of transformation (disappeared dunes, dunes smaller in size and dunes that have undergone few changes) and land cover changes surrounding the beaches.

At this time in Catalonia, the most extensive coastal dune systems are located in Empordà county (Roses Bay and Baix Ter Bay) and the Ebro Delta. The results reflect that the loss of dune habitat during recent decades has affected more than 90% of the Catalan beaches assessed, 60% of which have disappeared and 30% reduced in size. The most affected province is Barcelona, where disappearance of dunes has affected over 80% of beaches and no beaches present almost untouched dunes; Girona and Tarragona have also been seriously affected, with dunes disappearing from 60% to 40% of the beaches assessed, respectively. However, on a minority of beaches along the Catalan shoreline, a few dunes remain almost untouched (10%).

Land cover changes surrounding the beaches show that dune habitats have been drastically reduced due to human pressure, especially urbanization and tourism-related processes. A multiple correspondence analysis (MCA) has shown that the dune systems that have disappeared are located in non-protected areas and low-lying coastal zones, whereas dunes that have become smaller in size or undergone few changes are located in protected natural areas and on cliffed coasts.

1. Introduction

Coastal dunes are an essential part of beach-dune systems as they provide a variety of ecological and social functions. Dunes act as repositories of biodiversity that have their exclusive habitat in dune communities offering particular landscapes derived from unique plant communities and landforms. At the same time, dunes protect tangible goods located near the coasts affected by wave-induced erosion particularly during storms (Valdemoro and Jiménez, 2006; Pilkey et al., 2011; Taylor et al., 2015). Moreover, dune environments offer recreation and therapeutic opportunities associated with their aesthetic values (Nordstrom, 2008; Sardá et al., 2012).

Although dune landscapes have traditionally been undervalued or perceived as a problem, their importance has recently been

acknowledged and most are now protected by local, national, or supranational legislation (Baeyens and Martínez, 2004). Dune habitats feature a great biodiversity and numerous species of interest, which has led to their being awarded European Community interest status and being included in the 92/43/EEC Habitats Directive (European Commission, 1992, 2007). In Catalonia, 11 habitats have been identified as being associated with dune and upper beach environments (Vigo et al., 2008), as have up to 37 vascular plants with a habitat exclusive to the beaches and dunes of the Catalan coast (Pintó et al., 2014).

Nevertheless, dune systems on developed coasts have suffered a drastic decline in geomorphological and ecological quality over the last hundred years. It is estimated that nearly 70% of European dune systems have disappeared during this time (European Commission, 2008) due to land cover changes related to global environmental change

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processes, particularly the urbanization of coastal zones and other associated factors related to human activities (Nordstrom, 1994; Cooper and Alonso, 2006; Jackson and Nordstrom, 2011; Bajocco et al., 2012).

Consequently, the ecological and geomorphological status of beach-dune systems is seriously endangered even in the best-protected systems (Cori, 1999; La Posta et al., 2008). Human influence, the introduction of invasive alien species on beaches (Pino et al., 2006; Panareda and Pintó, 2015) and in particular the implementation of recreational services and tourist facilities (Hesp, 1988, 2002; Alonso et al., 2002; Nordstrom, 2000; Roig-Munar et al., 2012) have contributed to the erosion of foredune environments and threatened the conservation of dune morphologies and many sensitive species and communities. In this context of accelerated change, the use of historical data to reconstruct past ecosystems is of great interest in rediscovering the past and analysing the transformation to the modern-day situation (Egan and Howell, 2001; Malavasi et al., 2013). Historical ecology allows us to reconstruct the past in order to predict future trends and then apply management measures focused on ecosystem conservation and restoration (Swetnam et al., 1999; Egan and Howell, 2001; Alagona et al., 2012; Higgs et al., 2014).

Historical ecology methods are used to assess the recent historical evolutions of different ecosystems from different views. Repeated photography is often used to describe the vegetation change in mountains and rural environments (Zier and Baker, 2006; Hendrick and Copenheaver, 2009); other studies use old maps to assess the recent historical evolution in land use/land cover (Bajocco et al., 2012; Srinath et al., 2016) or old written documents to reconstruct historical environmental changes (McLeman et al., 2010). However, the most widely used technique in historical ecology is the combination of different historical sources (photographs, oral accounts, written documents or maps) to reconstruct different past ecosystems, whether forest (Gimmi and Bürg, 2007), agrarian (Morris, 2012) or fluvial (Beller et al., 2016). In addition, a combination of historical ecology methods has been applied to remodel coastal dune systems in different study cases, as in the Canary Islands (Santana-Cordero et al., 2014, 2015; 2016) or Menorca Island (Balearic Islands) (Roig-Munar et al., 2012).

