Iberian acid peatlands: types, origin and general trends of development

X. Pontevedra-Pombal[1], D. Castro[2], R. Carballeira[2], M. Souto[2], J.A. López-Sáez[3], S. Pérez-Díaz[3], M.I. Fraga[2], M. Valcárcel[4] and E. García-Rodeja[1]

[1]Department of Soil Science and Agricultural Chemistry and [2]Department of Botany, Faculty of Biology, University of Santiago de Compostela, Galicia, Spain
[3]GI Archaeobiology, Institute of History, CCHS–CSIC, Madrid, Spain
[4]Department of Geography, Faculty of Geography and History, University of Santiago de Compostela, Galicia, Spain

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SUMMARY

In the present study we reviewed the genesis, development and classification of peatlands in the Iberian Peninsula by conducting chronostratigraphic analysis of 108 of these ecosystems. The findings are summarised as follows:

1. The region has a wide variety of peatlands which are classified according to their biogeochemical, geomorphological and ecological characteristics into different types of bogs and fens.
2. Most of the peatlands occur in the Atlantic region followed by the Mediterranean and Alpine regions. Fens are more widely distributed than bogs, and blanket and raised bogs are mainly found in the Eurosiberian biogeographical region.
3. In many of the fens, the last active peat-forming cycle occurred during the Late Holocene (43 %). In most of the bogs, the peat-forming cycle occurred in the Middle Holocene (70 %), although in a substantial proportion of blanket bogs these processes occurred in the Early Holocene (30 %).
4. The peat formed in the last active cycle is, on average, thicker in raised bogs (322 cm) than in blanket bogs (257 cm) and fens (156 cm).
5. Vertical peat accumulation rates varied between 16 and 30 yr cm^{-1} in more than 40 % of the peatlands. The accumulation rates differed significantly between the different types of peatlands and were highest in the raised bogs. The accumulation rates were very variable in the fens.
6. The genesis, evolution and types of Iberian peatlands are similar to those observed in peatlands in northern latitudes in Europe and North America.

KEY WORDS: chronology, distribution of mires, Holocene, Iberian Peninsula, peat accumulation

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INTRODUCTION

Amongst the many important environmental services provided by peatlands, their capacity to accumulate carbon with a positive feedback to the climate system (Limpens *et al*. 2008), and their ability to act as natural archives of environmental evolution, have captured the attention of researchers.

The carbon accumulated in organic soils worldwide (> 600 Gt C since the Last Glacial Maximum; Yu *et al.* 2010) represents up to 50 % of the terrestrial reserve (Evans *et al.* 2006) and the equivalent of more than 60 % of the atmospheric reserves of carbon (Freeman *et al.* 2001). However, there is some latitudinal asymmetry in these reserves, determined by the effects of macroclimatic factors.

In the last ~150 years, peatlands (fens and bogs) have played an important role in increasing our knowledge of the environmental evolution of the planet (Blackford 2000, Bindler *et al.* 2008, Chambers *et al.* 2010). The study of peatlands has enabled archives of palaeoenvironmental information to be linked to the current status, evolution and projected status of these ecosystems within the context of developing strategies for sustainable management of the natural environment. With these aims, many scientific disciplines use various proxy measures, component analysis and other properties to help understand the patterns of change in the intensity and rhythm of development and geographical scale of distribution of peatland ecosystems.

Of the world's wetlands, 50 % are peatlands (Joosten & Clarke 2002), and most of these are found in northern latitudes (*i.e*. north of 45 ºN; Loisel *et al.*

2014). This fact, together with a certain degree of misleading information about the distribution of blanket and raised bogs (key to the study of terrestrial C and palaeoenvironmental evolution) has led to sparse attention being given to peatlands in the Iberian Peninsula. These peatlands have often been presented as being rare, poorly developed, with low rates of peat accumulation and only minerotrophic subtypes (Maltby & Proctor 1996, Raeymaekers 1999, Evans 2006).

