Changes in the *Erica ciliaris* Loefl. ex L. peat bogs of south-western Europe from the seventeenth to the twentieth century AD

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Abstract

This paper analyses a reconstruction of changes from the seventeenth to the twentieth century in peat bogs with *Erica ciliaris* Loefl. ex L. heathlands in south-western Europe. The reconstruction is performed by means of a multidisciplinary method based on photointerpretation, the examination of historical sources (documentation and maps), and an analysis of microtopography. Historical sources and aerial photos from 1956 and 1987 have also been used to reconstruct the impacts of anthropic activity. In the study area, Doñana Natural Park (SW Iberian Peninsula), peat bogs currently occupy slightly more than 8% of the area that they covered at the beginning of the seventeenth century. A parallel analysis of anthropic activity in the area over the last four centuries reveals the key role of humans in the disappearance of these peat bogs. This drastic reduction of peat bog area during the twentieth century is due to a drop in the water table as a result of the impacts of anthropic activity,

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primarily the establishment of monocultures of *Eucalyptus* spp. and *Pinus pinea*. An earlier drop in the water table, before these plantations, is attributable to a process of aridisation associated with post-Little Ice Age warming. Therefore, the impacts associated with climatic trends are synergistically superimposed on those derived from the intense anthropic activity that occurred during the second half of the twentieth century. This synergy resulted in a reduction of the surface occupied by the studied peat bogs and their associated *E. ciliaris* heathlands by 91.1% in SW Europe.

Keywords

Peat bogs, water table, *Erica ciliaris*, Little Ice Age, anthropogenic impact, historical data, Iberian Peninsula, Atlantic species

Introduction

The study of past forest change provides the historical context necessary for assessing the outcome of human-induced climate change and biological invasions (Petit *et al.*, 2008). Climate has been a major driving variable affecting wetland ecosystems throughout geological time, but climatic changes are relatively slow (Álvarez-Cobelas *et al.*, 2001). In contrast, as these authors note, man-made change is a more recent phenomenon, and its effects occur over shorter time periods. Therefore, the knowledge of human impacts on wetland ecosystems is, in our opinion, a prerequisite to addressing the impacts linked to climate change on plant communities. Peatlands and their linked plant communities are particularly vulnerable to climate change (Weltzin *et al.*, 2003). Particularly, the mineralisation rates of carbon and nitrogen in peatlands are affected by temperature and water table level (Keller *et al.*, 2004).

This paper focuses on the peat bog areas of south-western Europe and the changes that have occurred during the last four centuries. The southernmost *Erica ciliaris* Loefl. ex L. communities are linked to these peat bog areas, so that changes due to anthropogenic or climatic impacts affecting these wetlands will also affect the distribution area of their linked plant communities.

E. ciliaris heathland communities are interesting for two reasons: first, the distribution area of this community is affected by climate factors (Rose *et al.*, 1996), and second, *E. ciliaris* is a taxon whose distribution has been affected by anthropic activity (Chapman and Rose, 1994); in the case of the SW Iberian Peninsula, this is a very recent process (Sousa and García-Murillo, 2001). Thus, the southern edge of the distribution of *E. ciliaris* heathlands is a space that is unique, not only for studying its dynamics but also for examining what factors (anthropic or natural) have had the greatest effect. We seek to clarify whether, in recent centuries, anthropogenic and climatic impacts have affected the area occupied by peat bogs in SW Europe. Additionally, changes in the peat bogs can serve as proxy data for changes in the same period in these Atlantic communities of *E. ciliaris*.

Recent studies (Peñuelas and Boada, 2003; Sanz-Elorza *et al.*, 2003; Jump *et al.*, 2006; Lenoir *et al.*, 2008) suggest that the last few decades have witnessed changes at the southern edge of the ranges of some plant communities, associated with the climatic trends of the twentieth century. Those works are based on altitudinal migrations and are therefore associated with the relief and distribution of the bioclimatic stages. However, studies of latitudinal changes are scarcer than those of altitudinal retractions. Jump *et al.* (2009) argue that the lack of reported latitudinal range retractions is more likely to be due to a lack of research effort, compounded by methodological difficulties, than to the absence of these retractions. Therefore, in their opinion, the investigation of range retractions should become a priority in biogeographical research and most likely also in global change research.

According to Thomas *et al.* (2009), the relative lack of previous information about range declining and extinctions appears to stem, at least partly, from a failure to survey the distributions of species at a sufficiently fine resolution to detect declines and from a failure to attribute such declines to climate change. Moreover, as Parmesan *et al.* (2011) note, there are difficulties in attributing biological responses to climate change, such as the complex interplay among habitat destruction, land-use change, exploitation and pollution, in addition to climate change.

The aim of this study is to investigate the temporal dynamics of the peat bog areas of SW Europe (Doñana Natural Park, SW Spain) from seventeenth to the twentieth century. We intend to answer the following questions: (1) Have peat bogs and their linked communities of *E. ciliaris* in SW Europe changed in the last four hundred years? (2) What have been the primary factors driving these changes? (3) Have anthropogenic and/or climatic factors played a role in these changes?

To achieve these objectives, we shall (1) spatially reconstruct the extent of peat bogs from 1630 to 1987 AD using a multidisciplinary approach; (2) analyse the physical factors (geomorphological, hydrological, climatic, etc.) that may be involved in the evolution of these peat bogs and (3) study and quantify the changes in land use over the last four centuries along with the changes in climate trends in the study area.

Study area

The studied zone is located in Andalusia (SW of Spain, approximately 37º 10’ N and 6º 45´ W and 50-70 m a.s.l.), specifically within the boundaries of Doñana Natural Park (known in its western sector as Abalario), occupying approximately 25,000 ha between the tourist centres of Matalascañas, Mazagón, and El Rocío (Figure 1). In the study area, there is a series of small peat bogs known as Rivatehilos; *E. ciliaris* heathlands are associated with these water bodies (Rivas-Martínez *et al.*, 1980). Despite it forming small, dispersed patches, floristically, the state of conservation of *E. ciliaris* is good. In fact, as indicated by Allier *et al.* (1974) and García-Murillo (2006), the study area has the largest and best-conserved patches of hygrophytic heathlands of *E. ciliaris* in the whole environment of Doñana.

Figure 1 around here

The study area, because of its geographical position, is included within the Mediterranean climate domain, and—because of its closeness to the Atlantic coast—has a marked oceanic influence. This oceanic influence is evidenced by temperate winters (mean minimum temperature of the coldest month: 4.1 ºC) and milder summers (mean maximum temperature of the hottest month: 33.2 ºC). According to the data of the Bodegones weather station (situated at the edge of the study area), the annual mean temperature for the period 1951-1980 was 16.3 ºC and the annual mean precipitation 678.4 mm (41% of the precipitation occurring in the autumn months and 15% in the spring).

E. ciliaris heaths are recognised as Natural Habitats of Community Interest within the “priority” category (Habitats Directive 92/43/EEC) and are denominated “temperate Atlantic wet heaths with *Erica ciliaris”*. This type of heath [community of *Erico ciliaris-Ulicetum (minoris) lusitanicus*] constitutes one of the most complex and singular plant units for conservation within the Doñana Biosphere Reserve and its environs (Cobo *et al.*, 2002). Kingston and Waldren (2005) consider this taxon (*E. ciliaris*), along with another five species of Ericaceae, important for the conservation of European environments and its study relevant to past and present climate change scenarios.

The flora of the studied community, in spite of its location (with a Mediterranean climate and vegetation) is closely related to certain heathlands of Gallicia (NW Iberian Peninsula). Thus, many of the species found today — such as various *Sphagnum* taxa, *Molinia caerulea, E. ciliaris,* or *Calluna vulgaris* — are dominant or present in the peatlands of the Gallician mountains (Martínez-Cortizas *et al.*, 2000), situated more than 5º north of the study area. Furthermore, the wet meadow communities that share a location with these taxa have species in common, such as *Agrostis stolonifera*, *Potentilla erecta*, *Pinguicula lusitanica*, or *Simethis planifolia*, though the annual rainfall in these areas of Gallicia (1200-1900 mm) is much higher than that of the SW Iberian Peninsula. Some taxa present in the *E. ciliaris* heathlands of this region, such as *Calluna vulgaris*, *Potentilla erecta*, *Ulex minor*, *Sphagnum auriculatum*, or *Calipogeia fissa*, are even relatively frequent in the floristic tables for *E. ciliaris* subcommunities in SW Great Britain (Rose *et al.*, 1996).

According to Rose *et al.* (1996), *E. ciliaris* is found in heath and mire communities from the north-west tip of Africa northwards through western Europe to southern England and the west of Ireland (Figure 1a). In the Iberian Peninsula, the distribution of this taxon (Figure 1b) is *grosso modo* parallel to the Atlantic coast, and it is found discontinuously along the whole Cantabrian coast, down the Gallician and Portuguese coast, and continues along the coast of Huelva (Doñana and its area) and close to the southern sierras of Cadiz and Malaga (Bingre *et al.* 2007 and Proyecto Anthos - Real Jardín Botánico de Madrid, 2009). This distribution area is enclosed by the 200 mm isoline of winter pluviometry, according to the Lopez-Bustins *et al.* (2008) delineation, and the current 5 ºC mean January air temperature isotherm (Kingston and Waldren, 2005).

It is complicated to construct maps of the plant communities of SW Spain that enable the outlining and quantification of their dynamics because most of the Mediterranean area has been affected by human activity over several millennia (Stevenson, 1985). This intense and continuous anthropogenic impact has altered the original plant communities, greatly hindering the reconstruction of their distributions earlier than the mid-twentieth century. Therefore, the features of a territory such as Doñana Natural Park, which has not received a great impact from anthropic activity until recent times (Sousa and García-Murillo, 2001), are interesting for the study of natural changes in vegetation. This approach may be useful to clarify the extent to which the changes that have been detected in peat bogs with *E. ciliaris* heathland communities are linked to human activities as opposed to natural causes such as climatic ones. For this purpose, the anthropogenic impacts from the seventeenth to the twentieth century will be studied, and we will analyse whether they alone are sufficiently intense to explain all of the changes in the peat bog areas.

Materials and Methods

Changes in peat bogs and associated plant communities

The surface area occupied by peat bogs was mapped at the scale of 1:25,000, beginning with its present-day distribution and going back in time to four periods: 1987, 1956, the end of the nineteenth century (*c.* 1869), and the beginning of the seventeenth century (*c.* 1630). Depending on the period, it was necessary to use different data sources: field reconnaissance, aerial photographs and satellite imagery, data from historical sources (fourteenth-twentieth centuries), and a reconstruction of the microtopography at the scale of 1:10,000. According to Stein *et al.* (2010), the approach and challenges of historical analysis are shown as we integrate multiple disparate data sources collected over a variety of spatial and temporal scales. This enabled the reconstruction of the original condition and surface area of the peaty bowls with which the communities of temperate heaths were associated (Rivas-Martínez *et al.*, 1980).

The various data sources available for mapping the area occupied by this plant community for each of the four periods studied are given in Table I.

Table I around here

The series of aerial photographs consulted were from flights in 1946 (1:40,000), 1956 (1:33,000), 1987 (1:20,000), and 2000 (1:30,000) together with Landsat TM (1986), SPOT (1989), and Landsat TM (1990) satellite images.

The studied data obtained from archives and documentary sources were mostly from the sixteenth to the twentieth century. For the twentieth century, 49 deeds and forestry reports from the estates of the Forestry Region of southeast Huelva for the period 1932-1978 were examined (see Supplementary Material 1 available online). Additionally, 72 historical maps of the study area, above all for the eighteenth and nineteenth centuries and the beginning of the twentieth, were also studied. The complete list can be found in Supplementary Material 2 (available online), and items explicitly cited in the text are found in Appendix A. The methodological possibilities obtained from combining data from aerial photography or satellite images with historical maps to reconstruct ecosystem changes have been outlined in earlier studies of different regions and ecosystems of our planet (Cousins, 2001; Petit and Lambin, 2002b; Bromberg and Bertness, 2005; Börjeson, 2009; Sousa *et al.*, 2009a, 2010; Stein *et al.*, 2010). Other authors have combined historical land-use maps with pollen records (Andrič *et al.*, 2010) to study environmental changes recorded in alpine peat bogs during the fifteenth, nineteenth and twentieth centuries. A wealth of different historical sources (drawings, paintings, prints, photographs, maps and written accounts) have been used for the reconstruction of glacier length variations during the Little Ice Age (Nussbaumer *et al.*, 2011).

The situation in 1987 and then in 1956 of the peat bogs with which *E. ciliaris* heathlands are associated were mapped from fieldwork and from the photointerpretation of aerial photographs and satellite images. The situations at the end of the nineteenth century and beginning of the seventeenth century was mapped based on the interpretation of the historical documentation, taking as reference or basis the previously constructed map for 1956. However, these data do not allow a standard mapping by themselves, as the historical maps do not have a standardised projection. The information obtained from historical sources should also be contrasted with another, independent source (e.g., microtopographic analysis) to avoid possible inaccuracies and errors in the drawing of the map. To transfer the data from the historical sources to a standardised cartography at the 1:10,000 scale, the microtopography of the lagoon basins was reconstructed by manual interpolation of 250 topographic heights following the method developed in an earlier publication (Sousa *et al.*, 2010). As shown in Figure 2, the 1:10,000 scale map shows topographic isolines only every 10 m but also includes a large number of topographic heights (Figure 2a, b), which enabled us to trace interpolated topographic isolines approximately every 2 metres to construct a hypsometric map (Figure 2c). Thereby, the areas of lower altitude are recognised, thus revealing the original situation of the extinct large lagoons (Figure 2d) and corroborating the historical sources.

Figure 2 around here

In contrast the historical maps, those based on microtopography present a standardised projection, suitable for treatment in a geographic information system and thereby quantifiable.

The value of studying the topography in detail to identify changes in vanished or transformed wetlands have been stated by Heimo *et al.* (2004).

Impact of anthropic activity

Most of the sources cited in the previous section were used in the reconstruction of the anthropic changes. The 49 deeds of purchase, sale, and valuation of the 10 forestry estates making up the study area provided much useful information (see Supplementary Material 1 available online). This was corroborated with the forestry maps of the area at a scale of 1:25,000, produced using the aerial photos from the flights of 1956 and 1987.

Soil-use data for earlier dates were compiled from various historical documentary sources and scientific and technical documents from the end of the nineteenth century and beginning of the twentieth (cited in upper case and listed in Appendix B). When the documentary sources are dated earlier than the second third of the twentieth century, generally they do not allow the quantification of the changes, although they do give a clear idea of the primary soil use and its location.

Impacts linked to climate trends

The series of instrumental observations from the stations of Huelva, Bodegones, Sanlucar de Barrameda, San Fernando, Cadiz (Cortadura) and Gibraltar were used to reconstruct the primary climatic trends—dry and wet years. The station that presented the longest and most complete precipitation series (1820-2000) was San Fernando. Because of the possible heterogeneities before 1882 suggested by some authors (Almarza *et al.*, 1996), the whole series was rectified. Consequently, the period 1863-1881 was rescaled according to the observatory closer to San Fernando that presented an historical series with simultaneous observations (Gibraltar, Cadiz-Urrutia brothers and Lisbon). Years were classified as dry if the annual rainfall is under the 40th percentile and wet if the rainfall is over the 60th percentile, taking into account the whole series of data. Finally, the accumulated frequency of the different types of years was represented.

The evolution of the irregularity of seasonal precipitation has also been studied. To analyse the evolution of precipitation irregularity, the specific disparity index (I_{di}) was calculated (García-Barrón *et al.*, 2011). We used this index to establish the consecutive alternation of dry and wet years. For its calculation we use the following equation:

$$I_{di} = [((p_i - p_{i+1})^2 + (p_i - p_{i-1})^2) / 2]^{1/2} / \mu_i$$

where p_i is the total precipitation in year i, p_{i+1} and p_{i-1} are the subsequent and previous years' precipitation, respectively, and finally μ_i is the average of the three preceding values.

Other issues related to the primary trends derived from the analysis of climatic variables (relative accumulated deviation of the annual mean precipitation, mean maximum temperature and mean minimum temperature) are studied by García-Barrón (2002), García-Barrón and Pita (2004) and Sousa *et al.* (2010).

Results

First, the results relating to land-use changes in the study area over the past four hundred years will be presented, followed by changes in peat bogs during the same period and finally the results related to climate trends will be examined.