The aim of this paper is to combine historical ecology methods to assess the recent historical evolution of dune system presence along the Catalan shoreline over the last hundred years. Data from photographic, cartographic, and documentary sources between 1890 and 1960 have been examined and contrasted with the current status of dunes to evaluate the loss of dune habitat along the Catalan shoreline. The use of historical data allows us to reconstruct a hypothetical map of historical dune presence along the Catalan coast between 1890 and 1960. This facilitates the creation of a beach inventory, which can be used to conduct a comprehensive analysis of those beaches where dunes were found in the historical sources consulted.

2. Study area

Located in the north-east of the Iberian Peninsula, the Catalan coast is one of the major coastal areas for tourism in the north-western Mediterranean. It has a coastline of approximately 600 km, made up of a wide variety of coastal morphologies, including cliffs, coves, large bays, and long straight beaches of mainly medium and fine sands (Fig. 1).

In the past, coastal dunes reached great sizes along the Catalan coast, especially near the mouths of rivers and on the plains, where strong winds blow frequently (Pintó and Panareda, 2008; Pintó and García-Lozano, 2016). This was the case of the fluvial plains of Empordà and Baix Ter, where the Fluvià and Ter rivers flow and the *Tramuntana*, a strong wind that blows from the north, has sufficient energy to transport sandy sediments; or the Ebro River Delta, where the *Mestral*, another strong wind blowing from the north west, formed the largest dune fields on the Catalan coast. According to Pintó et al. (2008, 2016) other areas with well-developed dune systems could be found

along the Llobregat River Delta, and to a much lesser extent, the Tordera River Delta.

Currently, along the three provinces which configures the Catalan shoreline (Girona, Barcelona and Tarragona) we can find over 800 beaches of different lengths, and around 110 of these have some kind of dune system (García-Lozano and Pintó, 2017). Some dune systems are found on urban beaches, i.e. beaches located in town centres with a high density of buildings surrounding the beach area. Different dune systems are found in residential estates on the outskirts of towns, i.e. areas with a low density of built-up environment, according to the terminology used by Ariza et al. (2008) and Sardá et al. (2009). Finally, other dune systems are found on natural beaches, i.e. beaches located beside woodland or cropland areas, with no adjacent developed land. In the better-preserved sites, there is a variety of distinct plant habitats: upper beach, embryo dune, main dune, transition zone, and stabilized dune. These habitats are related to the sea-to-land ecological gradient and are all listed by the EU as natural habitats of Community interest (Habitats Directive 92/43/EEC).

The main pressures exerted on beaches derive from the combination of natural and societal factors. On the one hand, the Catalan coast can be considered an eroding coast, due to the fact that around 70% of beaches have been retreating during recent decades (Jiménez et al., 2017). On the other hand, the coastal zone suffers a high demographic pressure: the 70 towns located on the Catalan coast are concentrated in just 6.7% of the surface area and have 43.3% of the population of Catalonia (IDESCAT, 2016).

The economy of the Catalan coastal zone is based on activities such as tourism, commerce and, at least until the financial and economic crisis that began in 2008, residential development (Sardá et al., 2005). Tourism is one of the main economic activities, providing around 11% of GDP, and coastal tourism has been the main destination for decades, nowadays only exceeded by the city of Barcelona (Valls et al., 2017).

Dune systems have been part of the public domain since the 22/1998 Spanish Shore Act, amended in 2013. This law protects coastal dunes, making their management the responsibility of local and regional administrations under the supervision of the State. Although most mandatory obligations are still centralized at the national level, through the management of the coastal public domain, or at the regional administration level, by managing land use planning, local authorities play an important role in beach management, their main responsibility being to run seasonal facilities and to keep beaches clean and free from waste. Local authorities also draw up plans for beach use before the start of the high season. These plans programme and locate the facilities and services to be provided on each beach.

3. Materials and methods

In order to determine the historical and current presence of dune-systems on Catalan beaches, different primary sources were used, including: fieldwork, orthophotomaps, old and contemporary aerial photographs, street-level pictures, historical and current maps and old written documents.

3.1. The historical presence of dunes and land cover surrounding beaches in the past

In order to study the historical presence of dunes on the Catalan coast, we identified those beaches that had some type of dune morphology (from dunes located in coves to dune fields) between 1890 and 1960. The reason for choosing this timeframe is that after this period there was a turning point in the dynamics of the country: before the 1960s the national economy followed an autarkic model, whereas from 1960 onwards the Spanish economy opened up to the outside world with Development Plans and there was an accelerated process of public and private investments to develop the country in terms of urbanization, industry and infrastructure. This also saw the beginning of sun and

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