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The Historical Reforestation Processes of Dune Systems in the Balearic Islands

Reforestación histórica de los sistemas dunaras de las islas Baleares

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Abstract

The study examines human influence on the evolution of beach-dune systems in the Balearic Islands, focusing on afforestation with *Pinus halepensis*. Historically, actions have been taken to stabilize these areas, significantly impacting the morphology and dynamics of the systems. Through a historical review and analysis of 31 such systems, it is evident that the presence of *Pinus halepensis* is largely associated with human interventions, significantly affecting the vegetation structure and biodiversity conservation. The systems exhibit variations in size and conservation status, reflecting historical afforestation practices and current challenges in managing these ecosystems.

Keywords: Balearic Islands, Dune Systems, Dune Afforestation, *Pinus Halepensis*, Landscape Change.

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Resumen

El trabajo estudia la influencia humana en la evolución de los sistemas playa-duna en las Islas Baleares, con un enfoque en la forestación con *Pinus halepensis*. Históricamente, se han llevado a cabo acciones para estabilizar estas áreas, impactando significativamente la morfología y dinámica de los sistemas. A través de una revisión histórica y el análisis de 31 de estos sistemas, es evidente que la presencia de *Pinus halepensis* está ampliamente asociada con intervenciones humanas, afectando significativamente la estructura vegetal y la conservación de la biodiversidad. Los sistemas muestran variaciones en tamaño y estado de conservación, reflejando prácticas históricas de forestación y los desafíos actuales en la gestión de estos ecosistemas.

Palabras clave: Islas Baleares, sistemas dunares, forestación de dunas, *Pinus halepensis*, cambio paisajístico.

1. INTRODUCTION

Coastal occupation is restricted and subjected to uses that in some cases are counterproductive to the stability of beach-dune systems, with the confluence of various interests posing the main threat. To properly understand this issue, the human species cannot be overlooked as it is a key factor in understanding the current functioning and imbalances of such systems, and has become one of the most decisive and effective agents in modifying their morphology and morphodynamic functioning. The stabilization of these systems for different exploitation purposes has been prioritized within the historical framework of beach management. However, such stabilization should not solely be associated with tourism processes as in the pre-tourism past many dune systems were stabilized. Although the starting point for most analyses which consider a pre-tourism element is the availability of aerial photography (1946-1956), other historical data can also be employed to show the uses, interventions and modifications of such systems, as for example in the stabilization of dune systems through afforestation (Roig-Munar *et al*., 2009; Pintó and Garcia-Lozano, 2016).

At the end of the 18th century, sandy coastal areas in Europe were still hostile, inhospitable and often dangerous spaces, which is evidenced by the few urban centers associated with the coast, many of which were walled (Grove and Rackham, 2003). Before the current coastal tourism period, a natural and balanced dynamism predominated which constituted a certain limitation to population settlement and crop-growing in many coastal areas due to the inland advancement of dunes. In Spain, according to Madariaga (1909), along certain parts of the coast large areas occupied by sand dunes had advanced inland, occupying fertile lands and rendering them unproductive and burying entire homes and populations. As the author stated: "In cases of productive lands affected by flying sands, the only option is afforestation to retain and stabilize mobile sandy lands until the definitive covering of the sands, turning these spaces or fields of desolation into sources of wealth and beauty". These processes of dune stabilization through afforestation have been extensively documented in the literature both in Spain and abroad (Valls, 1870; Artigas, 1887, 1889, 1890, 1896; Anónimo, 1890; De