Impact of anthropic activity

The impacts of anthropic activity on the natural resources of the study area have been divided into five phases.

Phase 1: AD 1577-1879 (Predatory and gathering period)

The first data come from the hunting book of King ALFONSO XI of Spain (1311-1350), which reports that the area close to the La Rocina brook can be crossed only in very dry winters, as in wet winters there are many quaking bogs. These quaking bogs are in marshy areas associated with emergences of shallow water and generally carpeted by bryophytes. Later, at the end of the sixteenth century, ARGOTE DE MOLINA (1582) refers to the numerous birds breeding on the lagoons and marshes close to La Rocina.

In this period, the study area was described as follows: "... *all dead sandy areas without use, without land giving pastures for grazing or any return for these expenses*...” (BRABO DE LAGUNAS, 1577a). The idea of this coastal strip as an immense unsheltered sandy zone is also noted by the cartographer of King Felipe IV of Spain (Texeira, 1634).

The reviewed historical documentation thus records a territory consisting of unproductive sandy areas that were not usable even for grazing livestock. The analysis of the historical maps of the seventeenth century confirms this situation (e.g., Jodocus Hondius, 1606; Texeira, 1634; Blaeu, 1640-1650; Doménico de Rossi, 1696). In addition, the tracks were very rough and difficult to negotiate, and the numerous lagoons that existed were optimal breeding grounds for malaria-transmitting mosquitoes [as reported by the *Relaciones* of Tomás López at the end of the eighteenth century (RUIZ GONZÁLEZ, 1999)].

All of this evidences that the study area and its surroundings were a demographic desert. At least from the sixteenth century, human activity was limited essentially to some gathering, fishing, charcoal burning and, only occasionally, hunting. The population was limited to some fishermen (BRABO DE LAGUNAS, 1577b), watchtower keepers and carabineers protecting the coast, generally in marginal nuclei. This situation largely continued until the beginning of the twentieth century (BARBADO, 1940; PATRIMONIO FORESTAL DEL ESTADO, 1941; MORA, 1981).

Phase 2: AD 1879-1936 (Transition to intensive usage of resources)

This phase saw a transition from a hunting and gathering period with a very limited effect of human activity on the environment to a forestry period. The trigger for this transformation was the surveying and registration of the territory (1851-52), with the conversion of common uncultivated land into private property. As seen in Figure 3, the territory was divided into a series of estates that became private ("Cotos") and whose owners began activities intended to increase their profitability.

Figure 3 around here

Therefore, the period 1879-1936 is a transition time, linked to the area's discovery and conquest by private property after the sale of these lands by the Spanish government between 1864 and 1879 (Espina and Estévez, 1993).

Phase 3: AD 1936-1972 (Forestry exploitation period)

The attempts of some owners, more or less independently, to make the area productive (DE LA LAMA, 1951) crystallised in an ambitious process of forestry exploitation, during which the lands became state property. This, together with the Spanish political situation—the end of the Civil War (1936-1939)—led to its radical transformation.

The primary event triggering these changes was the "Declaration of National Interest" ("Declaración de Interés Nacional") leading to the afforestation of the lands situated in the "Southeast Huelva Forestry Region" ("Comarca Forestal del Sureste de Huelva") (Espina and Estévez, 1993).

The first purpose of afforestation was to curb the advance of the dunes, as indicated by Espina and Estévez (1993). Then, there was the insalubrious condition of the territory due to the spreading of malaria (KITH, 1936; PATRIMONIO FORESTAL DEL ESTADO, 1941) from the numerous lagoons. In time, this initial idea was transformed into the creation of a forest contributing to the revaluation of an unproductive territory.

This intervention was undertaken by three bodies that distributed the territory: the Hydrological-Forestry V Division in the most coastal estates, the State Forestry Heritage, and the National Institute of Industry. As a consequence, new forestry infrastructures (hamlets, nurseries, and small forestry treatment plants; see Figure 3) were generated, connected by a dense network of 30 new tracks at the end of the 1940s.

This intense process of forest production has been quantified using essentially two sources: the analysis of the aerial photos of 1956 and 1987 and the purchase-sale-valuation deeds from the various estates or reserves involved. The data from the photointerpretation of the flights not only provides information on and exact mapping of the distribution of the forest crops at two points in time (1956 and 1987), it is also a tool for assessing the reliability of the figures in the estate deeds. The overall result of this analysis is depicted in Figure 4.

Figure 4 around here

The population of the zone reached a peak in the mid-1950s (945 inhabitants in 1955). As seen in Figure 4b, the changes in the area afforested with eucalyptus were parallel to the change in the estimated number of inhabitants (although due to the sample size, it was not possible to establish any statistically significant correlation), concentrated mostly in the forest hamlets. The localisation of the greater part of the monocultures of eucalyptus precisely in the area of the peat bogs and the type of growth of this allochthonous species explain the impact of afforestation on the plant communities associated with the peaty zones.

From the 1950s onwards, forestry activity declined, with practically all of the available area having been afforested. By 1956, almost 90% (21,089 ha) of the area was occupied by forest production uses. In the case of eucalyptus, tree felling resulted in a decrease in the area occupied beginning in the early sixties. At the same time, the forest hamlets began to be depopulated, until a demographic vacuum (191 inhabitants in 1986) similar to the original one was reached. Another important fact is that by 1987, nearly 10% (2,468 ha) of the zone was dedicated to irrigated crops on the La Rocina I estate.

Phase 4: AD 1972-1989 (Transition to a less intensive usage)

In 1972, the management of the lands of the State Forestry heritage and the Hydrological-Forestry V Division passed to the Institute for Nature Conservation. At the same time, the stands of eucalyptus were losing their economic profitability.

In 1978, the Reformation and Agriculture Development Institute of the Spanish Agriculture Ministery included 1,460 ha of Coto de la Rocina II and 266 ha of Coto del Sacristán in the Almonte Marshland Plan, transforming the NE region of the area of study into an irrigated land for a short time. In 1984, the Regional Government of Andalusia became responsible for the forest issues and created the Natural Park of Doñana in 1989, belonging to the Protected Natural Environments Network.

Phase 5: AD 1989-2011 (Conservationist period)

From 1989 to the present, the repopulation space that includes the study area is dedicated essentially to conservation. In the last decade of the twentieth century, investment was made in a project for the ecological restoration of the lagoons of this natural park, with a gradual elimination of the area growing eucalyptus (García-Murillo, 2006; Custodio *et al.*, 2009). Currently, the forest hamlets are in ruin or abandoned.

The usage during this period is basically linked to tourism in the coastal urban nuclei adjoining the protected zone (Matalascañas and Mazagón). The high profitability of such usage has enabled the reduction of most of the pressure on the intensive exploitation of the natural resources in the rest of this space. In addition, part of the (more or less traditional) marginal usage of the area has been revived, although largely sustained by subsidies from the European Union.

A summary of the main events and exploitations during these five phases from 1577 to present is shown in Table II.

Table II around here

As shown in Table II, the intensive use of the natural resources of this territory is limited only to the period after 1936 (Sousa and García-Murillo, 2001).

Changes in peat bogs and associated plant communities

Table III displays the changes in the vegetation and associated wetlands present in the study area based on the stereoscopic photointerpretation of the flights of 1956 and 1987.

Table III around here

What stands out most in this table is the significant decrease in the area occupied by peat bogs along with the community of heaths of *Erica ciliaris* and *Ulex minor*, which are essentially replaced by a hygrophyte scrub of *Erica scoparia* and *Ulex australis* (denominated Monte Negro by Ramírez Díaz *et al.*, 1977). A decrease in area of 88.2% in just 31 years is evidenced not only by the data on surface area but also by the number of patches or polygons of mapped vegetation. The peat bogs and the heathlands of *E. ciliaris* decrease in 148 polygons, whereas at the same time the heathlands of *Erica scoparia* increase in 143 patches.

From these data, and with the help of the historical sources and the microtopographic analysis, the historical evolution of these communities during the last four centuries can be reconstructed, as seen in Figure 5.

Figure 5 around here

The outstanding feature of Figure 5a, aside from the reduction in the period 1956-1987, is that the disappearance of these communities began much earlier. Its origin goes back at least to the beginning of the seventeenth century, and it became more marked at the beginning of twentieth century. This is clearly shown in Figure 5b.

With the beginning of the twentieth century, some of the large patches of peat bogs and heaths of *E. ciliaris* disappeared; such is the case for the large Mediana lagoon (which occupied some 197 ha at the beginning of the seventeenth century), and Hilo lagoon (155 ha at the beginning of the seventeenth century; Figure 5a). This can be seen from various historical maps of the period, such as Coello (1869), Gonzalo y Tarín (1870), Valverde (1880, 1888), Carrasco y Padilla (1892), and Ibáñez de Íbero (1902); in historical documents (VALVERDE, 1885-1888); and in the historical place names of the area (Sousa *et al.*, 2010).

There was, therefore, as seen in Table IV, a regressive process going back at least to the beginning of the seventeenth century (estimated annual rate of decrease: 1.2 ha/year), which intensified at the beginning of the twentieth century (annual rate of decrease: 2.4 ha/year). This means that the area originally occupied by these peat bogs decreased by approximately 15% from the seventeenth century to the nineteenth (296.4 ha) and by almost 25% up to the mid-twentieth century (502.4 ha).

Table IV around here

This regressive trend intensified exponentially during the second half of the twentieth century (annual rate of decrease: 43.6 ha/year; Table IV), until the area that had been occupied at the beginning of the seventeenth century had been reduced by 91.1%.

Impacts linked to climate trends

Figure 6 shows the evolution of the accumulated frequency of dry and wet years obtained by means of the analysis of percentiles of the annual rainfall—data from the Observatory of San Fernando. In this graph, horizontal segments represent neutral periods. The upward segments characterise the respective dry or wet periods in the two evolution lines. An increase in the accumulated frequency of wet years is evident at the end of the nineteenth century. It can be seen that the slope of the accumulated frequency increased during the last wet pulse of the Little Ice Age (hereafter, LIA) in Andalusia. There is a change in the trend at the beginning of the twentieth century, denoted by an increase in the accumulated frequency of dry years and a decrease in the number of wet years (the slope of the straight line flattens). These results coincide with the reconstruction of this period performed by Rodrigo *et al.* (1999) using proxy data and the dating of the end of the LIA in Andalusia by Castro-Díez *et al.* (2007).

Figure 6 around here

Regarding the availability of water for vegetation, it is also important to consider the rainfall distribution within each year and its irregularity between consecutive years (Figure 7). During the period 1820–2000, the average spring precipitation is 140.3 mm, but over the last sixty years of the twentieth century, that measurement tends to decrease. This declining tendency is close to 50% (Δp_s =-1.25 Δt +165; where p_s is the spring precipitation of each year in mm, t: years). However, the specific disparity index shows an increasing trend, especially at the end of the twentieth century.

Figure 7 around here

The variation in the availability of water in the ground can be affected changes in the isopiezometric levels caused by climate trends. This is relevant because the peat bogs in the study area, with which the *E. ciliaris* patches are associated, are fed hypogenically. To check for a relationship between the height of the isopiezometric level and the evolution of peat bog patches, the corresponding graphics have been superimposed. The relationship between the isopiezometric levels and the regression of the peat bogs beginning in the seventeenth century is illustrated in Figure 8a. It can be seen that the desiccation of the peat bogs follows the gradient of the water-table — from the southernmost to the northernmost peat bogs. This reconstruction can be compared with the situation in 1987 (Figure 8b).

Figure 8 around here

By comparing these two situations, we can observe that the first peat bogs to be desiccated were those in which the water table was furthest from the surface. This was the case for the Mediana and Hilo lagoons, which completely disappeared at the end of the nineteenth century.

The desiccation gradient during the period of greater forestry activity (1956-1987) progressed according to the water table height. In 1987, only those peat bogs with a water table close to the surface still remain (Figure 8b). Therefore, the lowering of the water table correlated with the peat bogs’ desiccation, both before and during the intense forestry period.

Discussion

Understanding long-term human-environment interactions is essential for understanding changes in terrestrial ecosystems and requires a historical reconstruction of past land-cover changes (Petit and Lambin, 2002a). Specifically, anthropogenic changes to wetland ecosystems are primarily a twentieth century process (Álvarez-Cobelas *et al.*, 2001). The results obtained in the previous sections confirm these statements and allow us to delimit and date the anthropogenic impacts in the study area.

Regardless, the results of this study highlight that, from the beginning of the seventeenth century to the end of the twentieth, the extent of the peat bog areas has been gradually reduced (see Figure 5b). Although at the end of the nineteenth century the annual rate of regression of peat bogs was accelerated, it was not until the second half of the twentieth century that this gradual process of aridisation became extremely marked. We will continue by discussing the factors that have intervened throughout these almost 400 years and that have affected the distribution of this community. In the Mediterranean area in Europe, anthropic activity has been the main driver of change and of landscape formation in recent millennia. Therefore, this is the first aspect to be discussed.

Impact of anthropic activity in peat bogs

The Mediterranean area is one of the most significantly altered biodiversity hotspots on Earth (Myers *et al.*, 2000), and it has been affected by anthropogenic impacts for millennia (Stevenson and Harrison, 1992; Geri *et al.*, 2010). As a result, only 4.7% of its primary vegetation remains—the agricultural lands, evergreen woodlands, and maquis habitats that dominate the hotspot today are the result of anthropogenic disturbances over several millennia

(Falcucci *et al.*, 2007). In the study area, only 8.9% of the area that had been occupied by peat bogs in the early seventeenth century still remains (see Table IV).

Within this general Mediterranean framework, the study area presents some peculiarities: it is a rough territory, historically not very transitable and secularly unproductive [with regard to livestock and agriculture because of its oligotrophic soils (Sousa and García-Murillo, 2001; Custodio *et al.* 2009)], and it is an area where the transmission of malaria is endemic because of the great area and typology of its wetlands (Sousa *et al.*, 2009b). We believe this explains why, despite being part of the Mediterranean environment, the study area was not subjected to intense anthropic impacts until the middle of the twentieth century (see Table II). The intensive use of the natural resources of this territory is limited to the period after 1936. Figures 4a and 5b show the coincidence in the study area between the huge reduction in peat bogs (1352.4 ha) and the phase of peak forest exploitation (1936-1972).

Although much of the forest area was planted with *Pinus pinea*, the greatest impact of this anthropic use was from afforestation with different species of eucalyptus on the estates where peat bogs were located. These water bodies are an optimal breeding ground for the culicid transmitters of the parasite that carries malaria. In consequence, these lagoons and other wet areas were subjected to an exhaustive antimalarial treatment (Sousa *et al.*, 2009b), together with a gradual process of desiccation. First, the species of eucalyptus most resistant to swamping (such as *Eucalyptus camaldulensis*) were planted, followed, as the lagoon bowls dried up, by less-tolerant species (such as *Eucalyptus globulus*; BURGUERS, 1949), until most of the peaty formations were dry. The most immediate consequence of this was the replacement of the communities of *Erico ciliaris-Ulicetum (minoris) lusitanicus* by a hygrophyte scrub, less demanding with respect to continuity in swamping levels.

Already in 1956 the presence of eucalyptus is very extensive, so the area originally occupied by the *E. ciliaris* community would have been even larger. By 2011, the greater part of the eucalyptus has disappeared, but the *E. ciliaris* communities have not recovered their 1956 extent.

The desiccation effect produced by the high evapotranspiration of the eucalyptus monocultures led to a loweringfall in the height of the water table, as confirmed by hydrogeological studies (Trick and Custodio, 2004; Manzano *et al.*, 2005; Custodio *et al.*, 2009). This process led to the desiccation of most of the peat bogs dominated by *E. ciliaris* and *Ulex minor* and their replacement by a hygrophyte scrub (dominated by *Erica scoparia* and *Ulex australis*) better adapted to seasonal swamping (Ramírez Díaz *et al.*, 1977; Sousa and García-Murillo, 2003). As Gavilán (2005) states, in Mediterranean territories, water availability in soils is a limiting factor for the development of vegetation in spring or autumn as well as in summer. These results seem to coincide with those from studies carried out on more northern peatlands (Weltzin *et al.*, 2003; Keller *et al.*, 2004), where the floristic composition of bogs and fens can be affected in response to warming and/or changes in water table elevation.