The border zone between the Eurosiberian and Mediterranean regions is regarded as extremely sensitive to climate change. This is of some importance in relation to the distribution of different types of peatlands, as well as to biological or climate-related diversity and palaeoclimatic patterns. The peatlands in this zone mainly occur in mountainous areas, in the floodplains of large hydrographical basins and on some low-energy coastal platforms. Although the European Union (EU) peatland report (Byrne *et al.* 2004) indicates that peatlands occupy an area of 8000 ha in the Iberian Peninsula, the minimum area estimated in a recent study is around 18000–22000 ha (Heras *et al.* 2017). In the north of the Iberian Peninsula, particularly in the NW, there is a large cohort of different types and subtypes of acid peatlands; these include blanket bog (watershed bog, valleyside bog, spur bog, saddle bog), raised bogs (semiconfined raised bog, unconfined raised bog) and fens (glacial fen, endorheic fen, slope fen, fluvial fen, topogenic fen). The particular geographical location of the Iberian Peninsula within Europe, the distribution of ecosystems and their characteristics within the general climate model, and the lack or scarcity of old trees coupled with geographical restrictions on the occurrence of other environmental archives (including ice and lakes), make the Iberian peatlands an essential tool for understanding Holocene environmental evolution in southern Europe (Pontevedra-Pombal *et al*. 2006).

The aim of the present study is to evaluate the existence of common and/or specific patterns in the evolution of Iberian peatlands in relation to the general trends of Holocene development of peatlands in the Northern Hemisphere, *via* an exhaustive review of published information on the genesis and development of these ecosystems.

STUDY AREA

The Iberian Peninsula, the westernmost peninsula in southern Europe, is located at the southern edge of the temperate latitudes in the Northern Hemisphere (between 43º 47' – 36º 00' N and 9º 30' W – 3º 19' E). The peninsula is surrounded by the Mediterranean Sea and the Atlantic Ocean in a proportion of 6/7 along the 4872 km of coastline. It is joined to the rest of the European continent by an isthmus to the north-east, constituted by the Pyrenean mountain range which extends uninterrupted from the Mediterranean Sea to the Bay of Biscay. The mean altitude of the whole peninsula is 600 m a.s.l. Around two-thirds of its total surface area is covered by a high-altitude plain, and this structure is surrounded by mountain chains whose peripheral positions largely determine climatic characteristics, with a marked continental influence towards the interior of the peninsula.

The Eurosiberian bioregion extends from northern Portugal through Galicia, Asturias, Cantabria, the Basque Country and the western and central Pyrenees (Figure 1). It is characterised by a wet climate, moderated by the oceanic influence, with temperate-cold winters and no clearly defined dry season. The Mediterranean bioregion incorporates all inland plateaus and mountains as well as the Mediterranean basin zones

The geographical isolation of the Iberian Peninsula, combined with its crossroads position and its geological and orographic complexity, has led to the development of an area of great diversity with strong physical, climatic, geomorphological and edaphic contrasts. Its complex environmental history is the result of geodynamic activity from ancient to more recent times, linked to the presence of active plate boundaries (Vera 2004). From the point of view of lithology, the geological substrate has traditionally been classified into three large groups: the siliceous materials that dominate the western Iberian Peninsula, the limestones in the eastern zone associated with the Alpine orogeny, and the clay substrates in inland depressions (Melendez & Fuster 2003), although the details may be very complex at finer scales (Vera 2004).

The flora and fauna reflect these conditions and include a large number of endemic taxa. As a result of its position on an important route between Africa and Europe, the Iberian Peninsula has been enriched by the arrival of a variety of flora including steppe, thermophilic, xerophytic, orophile and boreo-alpine plants. Many of these plants have survived thanks to the diversity of environments offered by the mountain ranges enabling them to extend their distributions to higher altitudes when the climate became too hot and to lower altitudes when it became too cold. The geological complexity of most of the Iberian mountains greatly increased the number of new environments to which plants were able to adapt, thus increasing the diversity and richness of the flora.

