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The ecology of the Iberian inland waters: Homage to Ramon Margalef

Post-Little Ice Age warming and desiccation of the continental wetlands of the aeolian sheet in the Huelva region (SW Spain)

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ABSTRACT

During the last few decades, studies have been performed and evidence has been found concerning the importance of the climatic period known as the "Little Ice Age" (mid 15th century through late 19th century). However, most of the studies have been focused to more northern latitudes and, therefore, scarce studies have still been made on the Mediterranean latitudes. In this paper, an analysis is made of the effects of the post-Little Ice Age warming and on its consequences upon the continental aquatic ecosystems of the Doñana coastal area and its surroundings. The results of such analysis evidence that the end of this period –climatically more benign in our latitudes– implied the start of an irreversible regression and disappearance of a large part of the most typical wetlands in the SW of the Iberian Peninsula. The significant impact of the human exploitation of natural resources in the area has masked the effect of this recent climatic change. Furthermore, when compared with those from other latitudes, the results of this analysis evidence the global or supraregional features of the impact caused by the post-Little Ice Age warming. Additionally, these results are useful for indicating which will be the future changing trends in the wetlands under study as a result of global warming.

Key words: Little Ice Age, global warming, wetlands, lagoons, peat-bogs, Doñana, Huelva, peatlands, aeolian sheets.

RESUMEN

En las últimas décadas se ha estudiado y puesto en evidencia la importancia del período climático conocido como Pequeña Edad del Hielo (mediados S. XV hasta finales del S. XIX). Sin embargo la mayoría de los estudios se han centrado en latitudes más septentrionales, por lo que todavía son escasas las investigaciones sobre latitudes mediterráneas. Este trabajo analiza los efectos del final de la Pequeña Edad del Hielo (post-Little Ice Age warming), y las consecuencias que tuvo sobre los ecosistemas acuáticos continentales del litoral de Doñana y su entorno. Los resultados de este trabajo desvelan que la finalización de este período –climáticamente más benigno en nuestras latitudes- supuso el inicio de la regresión y desaparición de forma irreversible de gran parte de los humedales más singulares del SW de la Península Ibérica. El gran impacto que tuvo la explotación de los recursos naturales de la zona por parte del hombre, ha ocultado el efecto de este cambio climático reciente. Asimismo los resultados de este análisis, al compararlos con otras latitudes, ponen en evidencia el carácter global o suprarregional del impacto del final de la Pequeña Edad del Hielo. Además estos resultados sirven para indicar cuales serán las tendencias futuras de cambios, en estos humedales, como consecuencia del Calentamiento Global.

Palabras clave: *Pequeña Edad del Hielo, Calentamiento Global, humedales, lagunas, lagunas turbosas, Doñana, Huelva, turberas, Manto Eólico Litoral.*

INTRODUCTION. THE LITTLE ICE AGE

A climatic period that took place approximately between 1430 and 1850 (Pita, 1997), characterised by the severity of its winters, is known as the Little Ice Age and was initially studied because of the advancements and retreats of the glacial moraines.

The Little Ace Age (hereinafter LIA) concept was originally defined by Matthes in 1939 (Grove, 1988) as an epoch of renewed but moderate glaciations that followed the warmest part of the Holocene, when he studied the Sierra Nevada (California, USA) glaciers. Therefore, its original definition arose from the field of glaciological (and not purely climatic) studies. Although, initially, this climatologically colder phase has been studied and acknowledged especially in the Alpine Glaciers (Grove, 1988; Le Roy Ladurie, 1991), it also implied a significant advancement in the European, North American and Asian glaciers. Specifically, in the Iberian Peninsula, it has been studied in the Pyrenean glaciers (Mateo García & Gómez Ortiz, 2000).

During the LIA, the presence of temperatures between 1 and 3°C lower than the current ones has been confirmed in the North Atlantic Ocean (at about latitude 50°). This cooling trend disappeared in the mid 19th century and was substituted by a new warming process that, with slight fluctuations, persists until our days (Pita, 1997).

One of the problems posed by this period, known as exceptionally cold at a global level, is the difficulty encountered in establishing its time limits (Font Tullot, 1988; Rodrigo *et al.*, 1995; Sousa, 2004). As it has been pointed out by several authors (Grove, 1988; Le Roy Ladurie, 1991; Rodrigo *et al.*, 1999), probably, part of the problem rests on the fact that the LIA itself involved rather a series of frequent fluctuations than a uniform block. However, most of the authors assert that it ended, approximately, within the second half of the 19th century.

The fact that it was not a single block and that warmer intervals arose among the dominating cold periods does also hinder its interpretation. This is why Rodrigo *et al.* (1995) consider that the concept of LIA must be used with care, since it cannot be considered as a uniform or constant climatic phase, in so far as the time scale is concerned (Rodrigo *et al.*, 1999). Thus, we are dealing with a climatic period involving a series of more or less marked fluctuations and, therefore, the general uniformity of its understanding will depend, to a large extent, on the time scale under consideration (Sousa, 2004).

The first great reviews on this period –as from a purely climatic perspective– were carried out in the late 80s and early 90s (Grove, 1988; Pfister, 1992). And, precisely, Spain was one of the 3 countries worldwide where the effects of the LIA were least known (Grove, 1988). Until then, only a few essentially descriptive studies had been made (Rodrigo *et al.*, 1999), such as those by Font Tullot (1988).