However, an examination of this desiccation process from the beginning of the seventeenth century yields striking results. Superimposing the sequence of desiccation of these communities and of the lagoons with which they are associated together with the isopiezometric data that indicate the height of the water table reveals that this drop in the water table is prior to the most intense anthropic activity in the zone.

Impacts linked to climate trends in peat bogs

Until the first half of the twentieth century, human presence in the study area was nominal (hunting and gathering activities). However, as seen in Table IV, from the beginning of the seventeenth century until 1956, the area occupied by *E. ciliaris* heaths has decreased by 502 ha, some 24.7% of the area estimated for 1630. This downward trend became sharper at the beginning of twentieth century, as the estimated mean annual rate of loss increased from 1.2 ha/year to 2.4 ha/year. What, then, are the causes of these changes prior to the intense human activity in the study area? The analysis of the instrumental series of precipitation and temperature reveals significant changes:

A. The first change is a trend towards a decrease in the accumulated frequency of wet years compared with the accumulated frequency of dry years. The beginning of the trend towards an increased frequency of dry years is seen at the beginning of the twentieth century, after the third and last wet period of the LIA (see Figure 6). This last wet period has been dated to the end of the nineteenth century in Andalusia by Rodrigo *et al.* (1999) and on the Spanish Mediterranean coast by Barriendos and Martín-Vide (1998) and is coupled with an increase in positive anomalies in annual mean precipitation (Sousa *et al.*, 2010). After this wet period, at the beginning of the twentieth century, the frequency of dry years increases, which would affect the hygrophyte and phreatophyte plant communities more markedly after the summer climate becomes more pronounced as a consequence of the decrease in spring precipitation (especially during the second half of the twentieth century; Figure 7a).

B. In parallel with this decrease in wet years and spring precipitation, there is an increase in the mean minimum temperature from the beginning of the twentieth century onwards (García-Barrón and Pita, 2004) and an increase of approximately 1 ºC in the annual mean temperature (Castro-Díez *et al.*, 2007). Furthermore, the results in Figure 7b show an increase in the disparity of the precipitation of the SW Iberian Peninsula, which could increase erosional and colmatation processes by mobilising sediments that would eventually be deposited over the lowest areas (lagoon basins and peaty areas). Granados *et al.* (1988), Merino *et al.* (1990) and Sousa *et al.* (2003) have studied this process, known as secondary dunification, in some areas of the Biosphere Reserve of Doñana. According to these authors, this process, whose origin is associated with changes in climate trends, would overlap with the impacts resulting from changes in land use. In this context, García-Barrón *et al.* (2011) indicate that, regarding the disparity in rainfall, there is a relative stability during the first third of the twentieth century coinciding with a period of low precipitation and a progressive increase during the last three decades of the twentieth century in the SW Iberian Peninsula.

Thus, there are two climatic processes that appear to be synergically superimposed at the beginning of the twentieth century: on one hand, the end of the LIA, and on the other, the beginning of global warming. These biological changes coincide with what Sorvari *et al.* (2002) and Sousa *et al.* (2006) term post-LIA warming.

If this interpretation is correct, it should be reflected in hydrogeology. In other words, being a peat-associated shrub, at least in the study area, these climate changes should be reflected in changes in the height of the isopiezometric levels. Therefore, if a climate factor regulates the availability of water at the soil level, the sequence of disappearance of the lagoons should follow the isopiezometric level. This can be observed in Figure 8.

The end of the LIA in Andalusia (Castro-Díez *et al.*, 2007) at the end of the nineteenth century is associated with a gradual lowering of the water table, affecting the stenohydric plant communities of the study area. The correlation of the historical climatic data (Granados *et al.*, 1988; Merino *et al.*, 1990; Barriendos and Martín-Vide, 1998; Rodrigo *et al.*, 1999, 2000) with the reconstruction of the area occupied by peat bogs in the zone and of the extinct large lagoons suggests that this was a process with a marked point of inflection. The dry phase that occurs after the end of the LIA (at the end of the nineteenth century and beginning of the twentieth) coincides with the desiccation of some wetlands in the southern (Valero-Garcés *et al.*, 2006; Martín-Puertas *et al.*, 2008; Sousa *et al.*, 2009a) and central-eastern (Romero-Viana *et al.*, 2009) Iberian Peninsula. In relation to this, Diodato *et al.* (2011) note that erosive forcing increased towards the end of the Little Ice Age (~1850) in the western and central Mediterranean and that forcing has increased in the recent warming period at low Mediterranean latitudes due to a higher frequency of intensive storms. These changes coincide in time with the waning of the glaciers in all Iberian mountains. The most southern historical glacier in Europe (Sierra Nevada in Andalusia, southern Spain) became extinct in Sierra Nevada during the first years of the twentieth century (González Trueba *et al.*, 2008). Morellón *et al.* (2012), studying multiproxy palaeoclimatic records in the Southern Pyrenees, detected a short-living return towards colder conditions and glacier stabilisation that occurred during the late 19th–early 20th century, followed by warmer and more arid conditions afterwards.

The regression of these communities is consistent with the effects on the biomes of the Mediterranean mountainous zones of Montseny (NE Spain; Peñuelas and Boada, 2003). Those authors demonstrate a progressive replacement of cold-temperate ecosystems by Mediterranean ecosystems, involving the displacement of—among others—heath communities. Similarly, Jump *et al.* (2006), studying the southern limit of communities of *Fagus sylvatica*, conclude that increasing temperatures may lead to a rapid decline in the growth of range-edge populations and a consequent retraction of the species distribution in southern Europe. In this regard, the models applied to Spain for the effects of global warming on plant biodiversity predict a “mediterraneisation” in the north and an “aridification” in the south of the Iberian Peninsula (Fernández-González *et al.*, 2005).

Keller et al. (2004) argue that climate change will directly alter peatland mineralisation pathways through changes in precipitation regimes (leading to changes in the aerobic status of peat) and changes in temperatures. It is also important to consider the changes in the plant communities associated with peat bogs (in this case, the replacement of the communities of *E. ciliaris* and *Ulex minor* by *E. scoparia* and *U. australis*) because climate change may also act indirectly through the contributions of litter due to variations in plant community composition (Keller et al., 2004).

The effects of climate change on the heath communities of *E. ciliaris* can also be related to other studies indicating that the recent increase in temperatures has affected the phenology, dynamics, composition, and distribution of very different communities (Walther *et al.*, 2002). Ecosystem responses to past climate change can provide insight into plausible scenarios of response to future change and can elucidate factors that may influence the overall predictability of such responses (Lloyd, 2005). Recent global climate change has already begun to affect species' geographic ranges. Poleward shifts in range limits correlated with climatic warming and changes in precipitation have been documented for a wide spectrum of temperate and subtropical species, and phenological changes portend even more significant poleward shifts (Colwell *et al.*, 2008). However, as noted by Thomas *et al.* (2009), linking extinction and climate change involves problems of detection and attribution. Unless detailed survey data are available, it is difficult to detect the initial stages of decline, so that recognition of the association between extinction and climate change will lag after the event.

Summary and conclusions

In this paper, we have reconstructed the changes in the peat bog areas over the last four centuries in SW Europe. These peat bogs have undergone a dramatic reduction (91.1%) compared to their extent in the middle of the seventeenth century. The key factor that has prompted this change is a lowering of the water table, which became especially stressed during the second half of the twentieth century, primarily due to afforestation with eucalyptus and to climate trends. Therefore, the changes in the peat bogs of SW Europe from the seventeenth to the twentieth century are due to both anthropogenic impacts associated with changes in land use and climate impacts, primarily caused by an aridisation process at the end of the LIA.

Parmesan *et al.* (2011) state that land-use change can lead to more subtle synergisms, either enhancing or masking responses to climate change. That is, important regional or global alterations in plant communities as a result of climate changes during recent centuries may have remained undetected because of the strong impact that man has had and is having on certain natural spaces. García-Plazaola *et al.* (2008) have demonstrated that most Mediterranean species are able to acclimatise efficiently to heat stress, whereas Atlantic species such as the *E. ciliaris* heathlands associated with these peat bogs will be more strongly affected by climate warming. As those authors note, this could be of special relevance in the context of future climate warming in which Atlantic species are more severely affected.

Thus, the results of this study underline the fact that the hygrophytic heathland community of *E. ciliaris*, associated with peaty areas, is sensitive to both anthropogenic impacts and changes in climate trends. Understanding these trends could be a tool of interest not only for studying the dynamics of these oceanically influenced communities but also for analysing the impacts of global change, and recognising the impacts of past and future climate changes. In fact, the forecasted scenarios for the end of the 21st century predict that the Mediterranean climate and grassland ecosystems will most likely experience the greatest proportional change in biodiversity due to the substantial effects of all drivers of biodiversity change (Sala *et al.*, 2000).

The changes in the water table have played a key role in the disappearance of the peat bog areas of SW Europe. This becomes even more important if we take into account the projections of the future effects of climate change in the study area. The results of the modelling study of Doñana by Guardiola-Albert and Jackson (2011) indicate that, in general, the changes in climate that will occur by the 2080s will lead to a reduction in groundwater resources. According to Muñoz *et al.* (2012), under future climate change, the summer swamping of *E. ciliaris* heathlands will decrease and the phreatic layer will descend, drying the substrate and modifying the species composition of the community, decreasing the number of specialist species in favour of generalist species. Thus, these ecosystems will lose their ecological identity.

Further palaeoecological studies based on information obtained from dating the peat could complete the analysis performed in this article. We believe that the method described in this study can be used as a tool of interest for reconstructing peat bogs and their associated plant communities, especially those acting as indicators of biological changes of anthropic and/or climatic origin. Therefore, regional studies that use an *ad hoc* interdisciplinary analysis to examine the southern boundary of plant communities sensitive to climate changes, as in this case, can be a useful tool for progress in this field.

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Appendices

Appendix A. Historical Maps cited

1606. *"Andalucía Nova (Jodocus Hondius, 1606)"*. Map Library Instituto Geográfico Nacional, Madrid.

1634. “*Tabla del Reyno de Andalvzia*”. Pedro Texeira”, in: Pereda, F., Marías, F. (Eds.), El Atlas del Rey Planeta. La Descripción de España y de las costas y puertos de sus reinos de Pedro Texeira, 2nd edn. Nerea, Madrid.

1640-1650. *"Andaluzia continens Sevillam et Cordobam"*. Theatrum du Monde au Nouvel Atlas. Willem Blaeu. Map Library Instituto Geográfico Nacional, Madrid.

1696. *"Li Regni de Granata E D'Andalucía"* Domenico de Rossi (Domenicus Rubeis). Map Library Instituto Geográfico Nacional, Madrid.

1869. "*Huelva*", Francisco Coello Coronel de Ingenieros Militares. Historic library of maps Servicio Geográfico del Ejército, Madrid.

1870. “*Carta Geográfico-Minera de la provincia de Huelva*”. 1:200,000. Joaquín Gonzalo y Tarín. Historic library of maps Biblioteca Nacional de España, Madrid.

1880. "*Provincia de Huelva*", Emilio Valverde. 1:750,000. Atlas Geográfico descriptivo de la Península Ibérica, Islas Baleares, Canarias y Posesiones Españolas en Ultramar. Historic library of maps Servicio Geográfico del Ejército, Madrid.

1888 “*Mapa General de Andalucía*”. 1:750,000. Emilio Valverde. In: Valverde, E. (1885-1888). Guía del Antiguo Reino de Andalucía. Colección Los Libros del Caballero Andante 12. Don Quijote 1992, Seville.

1892. "*Nuevo mapa geográfico estadístico de la provincia de Huelva*", José Carrasco y Padilla (Excma. Diputación Provincial de Huelva). 1: 300,000. Map Library Instituto Geográfico Nacional, Madrid.

1902. "*Mapa de España*", Ibáñez de Ibero. 1:500,000. Mapa de España formado por el Excmo. señor Mariscal de Campo D. Carlos Ibáñez é Ibáñez de Ibero con motivo de la división del territorio en zonas militares para situar las reservas y depósitos del ejército (sic). Publication 1884 and edited in 1902. Lit. Instituto Geográfico y Estadístico. Library Instituto Geológico y Minero, Madrid.

Appendix B. Historical documents and unpublished technical reports cited

ALFONSO XI, 1311-1350. Libro de montería que mandó escribir el muy alto y muy poderoso Rey Don Alonso de Castilla y de León, último deste nombre. Acrecentado por Gonzalo ARGOTE DE MOLINA. Reproducción facsímil de la edición de Sevilla de Andrea Pescioli (1582). Sociedad de Bibliófilos Andaluces (1979), Valencia.

ARGOTE DE MOLINA, G., 1582, Discurso sobre el libro de la montería que mandó escribir el muy alto y muy poderoso Rey Don Alonso de Castilla, y de León. In: Libro de montería que mandó escribir el muy alto y muy poderoso Rey Don Alonso de Castilla y de León, último deste nombre. Acrecentado por Gonzalo ARGOTE DE MOLINA. Reproducción facsímil de la edición de Sevilla de Andrea Pescioli (1582). Sociedad de Bibliófilos Andaluces (1979), Valencia.

BARBADO, J.A., 1940. Tasación para la adquisición por convenio de la finca de “Coto Ibarra. Patrimonio Forestal del Estado. Unedited technical Report.

BRABO DE LAGUNAS, L., 1577a. File D-13 que trasmite la orden de S. M. para construir cuatro torres (Salabar, Carbonera, Higuera y Asperillo) en la costa de Arenas Gordas. Oposición del Cabildo y alternativa que expone. 5 de julio de 1577. Compiled by Mora, L. (1981). Torres de almenara de la costa de Huelva. Diputación Provincial de Huelva, Huelva

BRABO DE LAGUNAS, L., 1577b. File D-24 que trasmite al Conde de Barajas, Asistente de esta ciudad, y al alcalde de la mar y río de la misma, la orden de S.M. para que los barcos sardineros y otros pesqueros que faenan en aguas de Arenas Gordas transporten piedras de Chipiona para las obras de las torres de almenara de la costa. Conformidad de los interesados. 22 diciembre de 1577. Compiled by Mora, L. (1981). Torres de almenara de la costa de Huelva. Diputación Provincial de Huelva, Huelva.

BURGUERS, T., 1949. El arboretum forestal de Villarejo. Revista de Montes 29, 400-404.

PATRIMONIO FORESTAL DEL ESTADO, 1941. Reconocimiento y propuestas de trabajos en la finca del Coto Ibarra. Unedited technical Report, Huelva.

DE LA LAMA, G., 1951. Diez años de trabajos forestales. Revista de Montes 39, 195-201.

ESPINA, J., ESTÉVEZ, A., 1992. Programa de recuperación del Patrimonio *del P.N.Doñana*. Vol. III. Abalario. Unedited technical Report, Huelva.

KITH, M., 1936. Propuesta de ampliación del proyecto de fijación y repoblación de las Dunas de Almonte. V División Hidrológico-Forestal del Guadalquivir. Unedited technical Report, Huelva.

MORA, L., 1981. Torres de almenara de la costa de Huelva. Diputación Provincial de Huelva, Huelva.

RUIZ GONZÁLEZ, J.E., 1999. Huelva, según las relaciones enviadas por los párrocos al geógrafo real Tomás López en el siglo XVIII. Diputación Provincial de Huelva, Huelva.

VALVERDE, E., 1885-1888. Guía del Antiguo Reino de Andalucía. Colección Los Libros del Caballero Andante 12. Don Quijote, 1992. Sevilla.

References

Allier C, González Bernáldez F and Ramírez Díaz L (1974) *Mapa Ecológico de la Reserva Biológica de Doñana y memoria a E. 1:10.000*. Seville: División del Consejo Superior de Investigaciones Científicas, 243 pp.

Almarza C, López JA and Flores C (1996) *Homogeneidad y variabilidad de los registros históricos de precipitación en España*. Madrid: Instituto Nacional de Meteorología, 318 pp.

Álvarez-Cobelas M, Cirujano S and Sánchez-Carrillo S (2001) Hydrological and botanical man-made changes in the Spanish wetland of Las Tablas de Daimiel. *Biological Conservation* 97: 89-98.

Andrič M, Martinčič A, Štular B, Petek F and Goslar T (2010) Land-use changes in the Alps (Slovenia) in the fifteenth, nineteenth and twentieth centuries AD: A comparative study of the pollen record and historical data. *The Holocene* 20: 1023-1037.