Castro, 1900a, 1900b; Mira, 1903; Codorniu, 1908; Tiismann, 1924; Whitehead, 1964; Ranwell and Boar, 1986; Gadgil and Ede, 1998; Tastet and Pontee, 1998; Hilton *et al*., 2000; Lemauviel and Roze, 2000; Pausas *et al*., 2004; Hilton, 2006). Generally, the goal was to prevent dune fronts from negatively affecting areas of interest for human activity (Ranwell and Boar, 1986; Gadgil and Ede, 1998), with such actions also acknowledged to constitute a negative impact on the conservation of these dynamic coastal environments (Ranwell and Boar, 1986; Gallego Fernández *et al*., 2003). In effect, they comprised one of the first agents of the artificial modification of sandy coastal systems and landscape change. In Spain, according to Ortuño (1990), these works were carried out in much of the state coastal territory as the result of an institutional policy aimed at stabilizing the dune systems. Maestre-Gil *et al*. (2004) confirm that even until the second half of the 20th century the southeast of the Iberian Peninsula was subjected to numerous reforestation efforts with *Pinus halepensis* to recover the tree plant cover lost as the result of various uses and disturbances. The stabilization of the Montgrí dunes took place between 1896 and 1910 (De Ferrer, 1895), representing the first major forest engineering project in Spain, carried out by the Forest District of Barcelona, Girona, and the Balearic Islands. This forest administration was created specifically for this purpose and was later succeeded by the Hydrological-Forestry Division (Pipió and Gelabert, 2013). In fact, in 1892, the Girona Dunes Commission was established to oversee the work conducted in the Montgrí mountains.

According to Artigas (1890), sands can advance inland from a few meters to more than 14 kilometers, altering the shape of the land due to the extremely fine grains covering fields, hills and buildings, and turning fertile lands and settlements into silent and inhospitable deserts. These constantly moving 'flying' sands, as stated by the author, do not destroy but merely modify, as the leaves of the trees remain green before disappearing under the sand. To carry out the tasks aimed at consolidating the sandy areas, Artigas (1890) proposed the following different stages of dune afforestation:

- Mapping and marking the boundaries of state-owned properties to be repopulated. Private properties wishing to stabilize the sands can do so by joining a state-approved project.

- The creation of defense cordons, known as coastal dunes or counterdunes, considered essential work for a successful repopulation. The tasks involve stabilizing the sands 100-200 m from the highest ordinary sea level through the creation of fence screens parallel to the coastline. With this method, it is estimated that within a year they will be covered with sediment. It is then proposed to remove the fencing and replant grasses, usually marram grass (*Ammophila arenaria*), on the new non-consolidated form. By this time, neodune formation (stoss and lee faces) will have taken place through aeolian interference processes (Savage, 1963; Savage and Woodhouse, 1969).

- Repopulation with tree-sized vegetation. Within the interior area of the system conditioned by the new coastal dune, replanting can take place with dominant species such as *Pinus pinaster* and protective or auxiliary plants (*Ulex parviflorus, Genista scoparia, Ammophila arenaria*, etc.).

According to Ramos (1981), from 1902 onwards afforestation became an effective measure to prevent the advance of sand at Spanish national level, with forestry engineers taking on many of these stabilization tasks through executive projects. Notable among these projects were the afforestation of dune systems in Catalonia in the Bay of Roses and Montgrí in Alt Empordà (Artigas, 1887; 1889). Dunes in Huelva and Cádiz in Andalusia (Maceira 1890; Fernández de Castro, 1917), in Guardamar in the province of Alicante (Mira, 1903; Codorniu, 1908), and in the Basque Country (Uriarte, 1998), were also stabilized. These stabilization efforts, led by the Spanish School of Forestry, were not limited to Spanish territory. Afforestation tasks were also performed in protectorate areas, such as the Tetuán area in Morocco where dune fields invaded new urban and agricultural areas as well as road infrastructures (Cantarino and Seva, 1997). There were also dune stabilization tasks not linked to state projects, as in the case of the dunes of Begur (Baix Empordà, Catalonia) which, according to Carandell (1978), were 'honorably' stabilized by owners who planted pine trees on what were vineyards and wasteland and where today we find masses of *Pinus pinea*, *Pinus halepensis*, and *Pinus pinaster*. Carandell (1978) attributes to these non-state tasks the transformation of desert areas and the control of constant dune-associated threats to the local population. Additionally, small-scale semi-stabilization efforts of dune forms associated with cala Borró in Alt Empordà (Roig-Munar *et al*., 2009), and other specific actions reported in Menorca, such as in St. Tomàs, es Grau, and sa Torreta (Roig-Munar *et al*., 2008), have also been highlighted.