Fortunately, in the mid 90s, the first doctoral theses dealing exclusively with this period in Spain started to be developed (Barriendos & Martín-Vide, 1998). The recent studies performed in Spain reveal that the LIA was characterised by the fact that the increase of aridity results from the interannual variability of rainfall and from the frequency of several extreme events, rather than from persistent droughts (Rodrigo *et al.*, 1995). In short, in diverse studies (Barriendos & Martín-Vide, 1998; Rodrigo *et al.*, 1999 and 2000) with some subtle differences, three periods within the LIA were detected as specially humid in the South of Spain: 1570-1630, 1780-1800 and 1830-1870.

Therefore, the LIA in Andalusia was a specially wet period (thus differing from other that in more-northern latitudes), even if dry periods occurred among these three humid episodes. After the LIA, as of the late 19th century, rainfall in Andalusia has been progressively decreasing and has only been interrupted by positive anomalies in the 1960s (Rodrigo *et al.*, 2000), as it was proved for the observatories in the SW of Spain by Sousa (2004).

Currently, in the most northern latitudes of the North Hemisphere, an anomalous warming has been taking place as compared with the last three centuries. This trend must be partially attributed to the recovery of the LIA, but also to a recent increase of the thermic level. Flannigan *et al.* (1998) do also point out an increase in temperature in the Northern Hemisphere after the termination of the LIA.

This corresponds with the results of the analyses performed by García Barrón (2002a and 2002b) at observatories in Huelva, which show a decrease in the spring rainfall and an increase of the minimum temperatures during the 20th century. They also serve to explain the presence of last humid peak of the LIA at the end of the 19th century, as well as the increase in dry years to the detriment of humid years since the end of the

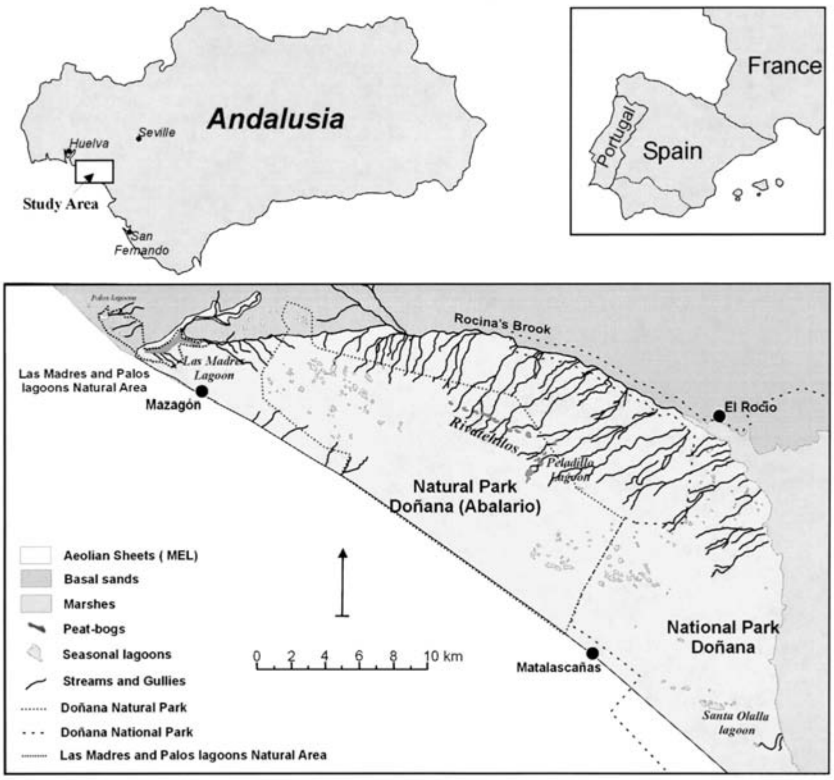

Figure 1. Location of the study area, where the extraordinary number of existing wetlands can be observed. *Localización del área de estudio, donde destaca el extraordinario número de humedales existentes.*

19th century, according to the series of rainfall data of the observatory in San Fernando (Cadiz).

This aridisation, loss of softness or Atlanticity in the climate since the late 19th century seems to have led to a global desiccation process in the local marshy formations (Sousa & García-Murillo, 2002 and 2003; Sousa, 2004), comparable with the one detected by Granados (1987) and Granados *et al.* (1988) in the Doñana National Park. This might also be related to the erosional processes detected by Devereux (1982) at the ravines (gullies) in Algarve, Portugal.

AREA OF STUDY. THE WETLANDS OF THE EASTERN COASTAL AREA OF HUELVA

The area under study is limited to the continental humid formations (lagoons and small creeks) located on the eastern coastal area of Huelva (between the mouths of the Tinto and Guadalquivir rivers). As can be seen in Figure 1, the main substrate of these marshy areas is the Coastal Aeolian Sheet. Therefore, we are referring to a vast coastal area (~44,000 hectares) located at the southwest of the Iberian Peninsula, within the Andalusia Region and, more precisely, in the Province of Huelva (including the municipalities of Almonte, Moguer, Palos de La Frontera and Lucena del Puerto).

The eastern coastal area is very rich and diverse in its formations and wetlands, which are distributed within three natural regions protected by the regulations in force: the Las Madres and Palos lagoons Natural Area, the Doñana National Park and the Doñana Natural Park (Fig. 1). It was only within the boundaries of the Doñana Natural Park (in its west sector known as Abalario) that we have studied the evolution of about 300 small lagoons (both peat-bogs and seasonal lagoons).