Barriendos M and Martín-Vide J (1998) Secular climatic oscillations as indicated by catastrophic floods in the Spanish Mediterranean coastal area (fourteenth–nineteenth centuries). *Climatic Change* 38: 473–491.

Bingre P, Aguiar C, Espírito-Santo D, Arsénio P, Monteiro-Henriques T (Coords.) (2007) *Guia de Campo. As árvores e os arbustos de Portugal continental*. Lisbon: Fundaçao Luso-Americana para o Desenvolvimento, 462 pp.

Börjeson L (2009) Using a historical map as a baseline in a land-cover change study of northeast Tanzania. *African Journal of Ecology* 47: 185-191.

Bromberg KD and Bertness MD (2005) Reconstructing New England salt marsh losses using historical maps. *Estuaries and Coasts* 28: 823-832.

Castro-Díez Y, Esteban-Parra MJ, Staudt M and Gámiz-Fortis S (2007) Temperature and precipitation changes in Andalusia in the Iberian Peninsula and Northern Hemisphere context. In: Sousa A, García-Barrón L and JuradoV (eds.) *Climate Change in Andalusia: trends and environmental consequences*. Seville: Consejería de Medio Ambiente de la Junta de Andalucía, 57-77.

Chapman SB and Rose RJ (1994) Changes in the distribution of *Erica ciliaris* L. and *E.* x *watsonii* Benth. in Dorset, 1963-1987. *Watsonia* 20: 89-95.

Cobo D, Sánchez-Gullón E and García-Murillo P (2002) Flora y Vegetación. In: García Canseco V (ed.) *Parque Nacional de Doñana*. Talavera de la Reina: Canseco Editores, 109-174.

Colwell RK, Brehm G, Cardelús CL, Gilman AC and Longino JT (2008) Global warming, elevational range shift, and lowland biotic attrition in the wet tropics. *Science* 322: 258-261.

Cousins SAO (2001) Analysis of land-cover transitions based on seventeenth and eighteenth century cadastral maps and aerial photographs. *Landscape Ecology* 16: 41-54.

Custodio E, Manzano M and Montes C (2009) *Las aguas subterráneas en Doñana: aspectos ecológicos y sociales*. Seville: Agencia Andaluza del Agua, 243 pp.

Espina J and Estévez A (1993) El espacio de repoblación forestal de Cabezudos-Abalario. In: Granados M and Ojeda JF (eds.) *Intervenciones Públicas en el Litoral Atlántico andaluz. Efectos territoriales*. Seville: Agencia de Medio Ambiente, 95-107.

Diodato N, Bellocchi G, Romano N, and Chirico GB (2011) How the aggressiveness of rainfalls in the Mediterranean lands is enhanced by climate change. *Climatic Change* 108: 591-599.

Falcucci A, Maiorano L and Boitani L (2007) Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. *Landscape Ecology* 22: 617-631.

Fernández-González F, Loidi J and Moreno JC (2005) Impacts on plant biodiversity. In: Moreno JM (ed.) *A preliminary general assessment of the impacts in Spain due to the effects of climate change*. Spain: Ministry of the Environment, 179-242.

García Barrón L (2002) Un modèle pour l'analyse de la sécheresse dans les climats méditerranéens. *Publications de l'Association Internationale de Climatologie* 14: 67-73.

García-Barrón L, Aguilar M and Sousa A (2011) Evolution of annual rainfall irregularity in the southwest of the Iberian Peninsula. *Theoretical and Applied Climatology* 103: 13-26.

García-Barrón L and Pita MF (2004) Stochastic analysis of time series of temperature in the south-west of the Iberian Peninsula. *Atmosfera* 17: 225-244.

García-Murillo P (2006) Reconstruction of the Abalario Landscape. A referent model for environmental restoration in Doñana. In: García Novo F and Marín Cabrera C (eds.) *Doñana. Water and Biosphere*. Madrid: Ministerio de Medio Ambiente, 283-287.

García-Plazaola JI, Esteban R, Hormaetxe K, Fernández-Marín B and Becerril JM (2008) Photoprotective responses of Mediterranean and Atlantic trees to the extreme heat-wave of summer 2003 in Southwestern Europe. *Trees Structure and Function* 22: 385-392.

Gavilán RG (2005) The use of climatic parameters and indices in vegetation distribution. A case study in the Spanish Sistema Central. *International Journal of Biometeorology* 50: 111-120.

Geri F, Rocchini D and Chiarucci A (2010) Landscape metrics and topographical determinants of large-scale forest dynamics in a Mediterranean landscape. *Landscape and Urban Planning* 95: 46–53.

González Trueba JJ, Martín Moreno R, Martínez de Pisón E and Serrano E (2008) `Little Ice Age' glaciation and current glaciers in the Iberian Peninsula. *The Holocene* 18: 551-568.

Granados M, Martín A and García Novo F (1988) Long-term vegetation changes on the stabilized dunes of Doñana National Park (SW Spain). *Plant Ecology* 75: 73-80.

Guardiola-Albert C and Jackson CR (2011) Potential impacts of climate change on groundwater supplies to the Doñana wetland, Spain. *Wetlands* 31: 907-920.

Heimo M, Siemens AH and Hebda R (2004) Prehispanic changes in wetland topography and their implications to past and future wetland agriculture at Laguna Mandinga, Veracruz, Mexico. *Agriculture and Human Values* 21: 313–327.

Instituto Tecnológico y Geominero de España (1992) *Hidrogeología del Parque Nacional de Doñana y su Entorno*. Madrid: Instituto Tecnológico y Geominero de España, Madrid, 64 pp.

Jump AS, Mátyá C and Peñuelas J (2009) The altitude-for-latitude disparity in the range retractions of woody species. *Trends in Ecology & Evolution* 24: 694-701.

Jump AS, Hunt JM and Peñuelas J (2006) Rapid climate change-related growth decline at the southern range edge of *Fagus sylvatica. Global Change Biology* 12: 2163-2174.

Keller JK, White JR, Bridgham SD and Pastor J (2004) Climate change effects on carbon and nitrogen mineralization in peatlands through changes in soil quality. *Global Change Biology* 10: 1053-1064.

Kingston N and Waldren S (2005) The historical biogeography of 'Lusitanian' Ericaceae in the Irish flora. In: Bakker FT, Chatrou LW, Gravendeel B and Pelser P (eds.) *Plant species-level systematics: new perspectives on pattern & process.* Ruggell: Gantner Verlag, 203-215.

Lenoir J, Gégout JC, Marquet PA, Ruffray P de and Brisse H (2008) A significant shift in plant species optimum elevation during the twentieth century. *Science* 320: 1768-1771.

Lloyd AH (2005) Ecological histories from alaskan tree lines provide insight into future change. *Ecology* 86: 1687-1695.

Lopez-Bustins JA, Martín-Vide J and Sanchez-Lorenzo A (2008) Iberia winter rainfall trends based upon changes in teleconnection and circulation patterns. *Global and Planetary Change* 63: 171-176.

Manzano M, Custodio E, Mediavilla C and Montes C (2005) Effects of localized intensive aquifer exploitation on the Doñana wetlands (SW Spain). In: Sauquillo A, Capilla J, Martínez-Cortina L and Sánchez-Vila X. (eds.) *Groundwater Intensive Use*. Leiden: Balkema Publishers, 209-219.

Martínez-Cortizas A, Pontevedra X, Novóa JC and García-Rodeja E (2000) Turberas de montaña del noroeste de la Península Ibérica. *Edafología* 7: 1-29.

Martín-Puertas C, Valero-Garcés BL, Mata MP, González-Sampériz P, Bao R, Moreno A and Stefanova V (2008) Arid and humid phases in southern Spain during the last 4000 years: the Zoñar Lake record, Córdoba. *The Holocene* 18: 907-921.

Matthews JR (1937) The Oceanic Southern Element. *Journal of Ecology* 25: 15-35.

Merino J, Martín A, Granados M and Merino O (1990) Desertification of coastal sands of south-west Spain. *Agriculture Ecosystems & Environment* 33: 171-180.

Morellón M, Pérez-Sanz A, Corella JP, Büntgen U, Catalán J, González-Sampériz P, González-Trueba JJ, López-Sáez JA, Moreno A, Pla-Rabes S, Saz-Sánchez MÁ, Scussolini P, Serrano E, Steinhilber F, Stefanova V, Vegas-Vilarrúbia T, and Valero-Garcés B (2012) A multi-proxy perspective on millennium-long climate variability in the Southern Pyrenees. *Climate of the Past* 8: 683-700.

Muñoz A, García-Duro J, Álvarez R, Pesqueira XM, Reyes O and Casal M (2012) Structure and diversity of *Erica ciliaris* and *Erica tetralix* heathlands at different successional stages after cutting. *Journal of Environmental Management* 94: 34-40.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB and Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* 403: 853-858.

Nussbaumer SU, Nesje A and Zumbühl HJ (2011) Historical glacier fluctuations of Jostedalsbreen and Folgefonna (southern Norway) reassessed by new pictorial and written evidence. *The Holocene 21*: 455-471.

Parmesan C, Duarte C, Poloczanska E, Richarsson AJ and Singer MC (2011) Overstretching attribution. *Nature Climate Change* 1: 2-4.

Peñuelas J and Boada M (2003) A global change-induced biome shift in the Montseny mountains (NE Spain). *Global Change Biology* 9: 131-140.

Petit CC and Lambin EF (2002a) Long-term land-cover changes in the Belgian Ardennes (1775–1929): model-based reconstruction vs. historical maps. *Global Change Biology* 8: 616-630.

Petit CC and Lambin EF (2002b) Impact of data integration technique on historical land-use/land-cover change: comparing historical maps with remote sensing data in the Belgian Ardennes. *Landscape Ecology* 17: 117-132.

Petit R, Hu FS and Dick CW (2008) Forest of the past: a window to future changes. *Science* 320: 1450-1452.

Ramírez Díaz L, García Novo F, Merino J and González Bernáldez F (1977) Sistemas de dunas y arenas estabilizadas de la reserva Biológica de Doñana. In: García Novo F, Merino J, Ramírez Díaz L, Ródenas M, Sancho Royo F, Torres A, González Bernáldez F, Díaz Pineda F, Allier C, Bresset V and Lacoste A (eds.) *Doñana.*

Prospección e inventario de Ecosistemas. Madrid: Instituto Nacional para la Conservación de la Naturaleza, 159-193.

Real Jardín Botánico de Madrid (2009) *Proyecto Anthos*. http://www.anthos.es/. (last accessed 2 January 2012).

Rivas-Martínez S, Costa M, Castroviejo S and Valdés E (1980) Vegetación de Doñana (Huelva, España). *Lazaroa* 2: 5-190.

Rodrigo FS, Esteban-Parra MJ, Pozo-Vázquez D and Castro-Díez Y (1999) A 500-year precipitation record in southern Spain. *International Journal of Climatology* 19: 1233-1253.

Rodrigo FS, Esteban-Parra MJ, Pozo-Vázquez D and Castro-Díez Y (2000) Rainfall variability in Southern Spain on decadal to centennial times scales. *International Journal of Climatology* 20: 721-732.

Romero-Viana L, Miracle MR, López-Blanco EC, Vilaclara G, Garcia-Orellana J, Keely BJ, Camacho A and Vicente E. (2009) Sedimentary multiproxy response to hydroclimatic variability in Lagunillo del Tejo (Spain). *Hydrobiologia* 631: 231-245.

Rose RJ, Bannister P and Chapman SB (1996) Biological Flora of the British Isles. *Erica ciliaris* L. *Journal of Ecology* 84: 617-628.

Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M and Wall DH (2000) Global biodiversity scenarios for the year 2100. *Science* 287: 1770-1774.

Sanz-Elorza M, Dana ED, González A and Sobrino E (2003) Changes in the high-mountain vegetation of the Central Iberian Peninsula as a probable sign of global warming. *Annals of Botany* 92: 273-280.

Sorvari S, Korhola A and Thompson R (2002) Lake diatom response to recent Arctic warming in Finnish Lapland. *Global Change Biology* 8: 171-181.

Sousa A and García-Murillo P (2001) Can place names be used as indicators of landscape changes? Application to the Doñana Natural Park (Spain). *Landscape Ecology* 16: 391-406.

Sousa A and García-Murillo P (2003) Changes in the Wetlands of Andalusia (Doñana Natural Park, SW Spain) at the End of the Little Ice Age. *Climatic Change* 58: 193-217.

Sousa A, García-Barrón L, Morales J & García-Murillo P (2006) Post-Little Ice Age warming and desiccation of the continental wetlands of the Aeolian sheet in the Huelva region (SW Spain). *Limnetica* 25: 57-70.

Sousa A, García-Murillo P, Morales J and García-Barrón L (2009a) Anthropogenic and natural effects on the coastal lagoons in the southwest of Spain (Doñana National Park). *ICES Journal of Marine Science* 66: 1508-1514.

Sousa A, Andrade F, Félix A, Jurado V, León-Botubol A, García-Murillo P, García-Barrón L and Morales J (2009b). Historical importance of wetlands in malaria transmission in southwest of Spain. *Limnetica* 28: 283-300.

Sousa A, García-Murillo P, Sahin S, Morales J and García-Barrón, L (2010) Wetland place names as indicators of manifestations of recent climate change in SW Spain (Doñana Natural Park). *Climatic Change* 100: 525-557.

Stein ED, Dark S, Longcore T, Grossinger R, Hall N and Beland M (2010) Historical ecology as a tool for assessing landscape change and informing wetland restoration priorities. *Wetlands* 30. 589–601.

Stevenson AC (1985) Studies in the vegetational history of S. W. Spain. II. Palynological investigations at Laguna de las Madres, S. W. Spain. *Journal of Biogeography* 12: 293-314.

Stevenson AC and Harrison RJ (1992) Ancient forests in Spain: a model for land-use and dry forest management in South-West Spain from 4000 BC to 1900 AD. *Proceedings of the Prehistoric Society* 58: 227-247.

Thomas CD, Aldina AMA and Hill JK (2009) Range retractions and extinction in the face of climate warming. *Trends in Ecology & Evolution* 21: 415-416.

Trick T and Custodio E (2004) Hydrodynamic characteristics of the western Doñana Region (area of El Abalario), Huelva, Spain *Hydrogeology Journal* 12: 321-335.

Valero-Garcés BL, González-Sampériz P, Navas A, Machín J, Mata P, Delgado-Huertas A, Bao R, Moreno A, Carrión JS, Schwalb A and González-Barrios A (2006) Human impact since medieval times and recent ecological restoration in a Mediterranean lake: the Laguna Zoñar, southern Spain. *Journal of Paleolimnology* 35: 441-465.

Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin JM, Hoegh-Guldberg O and Bairlein F (2002) Ecological responses to recent climate change. *Nature* 416: 389-395.

Weltzin JF, Bridgham SD, Pastor J, Chen J and Harth C (2003) Potential effects of warming and drying on peatland plant community composition. *Global Change Biology* 9: 141-151.

Figure Legends

Figure 1 (A) The world distribution of the taxon *E. ciliaris* according to Matthews (1937), Rose *et al.* (1996), Kingston and Waldren (2005). **(B)** The distribution of *E. ciliaris* in the Iberian Peninsula, compiled from the data of the Proyecto Anthos (Real Jardín Botánico de Madrid, 2009) and from Bingre *et al.* (2007). The area where *E. ciliaris* is found is marked by a broken line and highlighted in darker tones. **(C)** The location of the study area in Spain (SW Europe), within the Doñana Natural Park

Figure 2 The methodological sequence used to obtain the microtopography of the study area. The six numbers that appear in the first figure **(A)** correspond to the official numbering of the six sheets of the topographical map (1:10,000) that was utilised.

Figure 3 The distribution of forest infrastructure during the critical phase of the period of forest exploitation (*AD* 1936-1972). Compiled from the interpretation of aerial photos at a scale of 1:33,000 from the flight of 1956, the Spanish Topographic Map, scale 1:50,000 (1951), and Espina and Estévez (1993).

Figure 4 (A) Changes in forestry crops in the study area, modified from Sousa and García-Murillo (2003). **(B)** Scatterplot of the extent of eucalyptus forestry crops and the population in the study area. The data are taken from municipal censuses of inhabitants (population of forestry nurseries 1945-1986) in ESPINA and ESTÉVEZ (1992)

Figure 5 (A) Maps showing changes in peat bogs in the study area. **(B)** Changes in the area occupied by peat bogs in the study area.