Studies in the Balearic Islands (Spain) have confirmed that parts of the dune systems in Menorca (Roig-Munar *et al*., 2008, 2009) and Mallorca (Mir *et al*., 2010, 2011) have been afforested, mainly with *Pinus halepensis*. In Menorca, Roig-Munar *et al*. (2008) compiled oral sources on afforestation tasks in the Morella, St. Tomàs, es Grau, and sa Torreta systems, carried out by the landowners (Fig. 1). In the case of Formentera, Mayol (2006) provides the first reference to afforestation in relation to the Dune Correction Project on the island of Formentera (1944), where various stabilization techniques were used with *Ammophila arenaria* and *Ampelodesmos mauritanica* as herbaceous plants, and with *Pinus halepensis, Pinus pinea*, and spot plantings of cypress (*Cupressus sp*.), tamarisk (*Tamarix sp. pl*.), date palms (*Phoenix dactylifera*), and castor bean (*Ricinus communis*). Associated with this project, Forteza *et al*. (2020) collected oral sources that describe, despite the intense grazing by goats and sheep in the dune area of Formentera, the protestations of landowners opposed to the afforestation project because they would lose pastureland. Other works do not provide data on public interventions, and only in Menorca is private intervention in some systems noted, as well as the recent intervention in 1990 in the sa Marina system stabilized with the support of the Leader program through the planting of *Pinus halepensis* (Roig-Munar *et al*., 2008a).

Figure 1. Landscape change due to the planting of *Pinus halepensis* vegetation in the es Grau system, Menorca (1920-2024). Source: Figure 1A.- Photos by Adolfo Coll (1920). Figure 1B.- Photos by the authors (2024).

The study described in the present paper examines human influence on the evolution of beach-dune systems in the Balearic Islands, focusing on afforestation with *Pinus halepensis*. These beach-dune systems appear to have homogeneous forest masses (in order and height) of *Pinus halepensis* in the semi-stabilized and stabilized morphological sectors. These forested areas are located in the inner part of the system, anchoring semi-stabilized and stabilized Holocene dunes (Servera, 1997), while preserving their original physiognomy, although some systems are experiencing preservation and conservation problems revealed by fragmentation and erosion processes.

2. METHODOLOGY

A notable initial aspect is the relatively low number of dune systems that, given their characteristics and the proposed methodology, allowed for data collection in Mallorca, with none found in Ibiza. This situation may be attributed to the state of degradation many of these spaces currently exhibit, which, according to Servera (1997), is a consequence of urbanization processes. The analyzed dune systems characteristically maintain considerable and easily identifiable forest masses, predominantly composed of *Pinus halepensis*. These forests are found in the interior part of the system, anchoring both semi-stabilized Holocene dunes and stabilized dune sectors.

Thirty-one beach-dune systems (Fig. 2) are analyzed in this paper based on studies conducted in Menorca by Roig-Munar *et al*. (2009), in Mallorca by Mir *et al*. (2010) and in Formentera by Mayol (2006), examining 19 systems in Menorca, 11 in Mallorca, and 1 in Formentera. Despite their varying conservation statuses, all these systems still retain morphological traits of their original structure, along with clear signs of afforestation. This is evident in the linear arrangement of trees, as shown in Fig. 3.