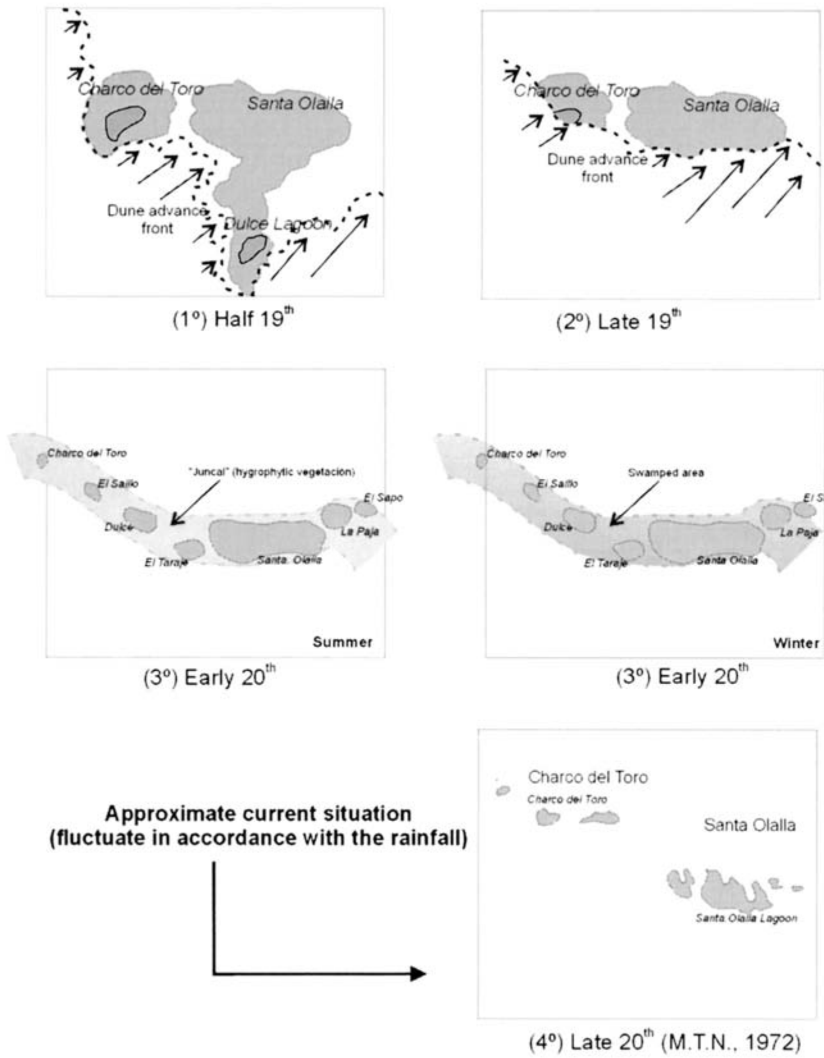

Figure 2. Segregation and division process in the swamped areas of the peridunal lagoons in the Doñana National Park, due to the advancement of live dunes between the late 19th century and the present. *Proceso de segregación y división de las zonas encharcadas de las lagunas peridunares del Parque Nacional de Doñana, debido al avance de las dunas vivas, desde finales del S. XIX hasta nuestros días.*

In addition to the Abalario humid complex –which would take up the most central area in this study– the various types of lagoons in the Doñana National Park were analysed, although the research work was especially focused on the peridunal ponds located inside the Doñana Biological Reserve (Brezo, Charco del Toro, Taraje, Zaillo, Dulce and Santa Olalla lagoons).

Also under analysis was the genesis of the coastal lagoons in Palos de la Frontera (Primera de Palos, La Jara and La Mujer), as well as the large Las Madres peat-bog, in Moguer, all of them located within the Las Madres and Palos lagoons Natural Area.

In spite of the heterogeneity of these continental wetlands, when viewed as from the limnological, hydrogeological and vegetation points of view, they are all located within a common geological substrate: the coastal Aeolian Sheet of Huelva. The coastal Aeolian Sheet (hereinafter MEL, in its Spanish acronym) is mostly composed by quaternary sandy sediments produced by the successive appearance of several dune fronts.

Table 1. Synthesis of the materials and methods used to rebuild the evolution of wetlands of the Aeolian sheets. *Síntesis de los materiales y métodos empleados para reconstruir la evolución de los humedales del MEL.*

Material and methods used	**Concrete features**
Field data (flora)	1998, 1999, 2000, 2001, 2004 and 2005
Transects of perilagoon vegetation	57 transects and 6 samplings (total 1632.8 m)
Vegetation units	Yes
Consultation aerial photographs	1956, 1984, 1987, 1988, 1991, 1992, 1994, 1996, 1998 and 2000
Satellite images analysed	LANSAT-TM (1986), LANSAT-TM (1987), LANSAT-TM (1990), and SPOT (1989)
Hygrophytic vegetation maps	1956, 1998 and 2000 (depending on the specific marshy area)
Historical floristic inventories	All the municipalities in the area under study (fundamentally from the 18th century, although also some data from the 19th century and from the first half of the 20th century)
Historical forestry inventories	All the municipalities in the area under study (fundamentally the Land Registry of Marqués de la Ensenada, although also some data from the first half of the 20th century)
Data obtained from files and other documentary sources	17th through 20th centuries
Historical cartography	> 70 maps and historical navigation charts from the 2nd to the 20th centuries (although the essential ones are as from the 18th century)
Hypsometric maps	1:50000 and 1:10000 scales
Microrelief	> 2,750 topographic heights interpolated at a 1:10000 scale
Topographic profiles based on microrelief	Several
Conductivity	Yes

THE DISAPPEARANCE OF THE WETLANDS

In order to attain a reconstruction of the evolution of the MEL's continental wetlands, a mixed method must be followed. The method is initially based in its reconnaissance and characterisation by means of field work. This allows to characterize the typology of the wetlands, as well as the phreatophytic vegetation related to them. This field phase serves as a basis for the photointerpretation and cartography –by means of aerial photographs and satellite images– of the marshy areas at a highly detailed scale.