Figure 6 The accumulated frequency of dry and wet years at the San Fernando Observatory (southern Spain). The date estimated for the end of the Little Ice Age (LIA) in

Andalusia is taken from Castro-Díez *et al.* (2007). The changes in the slope of the straight line in each section are highlighted with grey broken lines.

Figure 7 (A) Evolution of the specific disparity index and spring precipitation **(B)** at the San Fernando Observatory (southern Spain)

Figure 8 (A) Sequence of desiccation of the peat bog areas beginning in the early seventeenth century. This process begins in the south-westernmost lagoons and continues north-easterly (B), coinciding with the isopiezometric gradient. The isopiezometric and underground flow data are for April-May 1989; the source is the Instituto Tecnológico y Geominero, Spain (1992).

Tables

Table I Sources of data used for the reconstruction of the area occupied by peat bogs

Period	**Fieldwork**	**Aerial photography**	**Satellite imagery**	**Forestry archives**	**Historical documents**	**Historical maps**	**Microtopographic analysis**
Twentieth century AD (1987)	X	X	X	X	-	-	-
Twentieth century AD (1956)	-	X	-	X	X	-	-
Nineteenth century AD (*c.* 1869)	-	-	-	-	X	X	X
Seventeenth century AD (*c.* 1630)	-	-	-	-	X	-	X

Table II Phases in the ecological history of the Abalario area highlighting the primary land-use changes

Phases	**Period (years)**	**Main characteristic**	**Land uses**	**Population**
1st	*AD* 1577-1879	**Hunting and gathering**	Traditional and marginal communal use	Demographic vacuum
2nd	*AD* 1879-1936	**Transition**	Experimental lands aimed at obtaining yields for forestry use	Demographic vacuum
3rd	*AD* 1936-1972	**Forestry exploitation**	Growth of forestry monocultures to obtain raw materials, curb dune advance, and fight against malaria	Forest hamlets
4th	*AD* 1972-1989	**Transition**	Gradual reduction of forestry activity	Reduction in the occupation of the forest hamlets
5th	*AD* 1989-2011	**Conservationist**	Traditional uses, protected natural space, and coastal tourism	Demographic vacuum; urban concentration on the nearby coast (Matalascañas and Mazagon)

Table III Evolution of the vegetation and associated wetlands in the study area between 1956 and 1987 (augmented Sousa and García-Murillo, 2003)

Unit	**Community**	**Indicator species**	**Number of polygons (bowls or patches)**		**Area (ha)**	
			1956	**1987**	**1956**	**1987**
Peat bogs	*Erico ciliaris-Ulicetum (minoris) lusitanicus*	*Erica ciliaris* and *Ulex minor*	178	30	1533.0	180.5
Seasonal lagoons	*Preslio-Eryngium corniculati, Ludwigio palustris-Cyperetum michelianus,* among others	Charophytes and oligotrophic pastures	99	114	575.2	626.2
Monte Negro	*Erico scopariae-Ulicetum australis*	*Erica scoparia* and *Ulex australis*	55	198	154.1	907.5

Table IV Quantification of the changes in peat bogs in the study area during the period 1630-1987

Year	**Estimated area(ha)**	**Area vanished with respect to the previous period (ha)**	**Percentage remaining with respect to area in 1630 (%)**	**Percentage vanished with respect to area in 1630 (%)**	**Mean annual rate of regression in each period (ha/year)**
***c.* 1630**	2035.4	**-**	**-**	**-**	**-**
***c.* 1869**	1739.0	296.4	85.4	14.6	1.2
1956	1533.0	206.0	75.3	24.7	2.4
1987	180.5	1352.5	8.9	91.1	43.6

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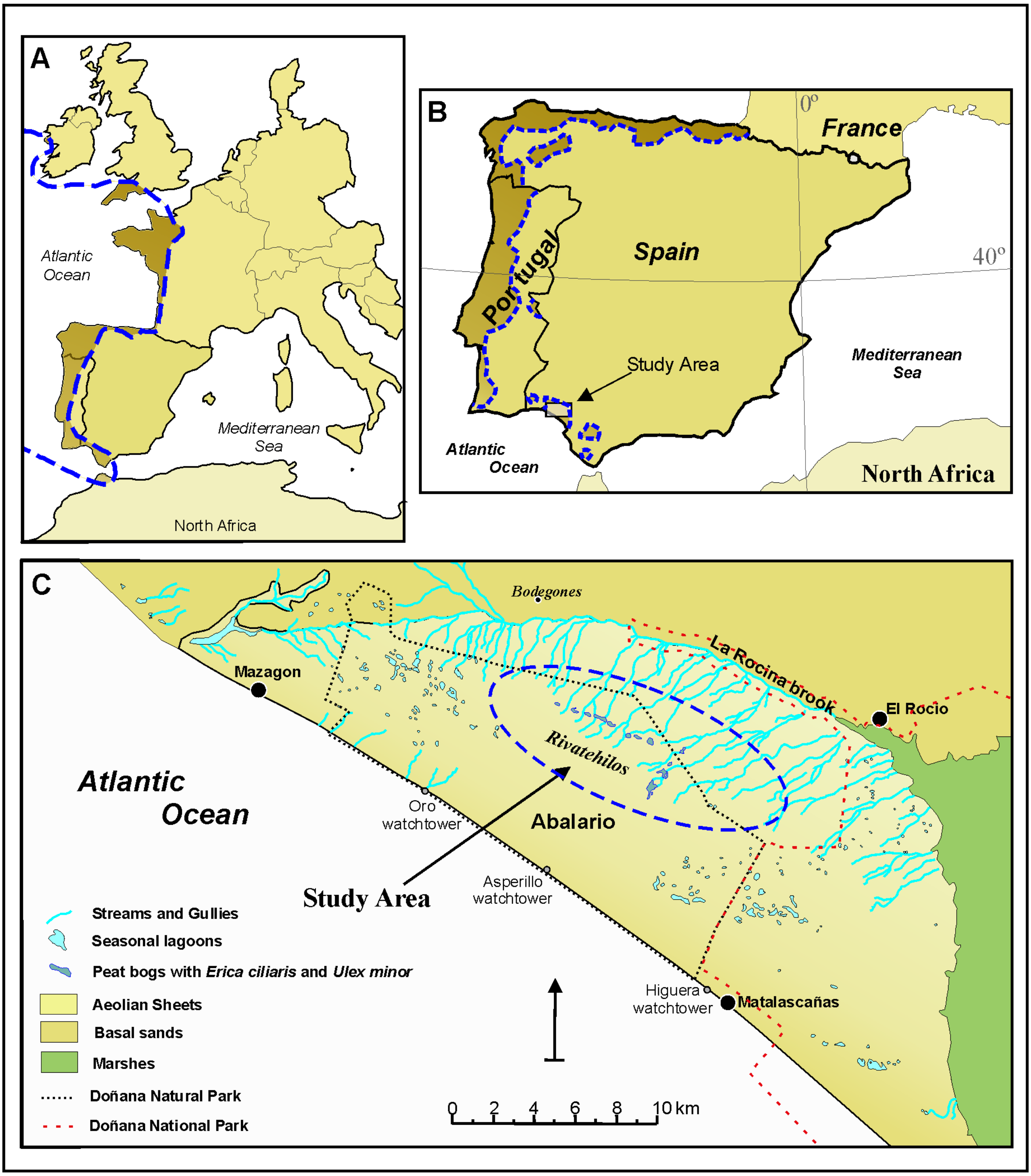

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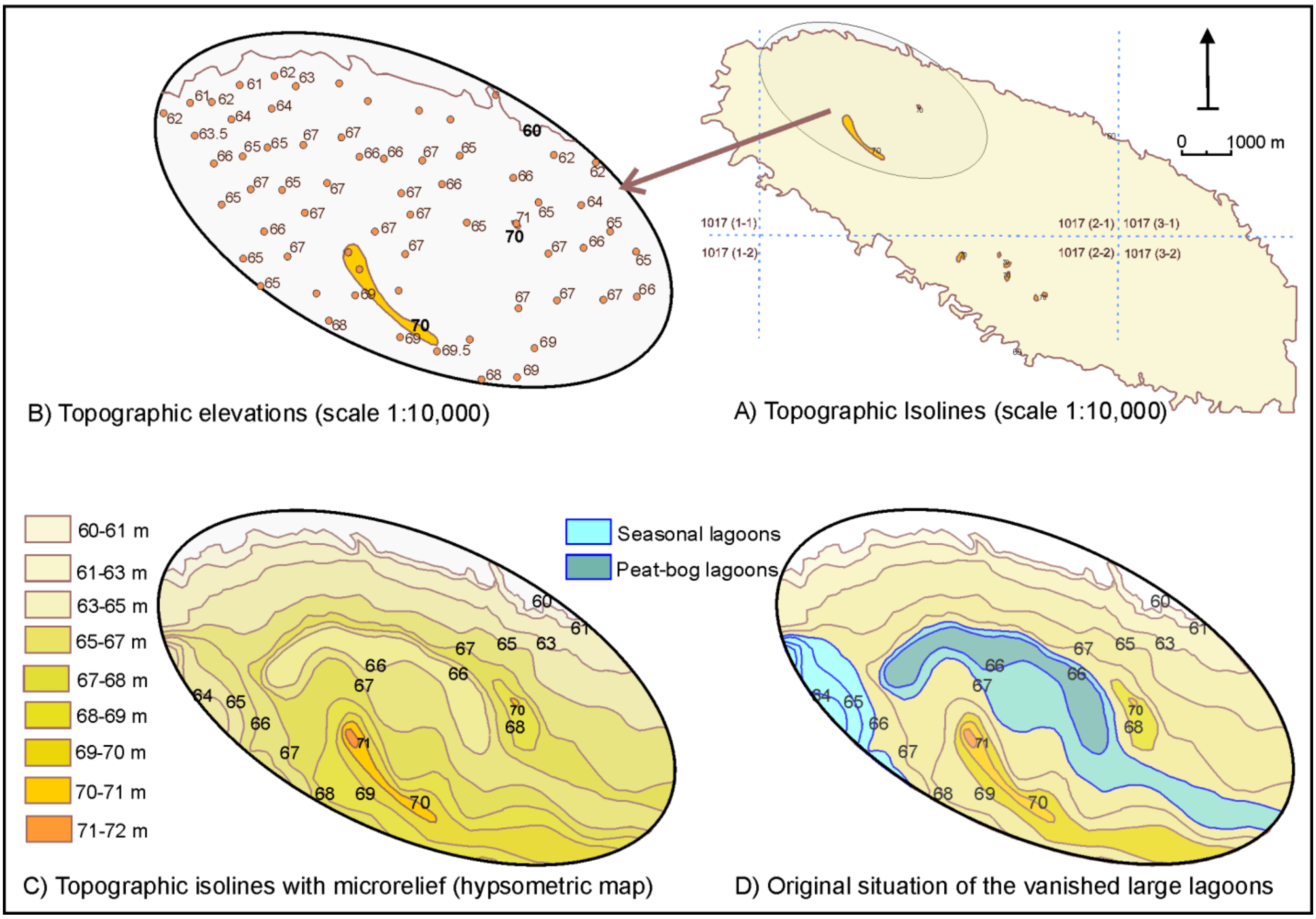


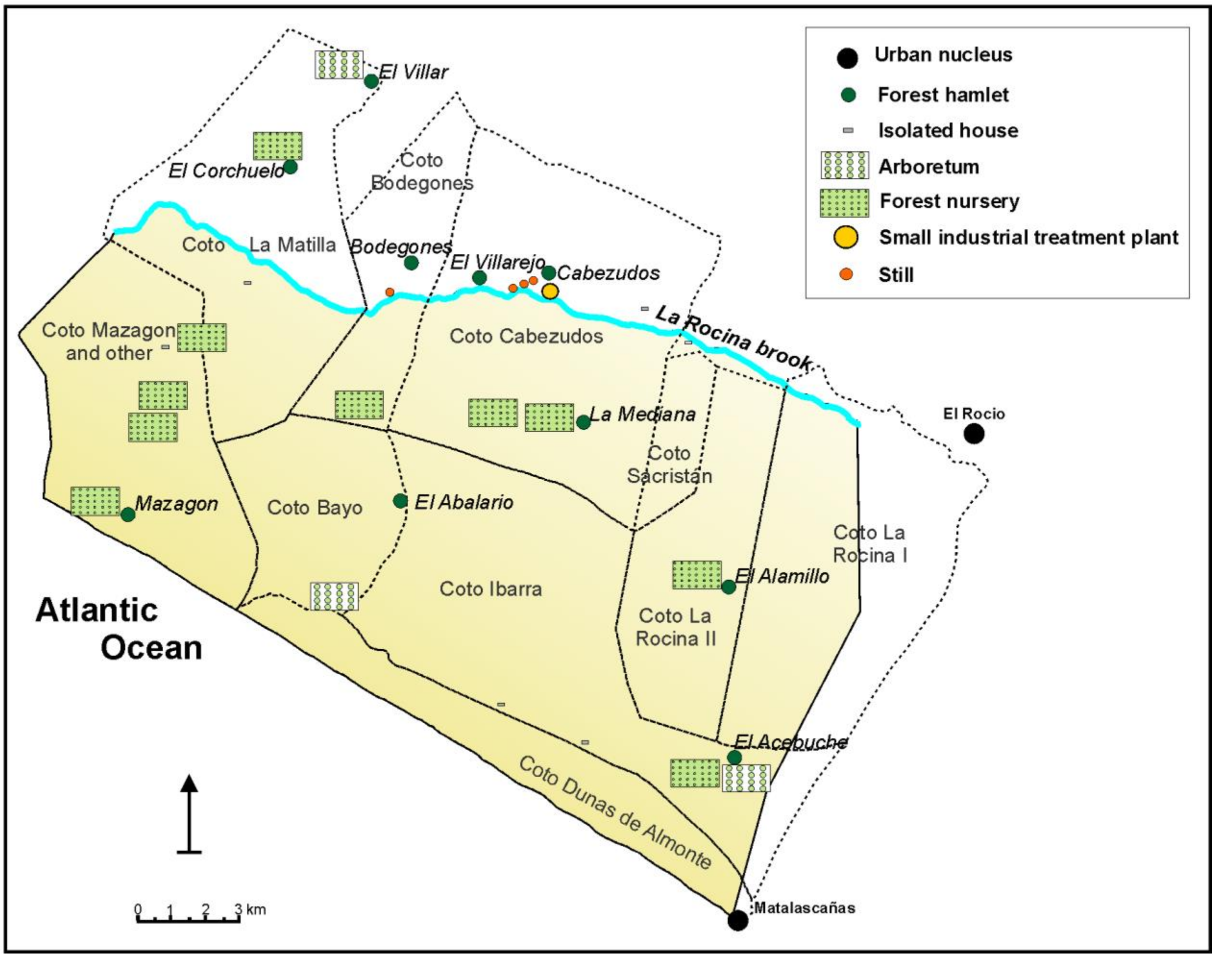
B) Topographic elevations (scale 1:10,000)

A) Topographic Isolines (scale 1:10,000)

C) Topographic isolines with microrelief (hypsometric map)

D) Original situation of the vanished large lagoons

Figure 3 (colour):



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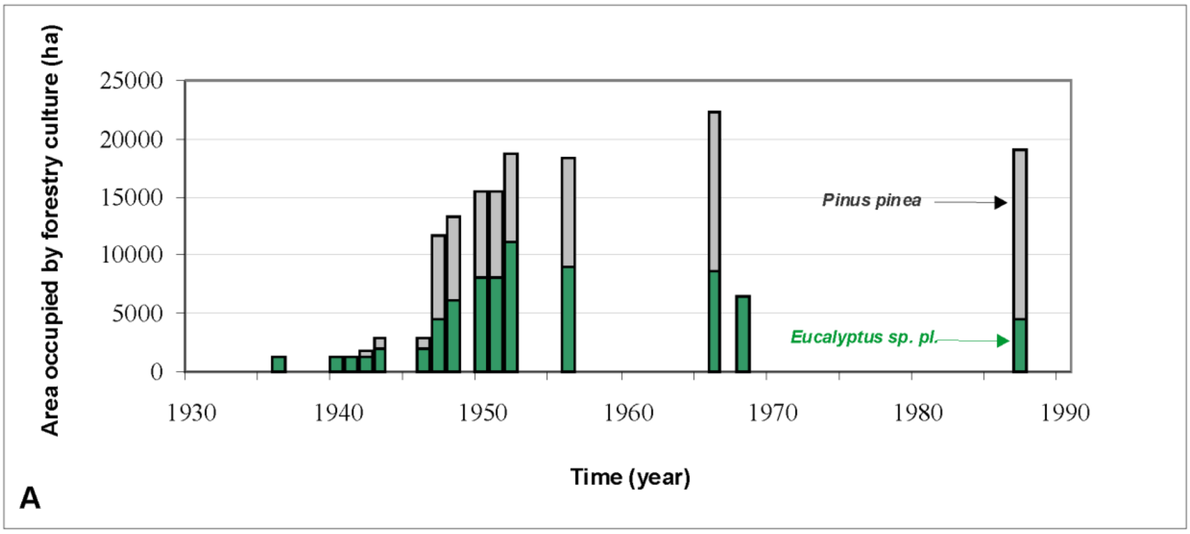