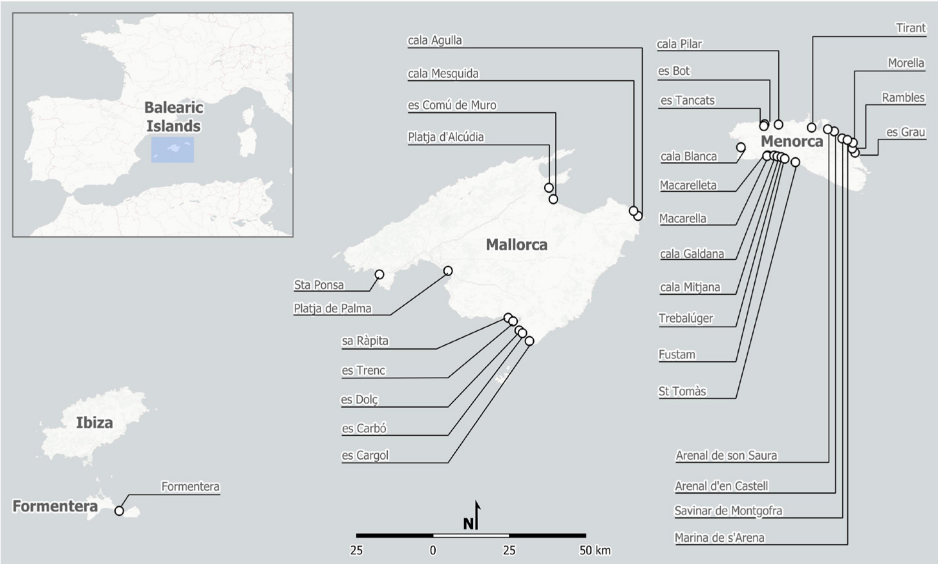

Figure 2. Location of analyzed *Pinus halepensis* forests in Mallorca, Menorca, and Formentera based on the studies by Roig-Munar *et al*. (2009) and Mir *et al*. (2010).

The systems are analyzed for current characteristics that show signs of stabilization actions on the semi-stabilized morphologies through the intentional introduction or positive discrimination of *Pinus halepensis*. The choice of this species as an indicator of anthropogenic actions is based on various factors reported by Roig-Munar *et al*. (2009):

i) There is evidence that it is not a common species in the vegetation of dynamic dune systems in the Balearic Islands (Bolòs, 1967).

ii) Its rapid growth and pioneering behavior make it a suitable species for stabilizing altered environments (Ortuño, 1990; Pastor-López and Martín-Martín, 1993).

iii) Ex situ production is relatively easy (Baeza *et al*., 1991; Maestre and Cortina, 2004).

iv) The adaptation process from cultivation site to final location is also straightforward, presenting few problems (Baeza *et al*., 1991).

v) Its use for afforestation is documented in various bibliographic sources in the Mediterranean region (Quézel and Médail, 2003; Escarré *et al*., 1989; Ortuño, 1990; Pastor-López and Martín-Martín, 1993; Olivera *et al*., 2003), and more specifically in the Balearic Islands (Mayol, 2006; Roig-Munar *et al*., 2009; Mir *et al*., 2010).

vi) There is evidence of stabilized morphologies through equidistant planting between individuals and the stabilization of erosive processes and blowout lobes (Roig-Munar *et al*., 2009).

Figure 3. Dune morphologies stabilized through planting in Balearic dune systems. A: Alcúdia, Mallorca / B: es Grau, Menorca / C: es Comú de Muro, Mallorca / D: sa Torreta, Menorca. Photographs by the authors (2023).

To analyze afforestation, the methodology proposed by Roig-Munar *et al*. (2009) was applied, selecting locations that meet the following criteria:

- The population of *Pinus halepensis* consists of a sufficient number of individuals to perform a random measurement of its quantitative characteristics.
- The population of *Pinus halepensis* shows clear evidence of being situated on mobile dune morphologies prior to planting (Fig. 3).
- The population of *Pinus halepensis* is more or less homogeneous in terms of characteristics, distribution and distance between individuals (see Fig. 3).
- Some historical elements, such as trenches from the Spanish civil war, are

fixed within the system, testifying to subsequent plantings (Fig. 3C).

After selecting the locations (Fig. 2), the trunk diameter at 1.3 m above ground level was measured of 30 randomly chosen individuals in each forested area. This quantitative data is commonly used for inventorying and characterizing forested areas with a single predominant tree species (Tsitsoni and Karagiannakidou, 2000; Montero *et al*., 2001; De Luis *et al*., 2009). The sample selection was random, always aiming to cover the largest possible area within the system to obtain representative spatial information, also obtaining the current values of square meters of reforested area and its perimeter in linear meters.