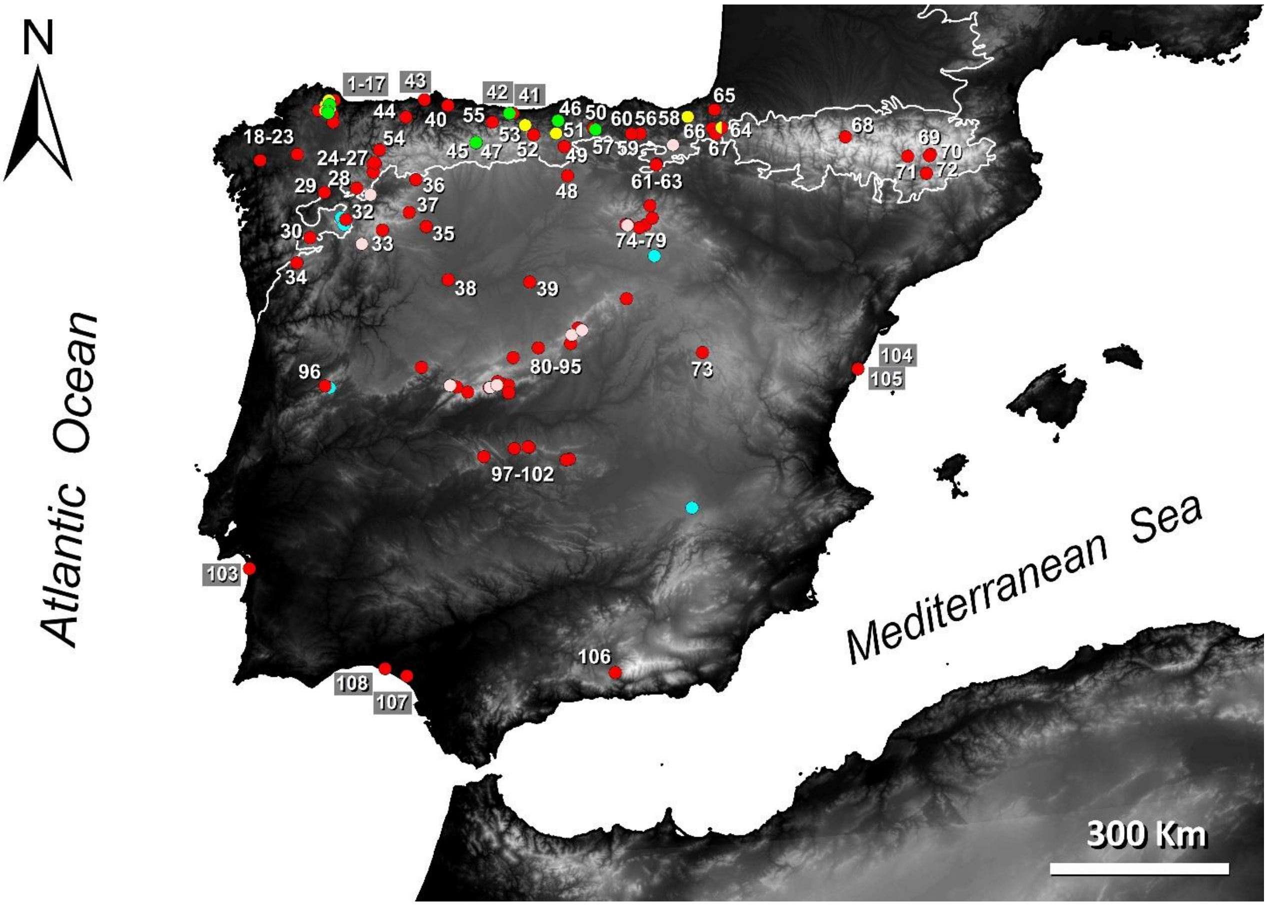

Figure 1. Geographical location of the 108 peatlands analysed. Sequence numbers refer to the Appendix. Red circles: fens; green circles: blanket bogs; yellow circles: raised bogs; blue circles: para-peaty soils; pink circles: peatlands without ^{14}C data. The white line separates the Eurosiberian, Mediterranean and Alpine bioregions.