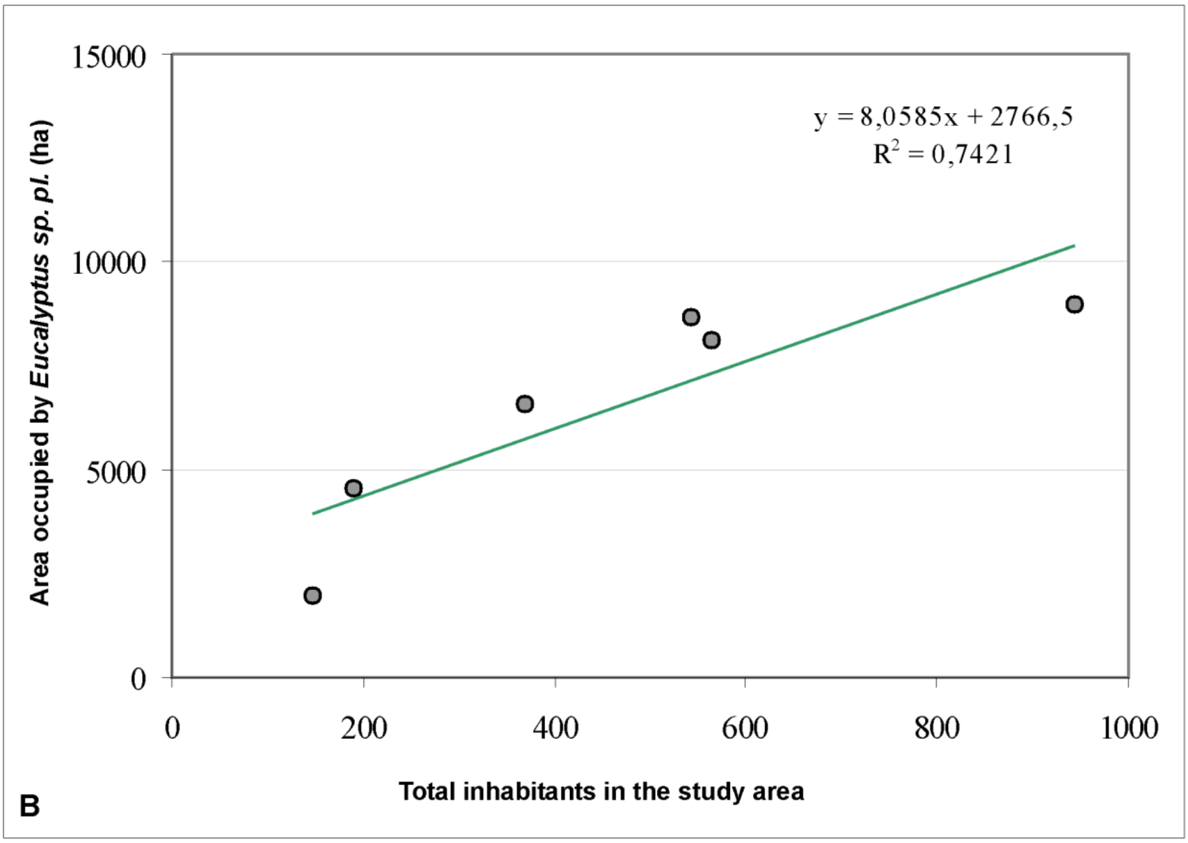

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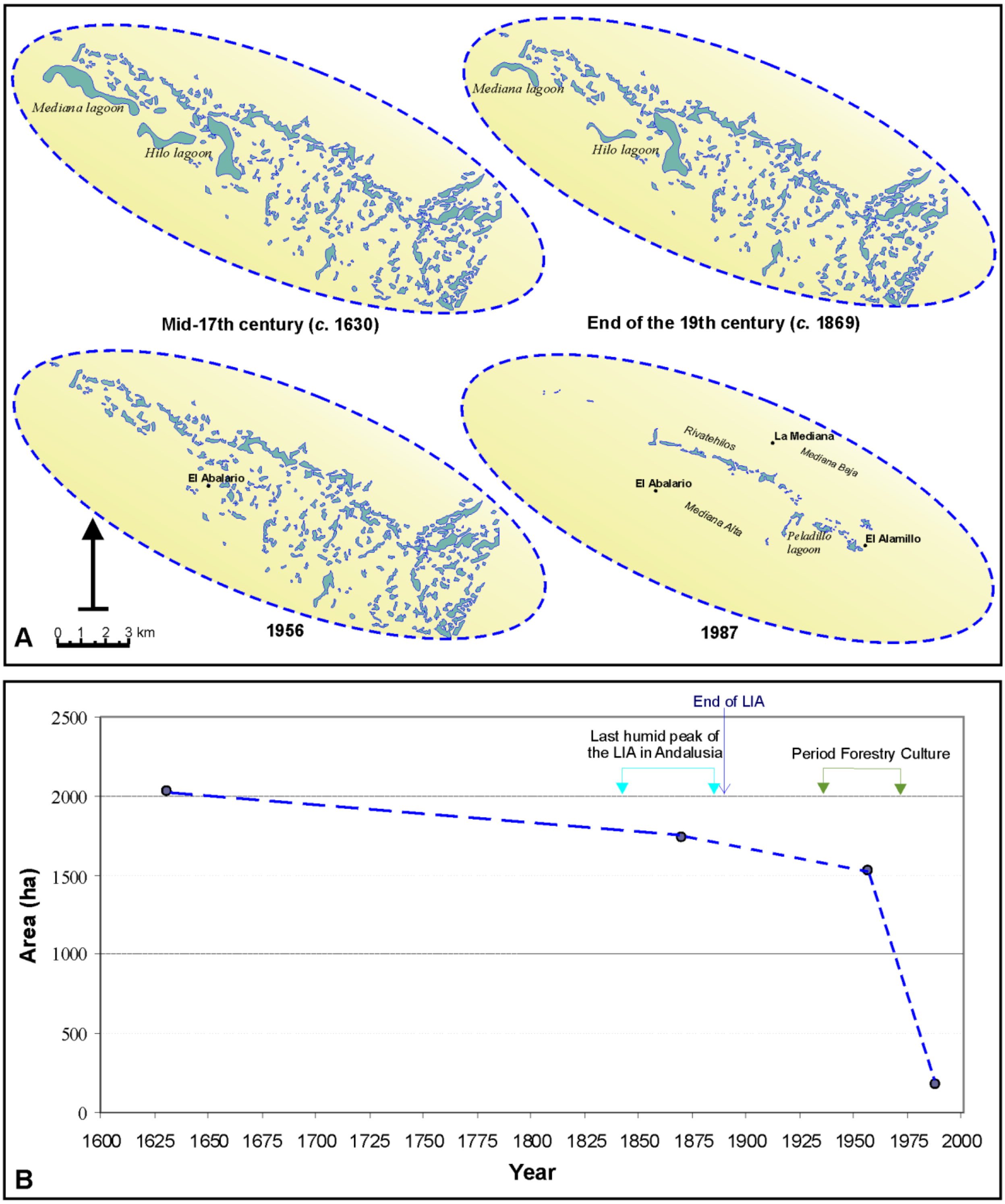

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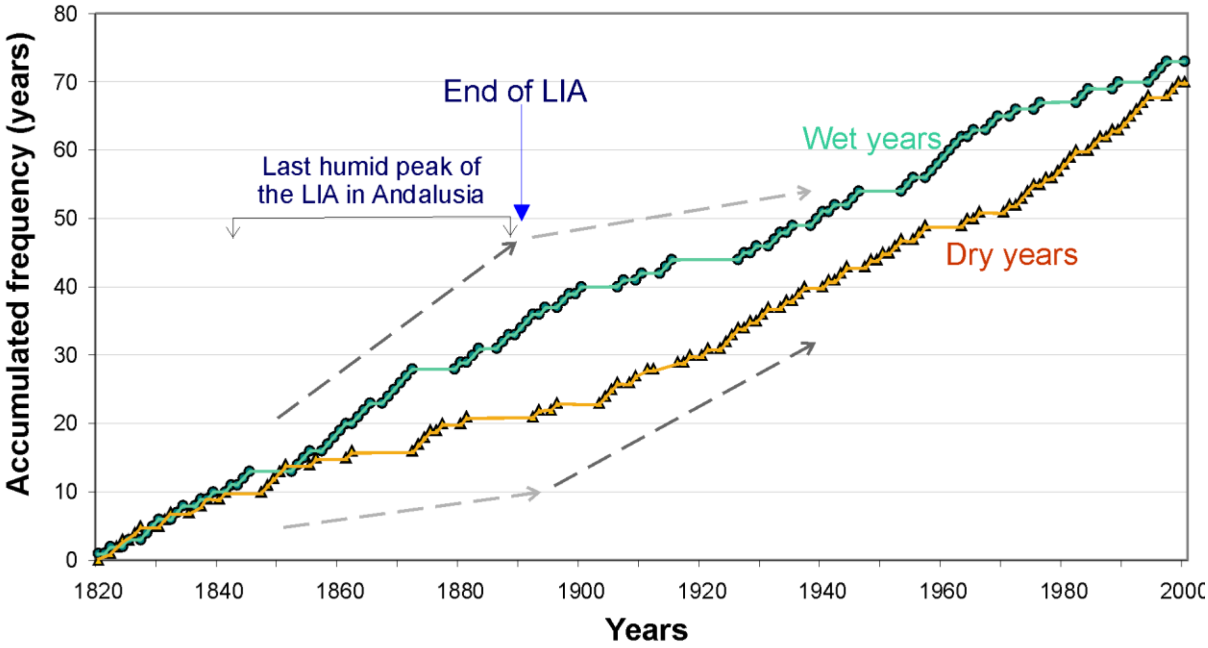

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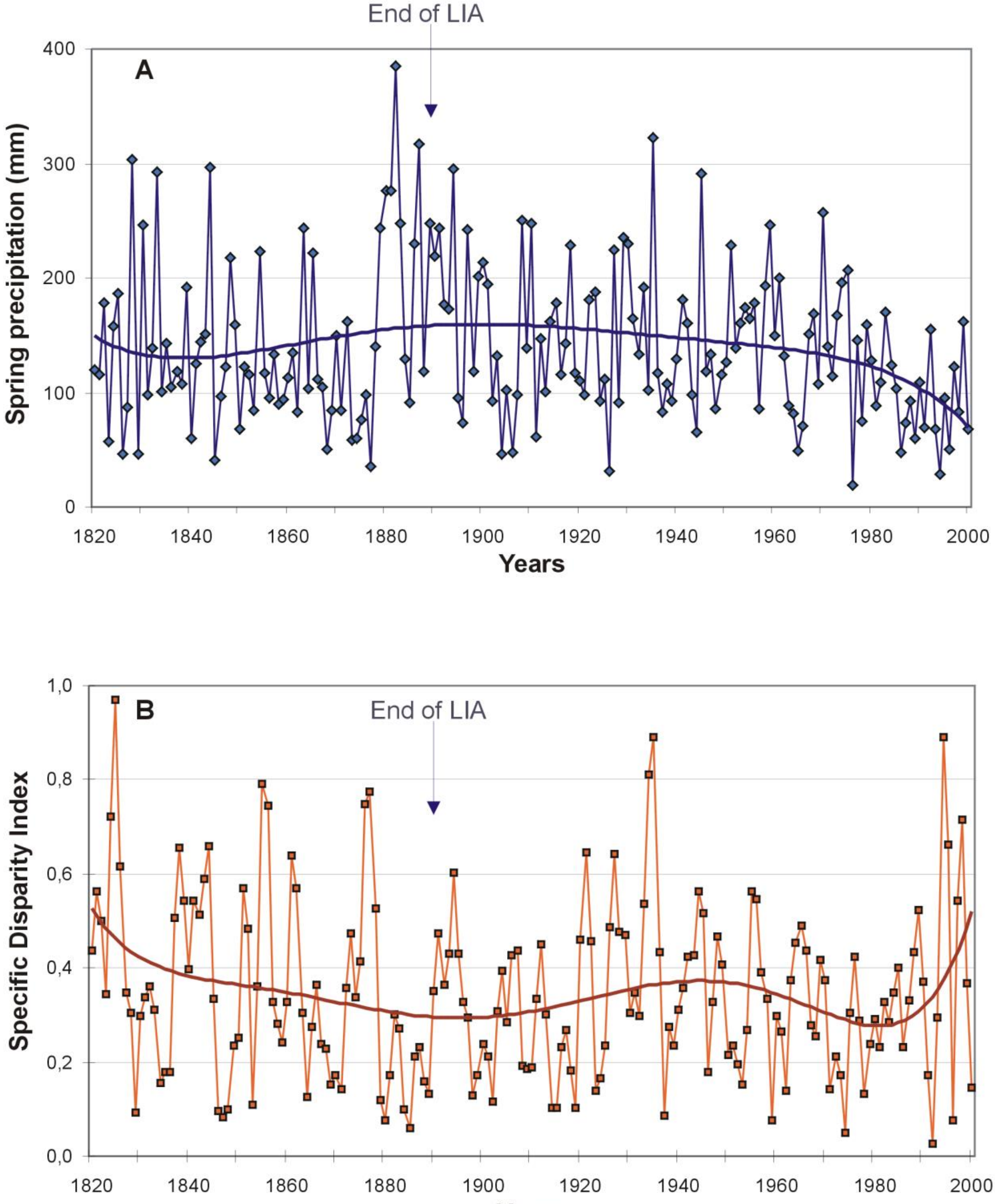

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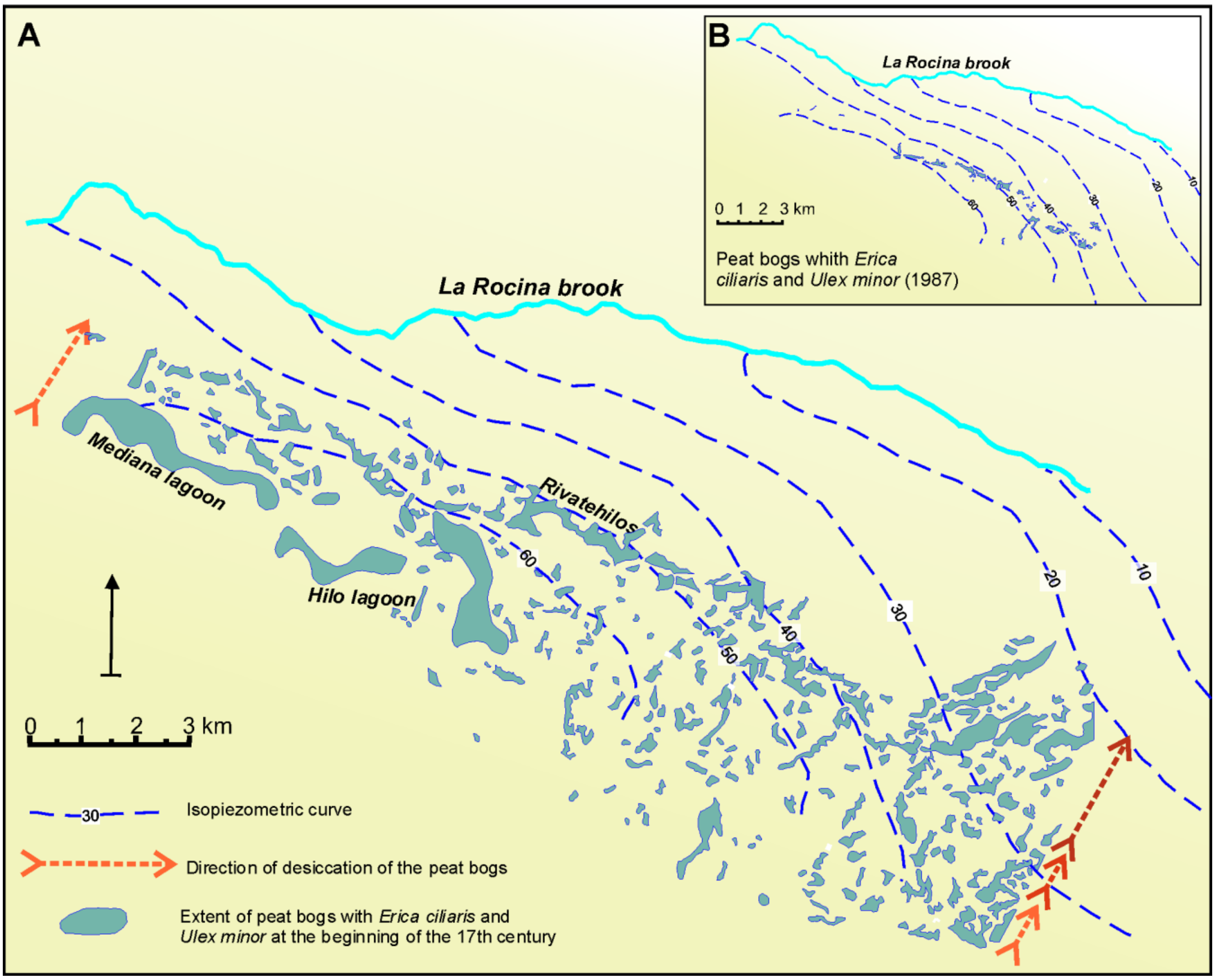

Supplementary Material

This supplementary material provides:

- Supplementary Material 1. Historic documents and unpublished technical reports for the study area not cited explicitly (listed by date).
- Supplementary Material 2. Historic maps reviewed that include the study area (listed by date).