3. RESULTS

The results show that today the forested areas associated with the stabilization of dune morphologies cover a surface of 49,746.26 m^2, with a perimeter of 70,826 m (Table 1), linked to various uses in the peripheral zones of the fixed forms. The surface and perimeter of each system, along with its characteristics, are summarized in Table 1. It can be seen that many of the dune systems were stabilized following a pre-tourism period policy of protecting agricultural land, with primary activities often still being conducted today. Noteworthy are dune systems displaying fixed blowout erosive morphologies (Fig. 3B), indicating the need for morphological fixation to prioritize agricultural fields, as in the case of es Trenc in Mallorca or es Grau in Menorca. Only a few systems that continue to be surrounded by forest environments show no clear evidence of recent agricultural use, and are limited to urbanized spaces such as St. Ponça, Platja de Palma, or Alcúdia in Mallorca, or St. Tomàs, s'Olla, Arenal d'en Castell, cala Blanca, and Galdana in Menorca. According to oral interviews conducted on the island of Menorca (Roig-Munar *et al*., 2008), the afforestation actions that have been verified were due to works of the owners rather than planned projects of public institutions, except for the case of Formentera where a state project was in place (Mayol, 2006).

Table 1

Data of the 31 cases analyzed in terms of occupied surface area, perimeter and land type

N	*Island*	*Location*	*Area (m^2)*	*Perimeter (m)*	*Type of land*
1	Menorca	es Grau	64,667	1,347	Agricultural interest
2	Menorca	sa Torreta	33,226	742	Agricultural interest
3	Menorca	Rambles	71,945	1,059	Agricultural interest
4	Menorca	Mongofre	30,170	1,139	Forestry sector
5	Menorca	Arenal d'en Castell	21,837	753	Forestry sector
6	Menorca	s'Olla	286,240	2,687	Agricultural interest
7	Menorca	Tirant	193,635	3,761	Agricultural interest

8	Menorca	Pilar	226,689	2,139	Agricultural interest
9	Menorca	es Bot	43,655	816	Agricultural interest
10	Menorca	Tancats	158,032	2,908	Agricultural interest
11	Menorca	cala Blanca	9,315	471	Agricultural interest
12	Menorca	Macarella	15,894	940	Agricultural interest
13	Menorca	Macarelleta	13,010	641	Agricultural interest
14	Menorca	cala Galdana	15,403	717	Forestry sector
15	Menorca	cala Mitjana	17,178	1,456	Forestry sector
16	Menorca	Trebalúger	86,048	1,642	Agricultural interest
17	Menorca	Escorxada	12,547	647	Forestry sector
18	Menorca	Marina de s'Arena	16,300	622	Agricultural interest
19	Menorca	St. Tomàs	13,235	836	Agricultural interest
20	Mallorca	Platja d'Alcúdia	22,749	1,224	Forestry sector
21	Mallorca	es Comú de Muro	556,372	4,612	Forestry sector
22	Mallorca	cala Mesquida	453,580	5,033	Agricultural interest
23	Mallorca	cala Agulla	272,060	3,345	Agricultural interest
24	Mallorca	es Cargol	338,975	2,841	Agricultural interest
25	Mallorca	es Carbó	322,379	2,803	Agricultural interest
26	Mallorca	es Dolç	159,922	1,762	Agricultural interest
27	Mallorca	es Trenc	1,492,146	11,231	Agricultural interest
28	Mallorca	sa Ràpita	373,990	3,401	Agricultural interest
29	Mallorca	Platja de Palma	96,042	1,734	Agricultural interest
30	Mallorca	Sta. Ponsa	26,742	6,887	Agricultural interest
31	Formentera	Formentera	13,305	10,589	Agricultural interest
			49,746.26	**70,826**	

Source: elaboration of the authors

Figure 4. Examples of degradation of the stabilized morphologies. A and B, Porcíncula, Mallorca. C and D, Comú Muro, Mallorca. Photographs by the authors (2023).

A common factor among the analyzed dune systems is their alteration due to socio-economic activity. Most systems, while still retaining aspects of their original physiognomy, face serious preservation and conservation issues, evidenced by high levels of fragmentation and erosion. These problems appear in the form of quarries, fragmentation due to unregulated paths, recreational use, and urbanization, jeopardizing not only the conservation of the forested areas but also the intervened morphologies (Fig. 4).