METHODS

Documentary information

In order to create a database of information on the genesis and development of peatlands on the Iberian Peninsula, we reviewed all of the data available in scientific articles, doctoral theses, books and technical reports published between 1950 and 2016. Only those sites that could be verified as peatlands were included in the database. The criteria proposed by Loisel *et al.* (2014) were used to distinguish between peat and non-peat material (gyttja, inorganic horizons rich in organic matter, carbonaceous lacustrine sediments, *etc*.).

Systems that we identified as para-peaty soils, palaeo-peat horizons, salt marshes, lacustrine and fluvial ecosystems with buried peat profiles or sediments, and mineral soils rich in organic matter were not included in the study, even if they were referred to as peatlands in the original publications. Peatlands for which no radiocarbon data were available were also excluded from the study. These peatlands, numbering eleven out of the 119 identified (see Menéndez Amor & Florschütz 1961, Menéndez Amor 1971, Ruiz Zapata & Acaso Deltell 1981, Jiménez Ballesta *et al*. 1985, Atienza Ballano 1993, Ramil-Rego & Aira Rodríguez 1993a, 1994; Peñalba 1994, Gil García *et al*. 1995, Muñoz Sobrino 2001), are acid fens distributed homogeneously throughout the Iberian geography (Figure 1) with sparse development and/or subject to intense mechanisms of detrital deposition of colluvial-alluvial origin. As only a small number of peatlands belonging to the best-represented types in this study were discarded for lack of chronological control, the potential effect of their exclusion on the data obtained can be disregarded.

The following data were recorded for each of the 108 peatlands selected: vernacular place name, geographical area, type and subtype of peatland, location, altitude, bioclimatic zone, lithology of the geological formation, age and depth of the last active peat-forming cycle, and the total depth of unconsolidated material before peat formation. This information is summarised in Figure 1 and the Appendix.

The last (current) active peat-forming cycle was taken to have begun when stratigraphical features (colluvial or alluvial deposits, burned horizons, stone lines) and/or the age-depth model indicated the existence of a hiatus in development of the peatland.

Dating and chronology

All of the radiocarbon dates reported in the literature reviewed, for which a stratigraphical control was included, were recalibrated in order to establish the chronological patterns of peatland development. The ^{14}C dates were calibrated using the CALIB 7.1 radiocarbon calibration program (Stuiver *et al*. 2015). Ages were expressed as calibrated years before present (cal yr BP), assuming the values obtained for the range of maximum probability 2 sigma intervals, which is considered to be a robust statistical value (Telford *et al*. 2004).

Peat accumulation rates

Vertical peat accumulation rates (PAR; yr cm^{-1}) were calculated for all peatlands analysed in this study by considering the basal age and thickness of the last continuous, active peat-forming cycle.

Statistical analysis

Statistical analysis (SPSS Statistics software 20) was performed to identify the central values and dispersion for the population under study. A nonparametric Kruskal-Wallis test was used to identify significant differences between the peatlands. The minimum accepted value of significance was $p < 0.05$.

RESULTS

Distribution of Iberian peatlands

Examination of the literature including information about the genesis, morphostratigraphy, chronology and classification of the peatlands on the Iberian Peninsula indicates that, of the 108 peatlands selected, 84 % are fens and only 16 % are raised or blanket bogs (Figure 2). Following the classification