A combination of these data with the documental sources available in the files allows for a very accurate reconstruction of the evolution of the wetlands under study. To go even further back in time, the aforementioned results must be compared with the historical documentary and cartographic sources. Finally, the analysis is completed with a study of the area microrelief (by means of a manual interpolation of the topographic heights at a 1:10000 scale), which allows to reveal the situation of these wetlands at the end of the 19th century and, with lesser accuracy, in the early 17th century. For further details on the concrete sources and methods developed on the overall area under study, please see Sousa (2004), Sousa & García-Murillo (1999, 2001, 2002 and 2003) concerning the Abalario area, or Sousa & García Murillo (2005) regarding the Doñana National Park. A summary of them is shown in Table 1.

The retreat of the continental wetlands in SW Spain cannot be interpreted as if they were a single homogeneous unit as far as their behaviour and evolution are concerned. This is because their ecological, limnologic, waterfeed and, especially, territorial features are significantly different. This is why we have grouped them as belonging to the Doñana National Park, to the Las Madres and Palos lagoons Natural Area or to the Doñana Natural Park.

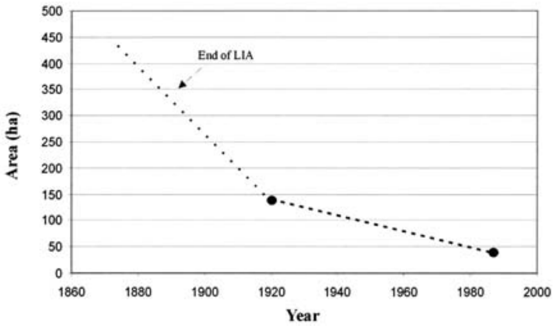

Figure 3. Retreat of the peridunal lagoons in the Doñana National Park, between the late 19th century and the present. *Regresión de las lagunas peridunares del Parque Nacional de Doñana desde finales del S. XIX hasta nuestros días.*

The peridunal lagoons in the Doñana National Park

At least between the early 18th century and the late 19th century, these lagoons were altered by the advancement pulses of the MEL's Aeolian Unit 5 (Rodríguez-Ramírez, *et al*., 2005). This turned the large original swampable area into two large lagoon areas: Santa Olalla and Charco del Toro; (Sousa, 2004; Sousa & García Murillo, 2006). In turn, these two large lagoons were, again, split into the current small ponds. Therefore, the current string of peridunal lagoons has been generated based on the advancement of the front of the coastal active dune systems and by silting and splitting the 2 large original lagoons between the late 19th century and the early 20th century (Fig. 2).

It is important to note that —as already mentioned by Granados (1987)— these dune advancement pulses are associated with the climatologically driest periods. As it was later demonstrated by Rodrigo *et al.* (1994 y1999) and Barriendos & Martín-Vide (1998), these dry periods are located among the three abovementioned humid peaks of the LIA.

Further to these changes, the drawing of water by the Matalascañas tourism centre, along with the centuries-old occurrence of fires in the

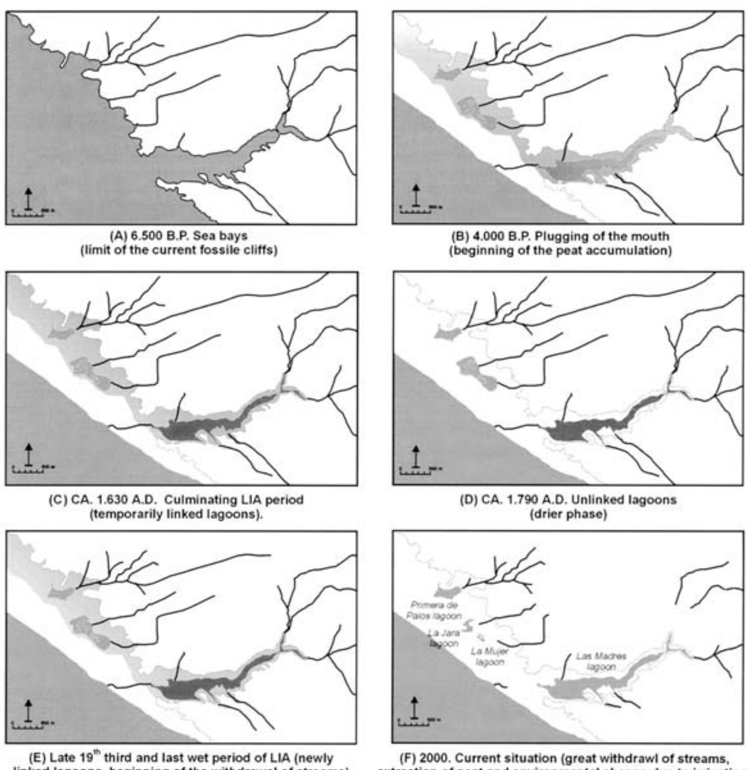

Figure 4. Different phases in the genesis of the Palos de la Frontera and Las Madres lagoons, since the initial plugging of the drainage of the original creeks [taken from Sousa (2004) modified]. *Diferentes fases de formación y génesis de las lagunas de Palos de la Frontera y Las Madres, a partir de la obturación inicial del avenamiento de los arroyos originales [tomado de Sousa (2004) modificado].*

region (Granados *et al.*, 1986; Granados, 1987;), have affected the original vegetation irreversibly (Sousa, 2004; Sousa & García Murillo, 2005). Thus, its area has been reduced until the current situation was reached (Fig. 3).