Figure 5 shows the mean, minimum and maximum values of the diameters of the sampled trees at the 31 analyzed locations, with the mean value ranging in most places between 32 and 40.4 cm, with only locations like Macarella, cala Fustam, and St. Tomàs in Menorca, and Sta. Ponça and Playa de Palma in Mallorca having mean diameters exceeding 40 cm. Additionally, based on in situ observations, the analyzed beach-dune systems do not seem to have artificial counterdune creations, as some still display fixed morphologies corresponding to internal deflation channels due to the rupture of front morphologies, fixed by reforestation in the inner area of the semi-stabilized and stabilized dune system. The creation of counterdunes, a common technique applied by forestry engineers, is only evident in the Formentera project, with no such intervention identified in the other systems. Throughout the systems, there is also no apparent presence of herbaceous vegetation plants from dune front stabilization interventions to facilitate retention processes. Moreover, there is no evidence or record of tasks developed for sediment retention in any of the dune systems.

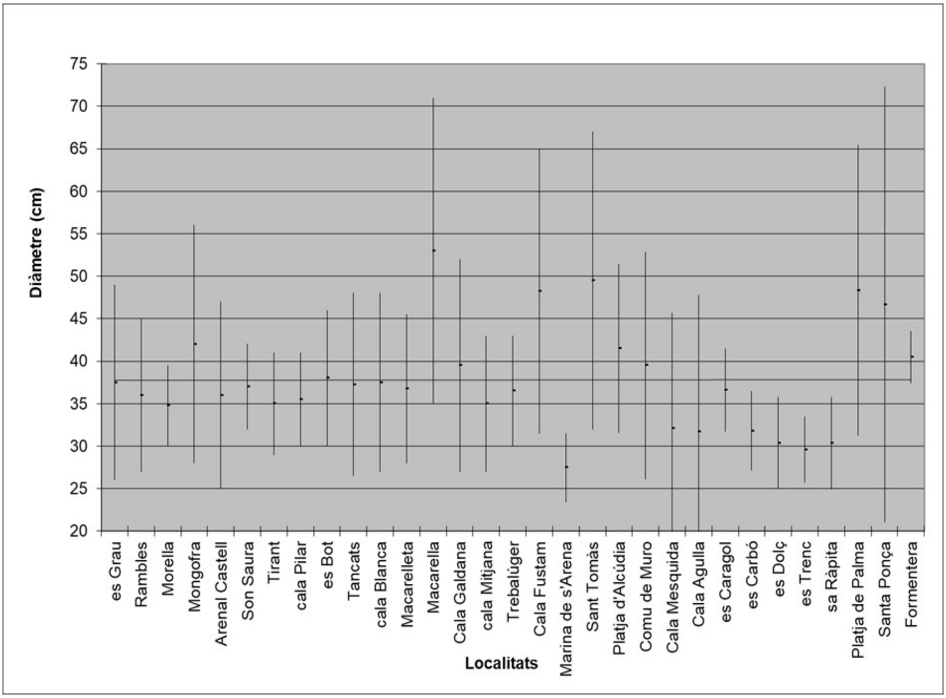

Figure 5. Graphical representation of the average, maximum, and minimum diameters of *Pinus halepensis* individuals sampled in the 31 dune systems.

Tree diameters in most of the dune systems in Mallorca show a greater dispersion (Fig. 5) than in Menorca (where they range from 34 to 37 cm on average). This potentially suggests that in Mallorca the planting activities or positive discrimination of *Pinus halepensis* may have been applied over a longer period, although other explanatory factors include the different response of the species depending on the location, the different evolution of individuals within each system and the orography associated with each system.

4. DISCUSSION

The results, in concurrence with other authors (Bolòs, 1967; Costa and Mansanet, 1981), also indicate that *Pinus halepensis*, in most cases, cannot be considered a characteristic plant species of natural dune systems but rather its presence is due to anthropogenic actions. Furthermore, as observed by other authors (Maestre and Cortina, 2004; Pausas *et al*., 2004), these actions have long-term negative effects, especially regarding biodiversity conservation (Ranwell and Boar, 1986; Gadgil and Ede, 1998; Hilton *et al*., 2000; Bellot *et al*., 2004; Fernández *et al*., 2006; Hilton, 2006) and the inherent dynamics of the beach-dune systems. It should be noted that similar actions have recently been carried out in some dune systems of the island (Roig-Munar *et al*., 2008a).