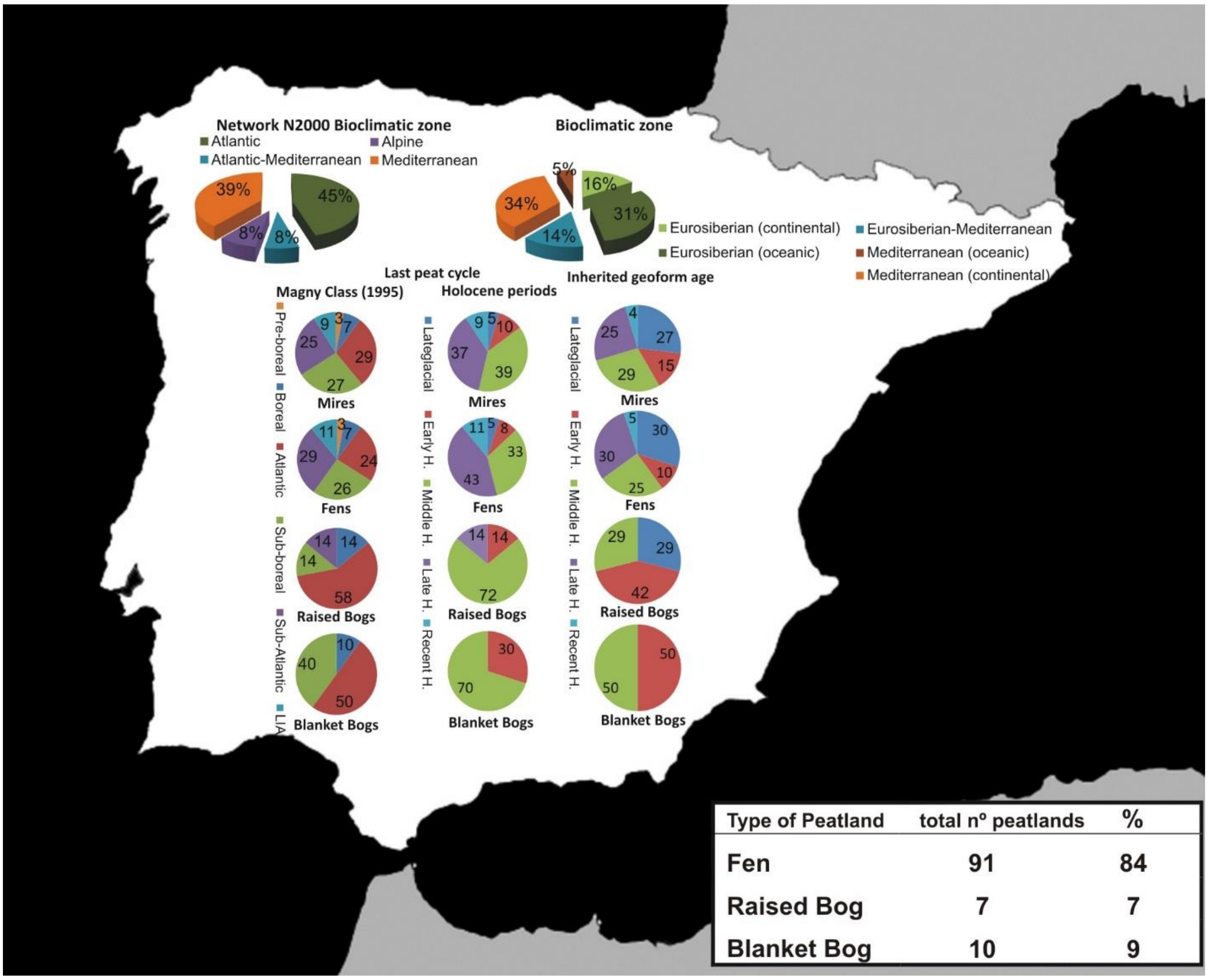

Figure 2. Typological, chronological and geographical distribution of peatlands in the Iberian Peninsula.

of biogeographical regions established in the Natura 2000 network (European Commission 2016), 45 % of the peatlands are included in the Atlantic region, 39 % in the Mediterranean region and 8 % in the Alpine region. Continental peatlands are the most numerous type in the Mediterranean region, and peatlands with oceanic influence are the most abundant in the Eurosiberian region (Figure 2).