Las Madres and Palos lagoons Natural Area

The case of this lagoon complex, located between the municipalities of Palos de la Frontera and Moguer, is indeed different. Its transformation and genesis, from the original Atlantic creeks (Menéndez & Florschütz, 1964), is due to intrinsic factors of the Spanish Atlantic coast (Sousa, 2004). This dynamics prompted the plugging of the mouths of these creeks, which were turned, first, into lagoons (Zazo *et al.*, 2000) and, later on, into the coastal lagoons that we can find nowadays. The microtopographic reconstruction of the area makes it evident that, at the end of the 19th century —during the last wet period of the LIA— these lagoons were all interconnected (Fig. 4). This temporary interconnection among them is confirmed after an analysis of the historical cartographic sources of that time (Sousa, 2004; Fernández Zamudio *et al.*, 2005).

The differences between the great Las Madres peat-bog and the rest of the Palos lagoons (Jara, Mujer and Primera de Palos) refer to the intrinsic morphometric and area features of their hydrological basins.

The lagoons of the *Doñana* Natural Park (Abalario sector)

In the case of the numerous lagoons of the Abalario humid complex, the evolution has been very different from the former ones. Thus, during the second half of the 20th century, the forestry activities in the region (especially the application of monocultures of eucalyptus), prompted the desiccation of many lagoons. This effect was especially significant upon the Rivatehilos peat-bogs, which went from 178 to only 30 lagoons during the 1956-1987 period.

These lagoons, located on peat soils and originally occupied by communities of *Erico ciliaris-Ulicetum (minoris) lusitanicus* (García Murillo & Sousa, 1999), underwent an intensive desiccation process that led to the mineralisation of all the retained organic matter. This desiccation, caused by the lowering of the phreatic level (Sousa & García Murillo, 1999 and 2003, Trick & Custodio, 2003), prompted the substitution of the above-mentioned heather communities by less-stenohydric hygrophytic bushes (*Erico scopariae-Ulicetum australis*).

However, when the evolution of these humid formations is historically reconstructed, it can be seen that this desiccation process is prior to the human activities in the region. Actually, it is a reduction process that started, at least, in the early 17th century, after the iciest period –and the most humid in our latitudes– of the LIA.

Since then, 17th century, the surface covered by the Rivatehilos peat bogs has been decreasing at mean rate of 1.2 hectares/year. When the third and last humid peak at the termination of the LIA (late 19th century), this rate is doubled and the lagoon area decreases at a mean rate of 2.4 hectares/year. The forestry activities throughout the Abalario region accelerate this process exponentially (mean rate 43.6 hectares/year) during the second half of the 20th century, masking the previous climatic changes (Fig. 5).

On the other hand, the seasonal lagoons in Abalario, due to their epigean waterfeed, have been less affected by the reduction of the phreatic level due to the implantation of large masses of eucalyptus.

Since these are lagoons that depend only on the rainfall and on the surface runoff, they reflect very rapidly any change in the climatic trends. Thus, after the last wet period of the LIA, in the late 19th century, a significant reduction starts to take place in the Laguna de Invierno (covering almost 400 hectares and 5 km long) and in other smaller seasonal lagoons, at a mean rate of 5.2 hectares/year. The disappearance of this large seasonal lagoon –known as *Laguna de Invierno* (*Winter Lagoon*)– is highly relevant because, in Valverde's opinion (1885-1888 and 1880), it was the largest in the province of Huelva. In fact, currently, in Andalusia, its area would only be exceeded by the Laguna de Fuente de Piedra (Málaga).