Referencing the data from Tsitsoni and Karagiannakidou (2000) and considering that the geo-environmental conditions of the Balearic Islands favor relatively rapid growth for this species (Gil *et al*., 2003), the measured individuals could be between 75 and 85 years old. This suggests that the possible plantings would have been carried out in the 1940s to 1950s. This assumption is also supported by the consulted graphic evidence. The similarity in diameters across different populations suggests that they were deliberately planted or at least are the result of clear positive discrimination (De Luis *et al*., 2009). As for systems with diameters significantly larger than 40 cm, this deviation could simply be due to more favorable conditions for the growth of *Pinus halepensis*, such as deeper soils or more protected environments, conditions that are indeed present in locations like Macarelleta and cala Fustam where these forest formations are nestled in small ravines directly associated with torrential streams and the presence of freshwater sources near the growth area. In contrast, this is not the case for St. Tomàs, es Comú, es Trenc, or sa Ràpita, where the studied forest mass is located in an open and relatively elevated space compared to the surrounding lands, which could slow down growth. In any case, further studies, such as dendrochronology, would be necessary to verify these assumptions. It should also be noted that, as is typical on the island, the diameters in southern localities are slightly larger than those in the north due to the greater suitability of calcareous and permeable soils for the development of this species (Ceballos and Ruiz de la Torre, 1979; Do Amaral Franco, 1986).

The reasons for the possible actions taken have not been fully determined across all systems, despite some oral sources (Roig-Munar *et al*. 2008b) and the certain existence of a single project (Mayol, 2006), but could vary from purely aesthetic or landscaping motives to others related to forest productivity or the consideration of dune systems as wastelands in need of afforestation. However, planting for the protection of agricultural land associated with the dune systems emerges as the most significant factor. The fact that the vast majority have direct contact with such land supports this hypothesis (Table 1). It is also important to differentiate between systems that directly border agricultural lands and those characterized by climbing dunes. Thus, we distinguish between beach-dune systems located in areas dominated by flat relief, like es Grau, es Tancats or Tirant (in Menorca), es Trenc, Platja d'Alcudia and es Comú Muro (in Mallorca) and Formentera, and those dominated by basin relief, like Morella or Macarella (in Menorca), where the shape of the beach or cove and the associated interior lands promotes the inward development of dune forms, in contact with crop fields, which were possibly reclaimed from the system with the eradication of interior dune forms, as is clearer in the case of es Tancats or cala Blanca (also in

Menorca). Also notable are those dune systems associated with small coves that were forested to prevent the evolution of climbing and falling dune morphologies related to the presence of crop fields, such as in Macarelleta, or interior crop lands, now distant from the beach, as in Morella, cala Galdana, Fustam or Trebaluger (all in Menorca). These actions were likely undertaken to prevent the advance of potential sand sheets or the arrival of suspended sedimentary material, among these actions on active interior climbing dune fields, the afforestation carried out in the interior system of cala Pilar stands out, aimed at preventing sediment from reaching the Alfurí estates located more than 1,200 m from the beach. Whatever the reason this action was undertaken for, it would also be reasonable to consider a possible connection with Spain's Forest Repopulation Plan, which was approved in 1939 and focused more on the restoration of areas considered degraded (Ortuño, 1990), although documentation is lacking.

5. CONCLUSIONS

The results demonstrate that some of the evolutionary works in the space-time of beach-dune systems (Roig-Munar *et al.*, 2006) did not start from a state of naturalness, as these systems had been previously anthropized through afforestation. The outcomes of the evolutionary analysis remain consistent with the objectives generally set in this type of work concerning coastline and dune morphology evolution. Based on additional observations in Mallorca, it is plausible that the existing or relic dune systems in the semi-stabilized or stabilized forms of the Palma and Alcúdia bays may not have been subject to intervention, as today we can observe pine forest with trees of similar diameter and homogeneous crown heights. The work shows that a significant portion of the dune systems in the islands have forest masses primarily composed of *Pinus halepensis*, with a similar temporal origin which suggests human involvement in the current configuration of their vegetation structure of the systems, indicating trends of positive discrimination regarding the presence of this species.

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