Supplementary Material

Supplementary Material 1. Historic documents and unpublished technical reports for the study area not cited explicitly (listed by date).

Brabo de Lagunas, L., 1577. File D-24 que trasmite al Conde de Barajas, Asistente de esta ciudad, y al alcalde de la mar y río de la misma, la orden de S.M. para que los barcos sardineros y otros pesqueros que faenan en aguas de Arenas Gordas transporten piedras de Chipiona para las obras de las torres de almenara de la costa. Conformidad de los interesados. 22 diciembre de 1577. Compiled by Mora, L. (1981). Torres de almenara de la costa de Huelva. Diputación Provincial de Huelva, Huelva.

Argote de Molina, G., 1582. Discurso sobre el libro de la montería que mandó escribir el muy alto y muy poderoso Rey Don Alonso de Castilla, y de León. In: Libro de montería que mandó escribir el muy alto y muy poderoso Rey Don Alonso de Castilla y de León, último deste nombre. Acrecentado por Gonzalo ARGOTE DE MOLINA. Reproducción facsímil de la edición de Sevilla de Andrea Pescioli (1582). Sociedad de Bibliófilos Andaluces (1979), Valencia.

Espinosa, P. de, 1624. Bosque de Doñana demostraciones que hizo el Duque VIII de Medina Sidonia a la presencia de S. M. el rey Felipe IV en el Bosque de Doñana. Reedición de Padilla Libros (1994), Sevilla.

Quintana y Cevallos, J., 1748-1752. Plano Geográfico y Mapa General de los Pueblos, Montes, sus arboledas, extensiones, justicias, guardas que los custodian, vecindarios, matriculados y embarcaciones que comprende la Provincia de Ayamonte, una de las que componen el Departamento de la Capitanía General de Cádiz, según la revista de la Inspección ejecutada por el Ministro Principal de Marina de la misma provincia Don José Quintana y Ceballos. In: Gómez, M. (1991) Atlas Histórico-Forestal de Andalucía S. XVIII. Universidad de Granada, Granada.

Anonymous, 1756. File D-27 Relación de las Plazas, Torres, Puestos Fortificados, Edificios Militares y Poblaciones de la Costa de Andalucía desde la Raya Occidental del Reyno de Granada hasta la de Portugal en Ayamonte según el Estado en que se hallan el año 1756. Compiled by Mora, L. (1981). Torres de almenara de la costa de Huelva. Diputación Provincial de Huelva, Huelva.

Álvarez de Cardoso, A., 1785. Respuesta del párroco de Almonte D. Alonso Álvarez de Cardoso a las Relaciones enviadas por Tomás López. Compiled by Ruiz González, J.E. (1999) Huelva, según las relaciones enviadas por los párrocos al geógrafo real Tomás López en el siglo XVIII. Diputación Provincial de Huelva, Huelva.

Unknown, ~ 1788. Respuesta del párroco de Moguer a las Relaciones enviadas por Tomás López. Compiled by Ruiz González, J. E. (1999). Huelva, según las relaciones enviadas por los párrocos al geógrafo real Tomás López en el siglo XVIII. Diputación Provincial de Huelva, Huelva.

Madoz, P., 1848. Diccionario Geográfico-estadístico-histórico de España y sus posesiones de Ultramar. Biblioteca Santa Ana (reprinted 1990). Almendralejo.

Gonzalo y Tarín, J., 1887. Mapa geológico y Topográfico de la Provincia de Huelva. 1:400,000 y Memoria. Instituto geológico y Minero de España, Madrid.

Heraso, J., 1890a. Estudio sobre la fijación de las dunas situadas en el término municipal de Almonte, provincia de Huelva. Primera Parte. Revista de Montes 322, 281-287.

Heraso, J., 1890b. Estudio sobre la fijación de las dunas situadas en el término municipal de Almonte, provincia de Huelva. Primera Parte. Revista de Montes 322, 311-318.

Heraso, J., 1890c. Estudio sobre la fijación de las dunas situadas en el término municipal de Almonte, provincia de Huelva. Segunda Parte. Revista de Montes 322, 343-348.

Heraso, J., 1890d. Estudio sobre la fijación de las dunas situadas en el término municipal de Almonte, provincia de Huelva. Cultivo de las arenas por medio de pinares. Revista de Montes 332, 388-397.

Heraso, J., 1890e. Estudio sobre la fijación de las dunas situadas en el término municipal de Almonte, provincia de Huelva. Revista de Montes 322, 448-457.

Heraso, J., 1890f. Estudio sobre la fijación de las dunas situadas en el término municipal de Almonte, provincia de Huelva. Revista de Montes 322, 472-479.

Heraso, J., 1890g. Estudio sobre la fijación de las dunas situadas en el término municipal de Almonte, provincia de Huelva. Revista de Montes 322, 496-502.

Castro, A.F., 1900a. Repoblación de dunas. Revista de Montes 559, 225-232.

Castro, A.F., 1900b. Repoblación de dunas. Revista de Montes 561, 281-285.

Castro, A.F., 1900c. Repoblación de dunas. Revista de Montes 568, 395-400.

Castro, A.F., 1912a. Repoblación de dunas. Revista de Montes 843, 151-167.

Castro, A.F., 1912b. Repoblación de dunas. Revista de Montes 878,165-592.

San Miguel, M., 1913. Las costas de la provincia de Huelva y sus variaciones en el período histórico. Boletín de la Real Sociedad Española de Historia Natural 13, 434-468.

V División Hidrológico-Forestal, 1932.Aprobación del proyecto de fijación y repoblación Dunas de Almonte (Kith Tassara), y respuesta de la jefatura. Unedited technical Report, Huelva.

V División Hidrológico- Forestal, 1934. Relación de propiedades y terrenos a adquirir para el proyecto de fijación y repoblación. Respuesta de los propietarios de la finca Dunas de Almonte (1934). Respuesta de los propietarios. Edicto I, B.O.E.(1936). Unedited technical Report.

V División Hidrológico-Forestal, 1934. Aprobación del proyecto de fijación y repoblación de Dunas de Almonte. Unedited technical Report, Huelva.

V División Hidrológico-Forestal, 1935. Comunicación del Ingeniero sobre hectáreas y fincas adquiridas de la finca Dunas de Almonte. Unedited technical Report, Huelva.

V División Hidrológico-Forestal, 1935. Escritura de Compra/Venta zona de dunas de Coto Ibarra y Coto Bayo. Unedited technical Report, Huelva.

Gavala, J., 1936. Mapa geológico de España E. 50,000 y memoria explicativa. Hoja 1017 (“El Asperillo”). Instituto Geológico y Minero de España, Madrid.

Dictamen del Gobierno Civil de Huelva, 1940. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1940. Características del Coto Ibarra antes de comprarlo. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1940. Escrituras de Compra/Venta a Coto Atlántico del Coto Ibarra. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1940. Memoria y reconocimiento de montes y propuestas de trabajos del Coto Ibarra. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1940. Relación de arrendatarios del Coto Ibarra. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1940. Tasación para la adquisición de la finca del Coto Ibarra. Unedited technical Report, Huelva.

V División Hidrológico-Forestal, 1940. Contestación del Coto Atlántico. Unedited technical Report, Huelva.

V División Hidrológico-Forestal, 1940. Decreto de Utilidad pública a efectos de expropiación [...] para proyecto de ampliación. Unedited technical Report, Huelva.

V División Hidrológico-Forestal, 1940. Expedientes para la adquisición por convenio de la finca Coto de Mazagón y Coto Ibarra. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1941. Escritura del Coto Bayo. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1941. Expediente para la adquisición por convenio del Coto Bayo. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1941. Oferta de venta de Forestal de Villarejo del Coto Bayo. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1941. Reconocimiento y propuestas de trabajos en la finca del Coto Ibarra. Unedited technical Report, Huelva.

V División Hidrológico-Forestal, 1941. Propuesta y presupuesto para el estudio de la ampliación del Plan Forestal y de repoblación de las dunas de Almonte. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1942. Escritura de Compra/Venta del coto Bodegones. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1942. Escritura de Compra/Venta del Coto La Matilla. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1942. Plano del predio rústico del Coto La Matilla 1:20,000. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1942. Valoración en informe previo sobre coto La Matilla. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1942. Valoración de la finca del coto Bodegones por De La Lama. Unedited technical Report, Huelva.

De La Lama, G., 1946. Valoración de la finca del Coto Cabezudos (Giménez-Quintana). Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1946. Informe y valoración del Coto La Rocina II (De La Lama, 1946). Unedited technical Report, Huelva.

De La Lama, G., 1947. Valoración de la finca del Coto Cabezudos (De La Lama y Giménez-Quintana). Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1947. Escritura de Compra/Venta del Coto La Rocina II. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1948. Escritura de carta de pago del Coto La Rocina II. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1948. Escritura de Compra/Venta del Coto Cabezudos. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1950. Comunicación de la expropiación por razones de interés forestal del Coto El Sacristán. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1951. Carta cediendo la Compra del Coto La Rocina I (1951). Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1951. Escritura de Compra/Venta del Coto El Sacristán. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1951. Informe de valoración del Coto El Sacristán (De La Lama, 1951). Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1951. Informe de valoración del Coto La Rocina I (De La Lama, 1951). Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1951. Ofrecimiento de la finca a la Empresa Calvo Sotelo del Coto La Rocina I. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1951. Situación de las escrituras antes de la Compra del Coto El Sacristán. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1952. Descripción de la finca del Coto El Sacristán. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1952. Escritura de Compra-Venta a la empresa Calvo Sotelo del Coto La Rocina I. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado, 1952. Informe de La Lama sobre la Compra/Venta del Coto La Rocina I. Unedited technical Report, Huelva.

Kith, M., 1952. Diez años de colaboración de la 5ª División Hidrológica-Forestal con Patrimonio Forestal del Estado. Revista de Montes 45, 166-152.

Ministerio de Agricultura, Pesca y Alimentación, 1965. Informe sobre la situación del Coto Ibarra desde 1935.

I.RY.D.A. (1978) Cesión a I.R.Y.D.A. del Coto La Rocina II. Unedited technical Report.

I.CO.N.A., 1982. Superficie de Dunas de Almonte después de la permuta con Wordl Hotel S.A. Unedited technical Report.

Gómez M., 1991. Atlas Histórico-Forestal de Andalucía S. XVIII. Universidad de Granada, Granada.

Espina J., Estévez A., 1992. Programa de recuperación del Patrimonio *del P.N.Doñana*. Vol. III. Abalario. Unedited technical Report. Huelva.

Anonymous. Camino de unión Dunas del Odiel- Dunas de Almonte Coto Mazagón. Unedited technical Report.

Ruiz González, J.E., 1999. Huelva, según las relaciones enviadas por los párrocos al geógrafo real Tomás López en el siglo XVIII. Diputación Provincial de Huelva, Huelva.

Patrimonio Forestal del Estado. Resumen de la situación de la propiedad del Coto Ibarra. Unedited technical Report, Huelva.

Patrimonio Forestal del Estado. Planos del catastro Dehesa Los Bodegones en el término de Almonte 1:25,000. Unedited technical Report, Huelva.

V División Hidrológico-Forestal. Escritura a nombre de V-División Hidrológico-Forestal de la finca Dunas de Almonte. Unedited technical Report, Huelva.

V División Hidrológico-Forestal. Informe de la Jefatura de la finca Dunas de Almonte. Unedited technical Report, Huelva.

Supplementary Material 2. Historic maps reviewed that include the study area (listed by date).

2nd C. “*Descriptio Secundae Tabulae Europae*”. Ptolomeo, Claudius. Impreso en Ulm, 1482.

1154. Mapa de Al-Idrisi. Edición de conmemoración del VIII Centenario de Averroes (1198-1998) (El Mundo en el siglo XII según al-Idrisi). Imprenta Pinelo, 1998, Camas-Sevilla.

1470. “*Hispania*”. Germano. In: Mapas Antiguos del Mundo, Aqualarga Editores (1996). Madrid, 159 p.

1482. “*El Mundo*” . Schnitzer, Johannes. In: LIBSA (2000a). *Mapas del Mundo*. Eds. LIBSA, Madrid, 86 p.

15th C. “*Tabula Moderna Hispania*”. Unknown. In: Pezzi M (1992). *Atlas Básico de Andalucía*. Pezzi M (Ed). Consejería de Educación y Ciencia (Junta de Andalucía). Granada. 102 p.

1506. “*Mapa Universal*”. Matheo Contarini & Francesco Roselli. Edición Facsímil Carlos Sanz. Gráficas Yagües. Madrid. 1961.

1527. “*Orbis Universalis Descriptio*”. Robert Thorne. Londres. Edición Facsímil Carlos Sanz. Madrid. 1961.

1538. “*Mapamundi*”. Gerardo Mercator. Proyección Doble Cordiforme. Edicción Facsímil. Reproducción publicada en Homenaje al Perú por Carlos Sanz. Gráficas Yagües. Madrid. 1961.

1548. “*Mapamundi*”. Giacomo Gastaldi. In: Mapas Antiguos del Mundo, Aqualarga Editores (1996). Madrid, 159 p.

1579. “*Hispalensis Conventus Delineatio”.* Jerónimo Chaves. In: Pezzi M (1992). *Atlas Básico de Andalucía*. Pezzi M (Ed). Consejería de Educación y Ciencia (Junta de Andalucía). Granada. 102 p.

16th C. a "*La Península Ibérica y el Mediterráneo Occidental*". Diego Holmen. *Atlas Básico de Andalucía*. Pezzi M (Ed). Consejería de Educación y Ciencia (Junta de Andalucía). Granada. 102 p.

16th C. b *"Atlas del Escorial"*. Unknown. In: Consejería de Obras Públicas y Transportes (1998), *Atlas de Andalucía*, Tomo I. Junta de Andalucía, 432 p.

16th C. c "*División de la Dehesa de Carrizal y de la Figuera*". In: Castrillo, M.C. (2000). *Doñana Nombre a Nombre. Estudio de la toponimia del Parque Nacional de Doñana.* Diputación Provincial de Huelva. Huelva. 288 p.

1606. *"Andalucía Nova (Jodocus Hondius,1606)"*. Map Library Instituto Geográfico Nacional, Madrid.

1617. "*Europa recens descripta".* Willen Blaeu. In: LIBSA (2000b). "*Gran Atlas de Johannes Blaeu S. XVII*". Eds. LIBSA, Madrid. 223 p.