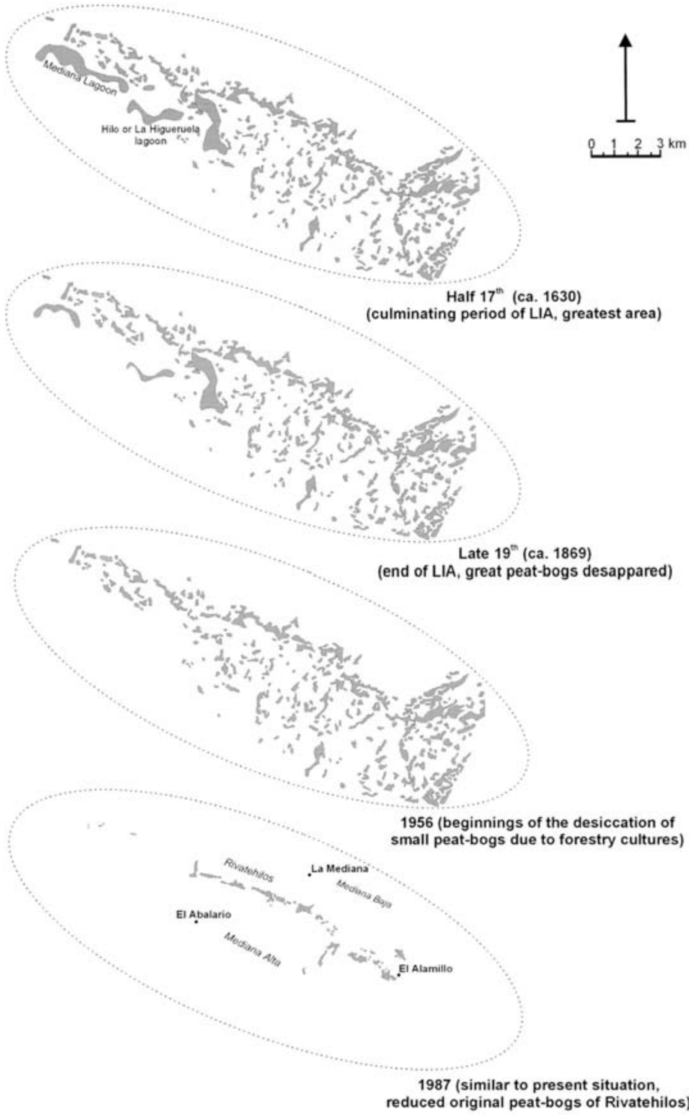

Figure 5. Evolution of the peat-bogs in Rivatehilos, showing the disappearance of some large lagoons and the reduction of others linked to recent forestry activities. *Evolución de las lagunas turbosas de Rivatehilos, con la desaparición inicial de las grandes lagunas y la reducción de otras vinculada a las actividades forestales más recientes.*

Table 2 shows a comparison of the mean annual reduction rates for the two lagoon types under study within the Doñana Natural Park.

Figure 6 shows a comparative version of the evolution of both types of lagoons at the Doñana Natural Park (Abalario Sector), between the 17th and the 20th century.

We have referred to different continental wetlands; nevertheless, similar processes have also been found in the linear wetlands of the region. This would be the case of gullies draining on the right margin of La Rocina Creek (Sousa & García Murillo, 1998 and 2000; García Murillo & Sousa, 1999; Sousa, 2004) or of the interesting Atlantic creeks, many of which disappeared before the start of the 20th century (Sousa & García Murillo, 1998; Sousa, 2004). Most of them are currently in a process leading to the full disappearance, in spite of the fact that they lodge exceptionally valued floristic com-

Table 2. Mean annual reduction rate of the lagoons in the Doñana Natural Park (Abalario sector), in hectares/year. *Tasa media anual de disminución de las lagunas del Parque Natural de Doñana (sector Abalario), en ha/año.*

	17th (≅1630)–19th (≅1869)	19th (≅1869) - 1956	1956-1987
Rivatehilos peat-bogs	1.2	2.4	43.6
Seasonal lagoons in Abalario	0.1	5.2	*

* Non significant because, practically, there is no reduction. Only a slight increase is noticed due to the fact that some peat-bogs start to behave as seasonal lagoons.

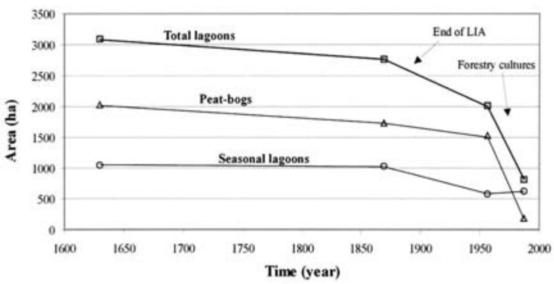

Figure 6. Comparative evolution of the peat-bogs and seasonal lagoons in the Doñana Natural Park. *Evolución comparada de las lagunas turbosas y temporales del Parque Natural de Doñana.*

munities with an Atlantic influence, as it is the case of the *Sphagnum inundatum* moss (García Murillo *et al.*, 1995), among other taxons.

Until now, we have outlined the evolution of these wetlands and mentioned some of the factors hidden behind these changes. In the following section, we are going to provide a more thorough description of the reasons for this retreat, using these results as a basis for analysing the effects of the ending of the LIA in the SW of Spain. What were the features of this climatic period that could affect these coastal wetlands so significantly?

REASONS FOR THE RETREAT OF THE WETLANDS

As it was mentioned above and as shown in different documents (Sousa & García Murillo, 1998, 1999 and 2001), human activities have conditioned and affected the wetlands of the MEL of Huelva very intensively. However, as shown by Sousa (2004), the studies on the usage of the region make it evident that human activities were not relevant until the second half of the 20th century. This can be followed up very clearly, in the case of the wetlands of the Doñana Natural Park, by analysing usage and the occupation by forestry monocultures.

In the case of the Las Madres and Palos lagoons Nature Area, the greatest impact is also recent and related to the exploitation of peat, the growing of strawberries and reforestation (Márquez, 1986 and 1992; Garrido, 1996; Sousa, 2004; Fernández Zamudio, 2005; Fernández-Zamudio *et al.*, 2005).

On the other hand, studies by Granados *et al.* (1986) and Granados (1987), reveal the important role played by fire as a differentiating factor at the Doñana National Park. The application of GIS to these data, along with the support of historical cartography, has also revealed the severe impact caused by fires upon the original phreatophytic vegetation of the peridunal lagoons in the Doñana Biological Reserve (Sousa, 2004; Sousa & García Murillo, 2005). Probably, the impact of fire, along with the decrease of the phreatic level in the region (due to usage and at the termination of the LIA), are the basic reasons for the retreat of a good number of peat-bogs in the Aeolian Unit 2 of the Doñana National Park.

However, all these human activities are not enough to explain the general retreat of the MEL lagoons in Huelva and, especially, that occurred until the start of the second half of the 20th century.

Hydrogeological studies (Trick & Custodio, 2003) reveal an important reduction of the phreatic level in connection with great forestry monocultures (pines and eucalyptus). However, when an analysis was made of the historical sequence in the disappearance of the peat-bogs of Rivatehilos since the 17th century (Sousa &

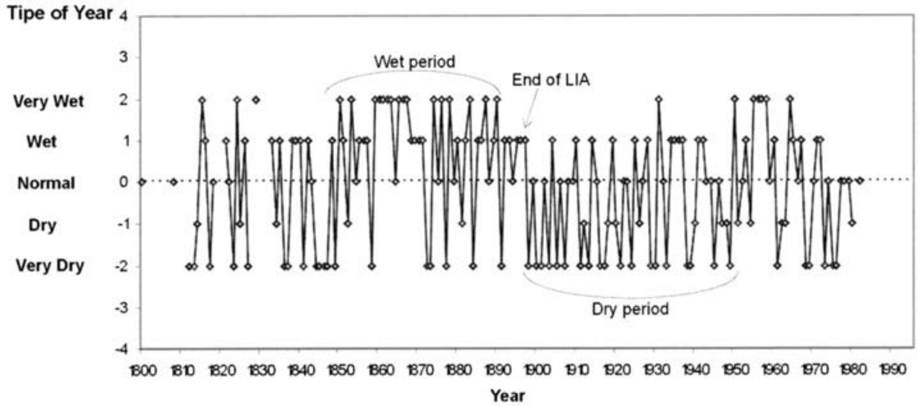

Figure 7. Representation of the absolute frequency of Very Dry, Dry, Normal, Wet and Very Wet years at the observatory of San Fernando (Cadiz). *Representación de la frecuencia absoluta de años Muy Secos, Secos, Normales, Húmedos y Muy Húmedos en el observatorio de San Fernando (Cádiz).*

García-Murillo, 1999 and 2003), it was confirmed that the process is prior to the reforestation (although intensified by the latter). Which are the reasons for this decrease of the phreatic levels, prior to the most intensive human activities in the region under study?

A comparative analysis of the reduction in the area of the seasonal lagoons and peat-bogs of Abalario between the 17th and the 20th centuries reveals a clear relationship with the climate. Thus, a decrease in the number of humid years and an increase in the number of dry years might explain the disappearance of the large seasonal lagoons in the MEL (Sousa & García Murillo, 1999), since the availability of feedwater (which is epigean) was smaller. This explanation seems to be fully coherent with the features and changes detected in the rest of the MEL's wetlands.

In order to confirm this hypothesis involving a change in the sequence of dry years vs. wet years in the late 19th century (and related to the last wet period of the LIA), an analysis can be made of the historical rainfall and temperature series.

Among the most complete instrumental series in the area, the one related to rainfall at the observatory of San Fernando (Cadiz) is outstanding (Sousa, 2004). The analysis of the trends is performed by means of a distribution of quintiles of the sample (Arlery *et al.*, 1973), following the recommendations of the WMO. The result obtained (Fig. 7) shows a markedly wet period at the end of the 19th century, as there is an increase of the absolute frequency in the humid and very humid years.

In order to further highlight this climatic inflection point, which coincides with the termination of the LIA, also the accumulated frequency can be represented. If, furthermore, the humid and very humid years and the dry and very dry years are grouped separately (Fig. 8), a change in the climatic trend appears clearly.

This wet period squares with what Barriendos & Martín-Vide (1998) dated between 1830 and 1870 for Mediterranean Spain and with what Rodrigo *et al.* (1994 and 1999) dated at the end of the 19th century for Andalusia (after studying floods and other non-directly climatic sources), as the third humid peak of the LIA.

This humid phase did also imply an increase in the spring rainfall (García Barrón, 2002a and 2002b) and greater anomalies in the rainfall (relative accumulated deviations of the mean annual rainfall). This increase in both spring rainfalls and irregularity appears as associated with the last wet period of the LIA. Contrarily, as of the 20th century, unmistakably, a decreasing trend of the spring rainfall can be found (although not of the total annual rainfall).

Another climatic factor to be considered could be the increase of the mean minimum temperatures, which was detected in several observatories near the area under study (García-Barrón & Pita, 2004). This increase is not observed in the mean maximum temperatures or in the mean annual

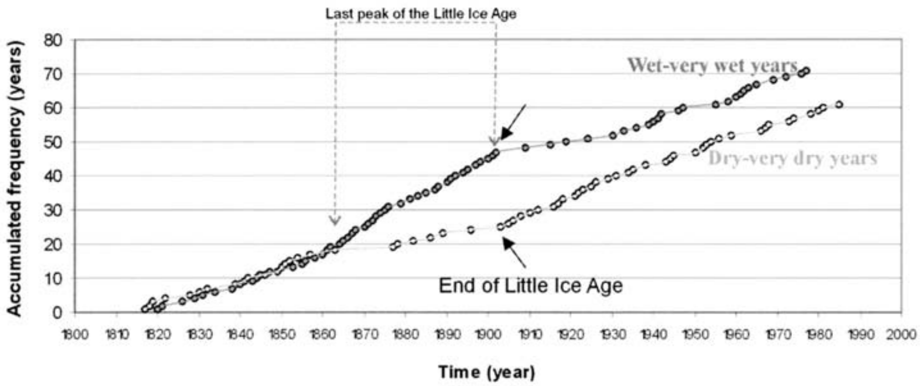

Figure 8. The representation of the accumulated frequency of wet versus dry years is a clear indication of the climatic inflection point occurred in the late 19th century: the end of the LIA in the SW of Spain. *La representación de la frecuencia acumulada de los años húmedos frente a los años secos, pone claramente de manifiesto un punto de inflexión climático a finales del S. XIX: el fin de la LIA en el SW de España.*

temperatures, thus differing from the situation in other more-northern observatories of the North Hemisphere (IPCC 2001 and even in the north of Spain (Castro *et al.*, 2005). Figure 9 shows the increasing trend of the mean minimum temperature at the Huelva station (Huelva).