≅ 1625. "*Mapa de España*". Pedro Texeira. In: Pereda, F. (2002). Un atlas de costas y ciudades iluminado para Felipe IV: la Descripción de España y de las costas y puertos de sus Reynos de Pedro Texeira; 29-48 p. In: El Atlas del Rey Planeta "La Descripción de España y de las costas y puertos de sus reinos" de Pedro Texeira, Pereda, F. & Marías, F. (Eds.). Eds. Nerea, 2ª ed. Madrid, 398 p.

≅ 1631. "*Regnorum Hispaniae nova descriptio*". Willen Blaeu. In: LIBSA (2000b). "*Gran Atlas de Johannes Blaeu S. XVII*". Eds. LIBSA, Madrid. 223 p.

1634 a. "*Plano de España y Portugal*". Pedro Texeira. "La Descripción de España y de las Costas y Puertos de sus Reynos"; págs. 117-192. In: El Atlas del Rey Planeta "La Descripción de España y de las costas y puertos de sus reinos" de Pedro Texeira, Pereda, F. & Marías, F. (Eds.). Eds. Nerea, 2ª ed. Madrid, 398 p.

1634 b. "*Plano del Reyno de Portvgal*". Pedro Texeira. "La Descripción de España y de las Costas y Puertos de sus Reynos"; pág. 117-192. In: El Atlas del Rey Planeta "La

Descripción de España y de las costas y puertos de sus reinos" de Pedro Texeira, Pereda, F. & Marías, F. (Eds.). Eds. Nerea, 2ª ed. Madrid, 398 p.

1634 c. "*Mapa del Reyno de Andalvcia*". Pedro Texeira. "La Descripción de España y de las Costas y Puertos de sus Reynos"; pág. 117-192. In: El Atlas del Rey Planeta "La Descripción de España y de las costas y puertos de sus reinos" de Pedro Texeira, Pereda, F. & Marías, F. (Eds.). Eds. Nerea, 2ª ed. Madrid, 398 p.

1634 d. "*Barra y Río de Gibraleón*". Pedro Texeira. "La Descripción de España y de las Costas y Puertos de sus Reynos"; pág. 117-192. In: El Atlas del Rey Planeta "La Descripción de España y de las costas y puertos de sus reinos" de Pedro Texeira, Pereda, F. & Marías, F. (Eds.). Eds. Nerea, 2ª ed. Madrid, 398 p.

1634 e. "*Baía de Cadiz y barra de San Lúcar*". Pedro Texeira. "La Descripción de España y de las Costas y Puertos de sus Reynos"; pág. 117-192. In: El Atlas del Rey Planeta "La Descripción de España y de las costas y puertos de sus reinos" de Pedro Texeira, Pereda, F. & Marías, F. (Eds.). Eds. Nerea, 2ª ed. Madrid, 398 p.

≅ 1635. "*Portugallia et Algarbia queae olim Lusitanica*". Fernao Alvares Seco. In: LIBSA (2000b). "*Gran Atlas de Johannes Blaeu S. XVII*". Eds. LIBSA, Madrid. 223 p.

1632. "*Nova Hispania Descriptio*". Joannes Janssonius. In: Mapas Antiguos del Mundo, Aqualarga ediciones (1996), 159 p.

1640-1650. *"Andaluzia continens Sevillam et Cordobam"*. Theatrum du Monde au Nouvel Atlas. Willem Blaeu. Map Library Instituto Geográfico Nacional, Madrid.

1696. *"Li Regni de Granata E D'Andalucía"* Domenico de Rossi (Domenicus Rubeis). Map Library Instituto Geográfico Nacional, Madrid.

17th C. a "*Nova Totius Terrarum Orbis Geographia ac Hydrographica Tabula*". Willen Blaeu. In: LIBSA (2000b). "*Gran Atlas de Johannes Blaeu S. XVII*". Eds. LIBSA, Madrid. 223 p.

17th C. b *"Mapa de España de Carlos III (J. Danckaert, siglo XVII)"*. Theatre de la Guerre de Espagne et en Portugal, Preferente a Charles III. Roy d'Espagne et des Indes, etc: etc: a Amsterdam. C. Danckerts avec Privilege (sic). Accuratis sima, totius Regni, Hispania, Tabula Per Instinum Danckaerts (sic). Map Library Instituto Geográfico Nacional.

1715. "*Totius Europae Littorae*". Louis Renard, In: LIBSA (2000a). *Mapas del Mundo*. Eds. LIBSA, Madrid, 86 p.

1743. "*Descripción de la costa del Coto de Dª Ana, y situación de la Almadava que en ella hay al sitio de la torre Carboneros, veintinueve de junio de 1743*".Francisco Fernandez de Sandobâl. In: Castrillo, M.C. (2000). *Doñana Nombre a Nombre. Estudio de la toponimia del Parque Nacional de Doñana*. Diputación Provincial de Huelva. Huelva. 288 p.

1748. "*Mapa del Reynado de Sevilla*". Francisco Llobet. In: Instituto de Cartografía de Andalucía. (1998). *La Nueva Cartografía en España (del S. XVIII al XX)*. Consejería de Obras Públicas y Transportes, Junta de Andalucía. Sevilla. 207 p.

1748-1752. "*Mapa de la Provincia Marina de Ayamonte*". José Quintana y Ceballos. Plano Geográfico y Mapa General de los Pueblos, Montes, sus arboledas, extensiones, justicias, guardas que los custodian, vecindarios, matriculados y embarcaciones que comprende la Provincia de Ayamonte, una de las que componen el Departamento de la Capitanía General de Cádiz, según la revista de la Inspección ejecutada por el Ministro Principal de Marina de la misma provincia Don José Quintana y Ceballos. In: Gómez Cruz, M. (1991). *Atlas Histórico-Forestal de Andalucía S. XVIII*. Universidad de Granada, Granada, 71p.

1765. "*Mapa o carta corográfica que comprende todas las provincias de marina que componen el Departamento de Cádiz, reducido de los que en escala mayor se han* *formado, con real orden*". José Espelius. In: Gómez Cruz, M. (1991). *Atlas Histórico-Forestal de Andalucía S. XVIII*. Universidad de Granada, Granada, 71 p.

1767. "*Mapa del Reyno de Sevilla*". Tomás López. In: Gómez Cruz, M. (1991). *Atlas Histórico-Forestal de Andalucía S. XVIII*. Universidad de Granada, Granada, 71 p.

1768. "*Plano de demostrazión de los caños*". Anonymous. In: Castrillo, M.C. (2000). *Doñana Nombre a Nombre. Estudio de la toponimia del Parque Nacional de Doñana.* Diputación Provincial de Huelva. Huelva. 288 p.

1781. *"Carte de Seville"*. F. L. Gussefeld. Imp. Herederos de Homann. Map Library Instituto Geográfico Nacional.

1795 a. "*Mapa Geográfico del Reyno de Granada*". Tomás López. Edición Facsímil Instituto Geográfico Nacional, Madrid. 1992.

1795 b. "*Mapa General de España (dedicado al Serenísimo Señor Don Fernando Príncipe de Asturias)".* Tomás López. Madrid. In: Cartografía Histórica de Andalucía (Microforma). Consejería de Obras Públicas y Transportes. 1994, Sevilla. Library de la Universidad de Sevilla.

18th C. a "*Carta Geográfica de las posesiones del Duque de Medinasidonia*". Pedro Alonso de Salanobâ. In: Castrillo, M. C. (2000). *Doñana Nombre a Nombre. Estudio de la toponimia del Parque Nacional de Doñana.* Diputación Provincial de Huelva. Huelva. 288 p.

18th C. b "*Pleyto sobre el Cobro de los Tributos de sal de las salinas sitas en el Coto de Dª Ana Termº de la Villa de Almonte*". Anonymous. In: Castrillo, M. C. (2000). *Doñana Nombre a Nombre. Estudio de la toponimia del Parque Nacional de Doñana.* Diputación Provincial de Huelva. Huelva. 288 p.

18th C. c "*Demostración del Reyno de Huelva? del Coto de Dª Ana que antes se nombró la Dehesa del Carrizal y la Figuera, término de la villa de Almonte frente de la Ciudad* *de S. Lucar de Barrameda, propia de Los Duques de MedinaSidonia*". Anonymous S. XVIII (paño de pintura). In: Rivera, M. L. (2002). *Arqueología e Historia* , págs. 340-352. In: Canseco, V. (2002). *Parque Nacional de Doñana.* Canseco editores, Talavera de La Reina, 430 p.

1810. "*Plano geográfico de Moguer, con los movimientos del General Lacy*", por D. Angel Saavedra, Ayudante Primero de E. M. Plano Geográfico de Moguer y sus inmediaciones, referentes a los movimientos de la División General Laci en Agosto de 1810 quando batió a las tropas del general ArambergoAtula de León y Septiembre primero de 1810= Mampoey=(sic). Historic library of maps Servicio Geográfico del Ejército.

1812. "*L'Espagne et le Portugal*". J. B. Poirson. Edición Facsímil Instituto Geográfico Nacional. Madrid. 1985.

1851. "*Hemisferio Oriental*". John Tallis. In: LIBSA (2000a). *Mapas del Mundo*. Eds. LIBSA, Madrid, 86 p.

1862. "*Plano de los ríos Tinto y Odiel*". Manuel Fernández y Coria. E. 1:25,000, Dir. de Hidrografía. Historic library of maps Servicio Geográfico del Ejército.

1865. "*Río Guadalquivir*". Coello y otros (sic). In: Instituto de Cartografía de Andalucía. (1998). *La Nueva Cartografía en España (del S. XVIII al XX)*. Consejería de Obras Públicas y Transportes, Junta de Andalucía. Sevilla. 207 p.

1869. "*Huelva*", Francisco Coello Coronel de Ingenieros Militares. Historic library of maps Servicio Geográfico del Ejército, Madrid.

1870. "*Carta Geográfico-Minera de la provincia de Huelva*". 1:200,000. Joaquín Gonzalo y Tarín. Historic library of maps Biblioteca Nacional de España, Madrid.

1875. "*Costa Sudoeste de España*". Hoja II (desde Huelva hasta la Torre de la Higuera). Según trabajos realizados desde 1865-1870 por la Comisión Hidrográfica a cargo de

D. José Montojo y Salcedo. Dirección de Hidrografía, Madrid 1875. Historic library of maps Servicio Geográfico del Ejército.

1878-1879. "*La enseñanza universitaria en España*". Vallín, A. F., Ministerio de Fomento. Publícase de Real Orden, siendo ministro de Fomento el Excmo. Sr. D. Fermín Lasala y Collado. Madrid, datos de diciembre de 1879. In: Cartografía Histórica de Andalucía (Microforma). Consejería de Obras Públicas y Transportes. 1994, Sevilla. Library de la Universidad de Sevilla.

1879. "*Mapa Geológico de España y Portugal*". Federico de Botella y de Hornos. La Parte Geográfica por Francisco Coello. E. 1:2,000,000. Madrid. Observaciones desde 1848 á 1879. In: Cartografía Histórica de Andalucía (Microforma). Consejería de Obras Públicas y Transportes. 1994, Sevilla. Library de la Universidad de Sevilla.

1880. "*Provincia de Huelva*", Emilio Valverde. 1:750,000. Atlas Geográfico descriptivo de la Península Ibérica, Islas Baleares, Canarias y Posesiones Españolas en Ultramar. Historic library of maps Servicio Geográfico del Ejército, Madrid.

1887. *"Mapa geológico y topográfico de la provincia de Huelva"*. E. 1:400,000. Acompaña de 3 cortes geológicos. Joaquín Gonzalo y Tarín. Ed.: I.G.M.E.. Library del Instituto Geológico y Minero.

1888 "*Mapa General de Andalucía*". 1:750,000. Emilio Valverde. In: Valverde, E. (1885-1888). Guía del Antiguo Reino de Andalucía. Colección Los Libros del Caballero Andante 12. Eds. Don Quijote, 1992. Sevilla, 586 p.

1892. "*Nuevo mapa geográfico estadístico de la provincia de Huelva*", José Carrasco y Padilla (Excma. Diputación Provincial de Huelva). 1: 300,000. Map Library Instituto Geográfico Nacional, Madrid.

1897-1900. *"Provincia de Huelva, nivelación"*, por el Instituto Geográfico Estadístico. Dibujado por F. Noriega y J. Cobo de Guzmán. Trabajos topográficos desde 1897 á 1900. Historic library of maps Servicio Geográfico del Ejército.

19th C. a *"Provincia de Huelva"*, Anonymous. Historic library of maps Servicio Geográfico del Ejército.

19th C. b *"Provincia de Huelva"*, Anonymous. Sin proyección, ni escala. Scale ~ 1:200,000. Historic library of maps Servicio Geográfico del Ejército.

19th C. c *"Parte Sudoeste de la Provincia de Huelva"*, Cuerpo de E.M. S. XIX ó 1870/1878 Parte de la Provincia de Huelva, Anonymous. Scale ~1:100,000. Historic library of maps Servicio Geográfico del Ejército.

1902. "*Mapa de España*", Ibáñez de Ibero. 1:500,000. Mapa de España formado por el Excmo. señor Mariscal de Campo D. Carlos Ibáñez é Ibáñez de Ibero con motivo de la división del territorio en zonas militares para situar las reservas y depósitos del ejército (sic). Publication 1884 and edited in 1902. Lit. Instituto Geográfico y Estadístico. Library Instituto Geológico y Minero, Madrid.

1905. "*Mapa Militar Itinerario de España*". Formado por el Cuerpo del Estado Mayor del Ejército. Hoja 83, 2ª ed (1916). In: Cartografía Histórica de Andalucía (Microforma). Consejería de Obras Públicas y Transportes. 1994, Sevilla. Library de la Universidad de Sevilla.

1913. *"Las costas de la provincia de Huelva y sus variaciones en el periodo histórico"*. Maximino San Miguel de la Cámara. *Boletín de la Real Sociedad de Historia Natural,* XIII, 434-468.

1921. "*El Tartessos, brazo occidental del Guadalquivir (desparecido)*". J. Bonsor. Coto de Doña Ana, 25 de agosto de 1921. E. 1:50,000. In: Bonsor, J. (1922). *El Coto de Doña*

Ana. Una visita arqueológica. Clásicos de la arqueología de Huelva 2/1989. Diputación de Huelva, reedición 1990. Huelva, 56 p.

1926. "*La llanura baja del Guadalquivir en los primeros tiempos de la época histórica, según Jorge Bonsor".* In: Hernández Pacheco, E. (1926). *La Sierra Morena y la Llanura Bética (síntesis geológica)*. Ed. Instituto Geológico de España. Madrid, 145 p.

1936. *"Mapa Geológico de España E. 1:50,000 y memoria explicativa"*. Sheet 1017 ("El Asperillo"). Juan Gavala y Laborde. Instituto Geológico y Minero de España. Tip. y Lit. Coullant, 1936. Library del Instituto Geológico y Minero.

1949. *"Cartografía Militar de España E. 1:25,000"*. Sheet 1017 ("El Picacho"), cuarto IV-III ("El Picacho"). Servicio Geográfico del Ejército, 1952. Dpto. Plant Biology and Ecology, University of Sevilla.

1949. *"Cartografía Militar de España E. 1:25,000"*. Sheet 1017 ("El Picacho"), Cuarto I ("El Abalario").. Servicio Geográfico del Ejército, 1952. Dpto. Plant Biology and Ecology, University of Sevilla.

1951.*"Mapa topográfico Nacional E. 1:50,000"*, Sheet 1017 ("El Picacho").. Dirección General del Instituto Geográfico Catastral y Servicio Geográfico del Ejército. Map Library Instituto Geográfico Nacional.

1972. "*Mapa Topográfico Nacional E. 1.50,000"* Sheet 1033 ("Palacio de Doñana"). Imprimed in 1974.

1994. *"Mapa de las lagunas de Abalario"*. Tragsatec, S. A. Documento técnico inédito.

1998. "*Parques Naturales de Andalucía. Doñana".* Instituto de Cartografía de Andalucía (Consejería de Medio Ambiente y Consejería de Obras Públicas y Transportes de la Junta de Andalucía), 1:75,000.

Unknown date. “*Antiqua Hispania, Sive Iberia*”. Augusto Marchetti. In: Cartografía Histórica de Andalucía (Microforma). Consejería de Obras Públicas y Transportes. 1994, Sevilla. Library de la Universidad de Sevilla.