These data obtained from the instrumental series confirm the initial hypothesis (previously outlined) concerning the features of the termination of the LIA in the SW of Spain. Thus, in addition to characterising this period as different from that in other more-northern latitudes (even in the north of Spain), it explains the reasons for the natural changes underwent by the Doñana wetlands and their surroundings, before the start of any significant human activity in the area.

POST-LITTLE ICE AGE AND GLOBAL WARMING THE FUTURE OF THE WETLANDS AT THE HUELVA MEL

It may be concluded that the termination of the LIA (what, in other more-northern latitudes of Europe has been named as the post-Little Ice Age warming) had different effects in southern latitudes as compared with those (far better known) of the more-northern latitudes.

Thus, the winter severity feature of the LIA in more-northern latitudes was characterized in the southern Iberian Peninsula by increased rainfall (Rodrigo *et al.*, 2000). The fact is that the climate change in the Iberian Peninsula may be related to precipitation rather than to temperature (Pfister *et al.,*1999).

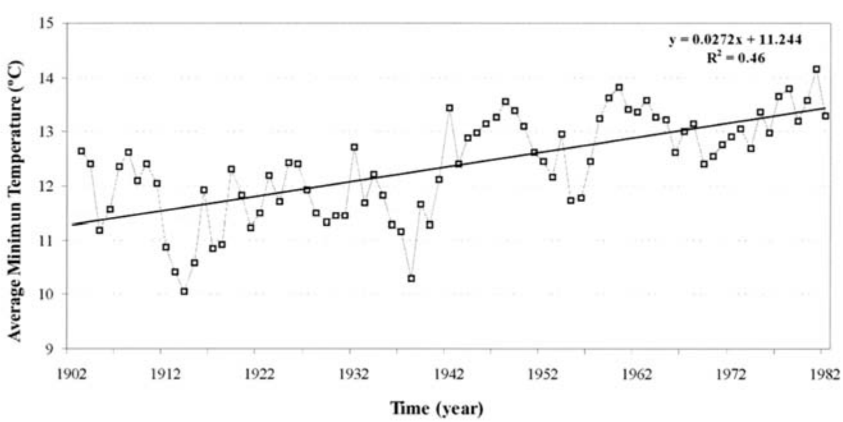

Figure 9. Since the early 20th century, a rise takes place in the mean minimum temperatures of the area under study. *Desde principios del S. XX se produce un incremento en las temperaturas medias de las mínimas en el área de estudio.*

This interpretation agrees with the studies on the rainfall anomalies in Andalusia (16th-20th centuries) performed by Rodrigo *et al.* (1994, 1995 and 1999), as well as with the climatic reconstruction studies made by Barriendos & Martín-Vide (1998) on the basis of the hydrological levels and floods in the rivers of the Spanish Mediterranean basin (Cataluña, Valencia, Murcia and Baleares).

This is why, as opposed to the situation in other more-northern European and Spanish latitudes, in the SW of Spain, the LIA brought along:

- A decrease in the frequency of wet years and, on the other hand, an increase in the number of dry years as from the late 19th century. This decrease in the number of wet years implied a decrease in the spring rainfall during the 20th century. In fact, this implies an aridisation or, at least, more marked Mediterranean conditions, as opposed to the oceanic and Atlantic features of the Huelva coastal region.
- This effect has been reinforced and sustained by a gradual and constant rise of the mean minimum temperatures that, in turn, produced an increase in the evapotranspiration rates (thus favouring the reduction of the flooded area and the retreat of the most demanding hygrophytic vegetal communities).

Sometimes simultaneously and sometimes consecutively, this natural process has been overlapped by forestry monocultures, irrigation practices, fires, charcoal burning, drawing of underground water, etc., depending on the specific area. This is how the natural alterations –which seem to tend to a simplification and a loss of the biological diversity and of the wet ecosystems– have been masked.

As from a limnological viewpoint, the intensity of the post-Little Ice Age warming effect may well be yet higher than what has been mentioned above. Sorvari *et al.* (2002) have detected changes in the composition of the Arctic lakes in Finland (especially in the diatoms), which coincides with the warming of the Arctic regions marking the termination of the LIA. This process –named by Sorvari *et al.* (2002) as *post-Little Ice Age warming*– would be the result of the post-19th century warming that –in our opinion– was due to the summation of the termination of the LIA and the start of the global warming.

Anyhow, these results make it evident that, if global warming is as intensive as predicted by the various models, the Doñana aquatic ecosystems and their surroundings will be affected negatively. This alteration will depend on which are the most affected climatic variables (important changes in the amount or seasonal distribution of the rainfall appears as more critical than changes in temperature). There will also be an incidence of the various biological and waterfeed features involved in the regimes of the different types of wetlands, even if everything seems to indicate that the ones more liable to be affected are those associated with an epigean waterfeed and with a more stenohydric vegetation (such as the areas with peat soil), as well as the floristic elements whose distribution shows Atlantic features.

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