In accordance with the Holocene palaeoecological zonation, and considering the modification proposed by Magny (1995), the last (current) peat-forming cycle was grouped into the following classes: > 10000 years (> 11500 cal BP), pre-Boreal; 10000–8000 years (11500–8850 cal BP), Boreal; 8000–5000 years (8850–5700 cal BP), Atlantic; 5000–2500 years (5700–2600 cal BP), sub-Boreal; and 2500–600 years (2600–600 cal BP), sub-Atlantic. A special class was also included to describe peatlands developed within the last 600 years - a period during which remarkable climatic variations occurred (Little Ice Age: LIA), the industrial revolution flourished, and anthropic modification of the environment was amplified. The interaction between anthropic and natural factors increased exponentially during this period, generating significant changes in the evolution of peatlands.

The chronostratigraphy reported in the literature reviewed showed that 29 % of the Iberian peatlands date from the Atlantic period, 27 % are sub-Boreal and 25 % are sub-Atlantic, 9 % originated in the LIA, 7 % are derived from the Boreal period, and only 3 % have remained active since the pre-Boreal period (Figure 2). The chronological classification of fens is, in general, very similar to that obtained for all of the peatlands (fens and bogs) studied, with a slight predominance of systems of sub-Atlantic origin (29 %). However, the pattern is very different for the bogs, especially the blanket bogs. In both cases, ombrotrophic peat formation was not initiated in the pre-Boreal or LIA periods. In almost 60 % of the raised bogs and in most of the bogs in general, formation of ombrotrophic peat began during the Atlantic period (Figure 2).

When the peatlands were grouped in relation to the last cycle of continuous peat formation, following the chronological classification proposed by Walker *et al.* (2012) for the Holocene (> 10000 years, late-glacial; 10000–8200 years, early Holocene; 8200–4200 years, middle Holocene; 4200–600 years, late Holocene; < 600 years, recent Holocene), the data revealed that 39 % of the peatlands correspond to the middle Holocene and 37 % to the late Holocene. The fens were grouped in a similar way, although a slightly higher proportion were formed in the late Holocene. In contrast, most of the bogs (70 %) were formed in the middle Holocene, and a significantly higher proportion of blanket bogs (30 %) were initiated in the early Holocene.

The sedimentary, geomorphological and edaphic processes that generated the structures leading to activation of the primary mechanisms of mire formation, terrestrialisation and paludification (Ruppel *et al.* 2013) in the Iberian peatlands are of heterogeneous origin. The processes originated in the late-glacial (27 %), middle Holocene (29 %), late Holocene (25 %), early Holocene (15 %) and recent Holocene (4 %). In fens, the processes generally originated in the late-glacial (30 %) or late Holocene (30 %). In raised bogs, the processes originated in the early Holocene (42 %). In blanket bogs, the formation processes began in the early Holocene (50 %) or the middle Holocene (50 %).

Peat accumulation rates in Iberian peatlands

The information collected on Iberian peatlands, and incorporated into the database used in this study, was examined to determine the thickness of the most recently-formed peat cycle (RPC, cm), which was used to calculate the vertical peat accumulation rate (PAR; yr cm^{-1}) (Table 1).

Table 1. Vertical peat accumulation rates (PAR) and thickness of the most recently-formed peat cycle (RPC) for different peatland types.

		PAR (yr cm^{-1})	**RPC thick (cm)**
Fen (91)	mean	38	156
	S.D.	25	105
	min	5	30
	max	167	580
Raised Bog (7)	mean	24	322
	S.D.	9	246
	min	11	80
	max	40	847
Blanket Bog (10)	mean	34	257
	S.D.	21	108
	min	16	60
	max	91	415

The mean RPC thickness values were 322, 257 and 156 cm for raised bogs, blanket bogs and fens, respectively, and the values obtained for blanket bogs were the least variable. The maximum depths of the fens and blanket bogs were around 5 m, and that of the raised bogs around 9 m; the minimum depths were around 30, 60 and 80 cm respectively.

The lowest mean PAR (most rapid accumulation) value of 24 yr cm^{-1} corresponded to the raised bogs, and values as low as 11 yr cm^{-1} were determined for this type of peatland. The mean PARs in fens and blanket bogs were 38 and 34 yr cm^{-1} respectively, although the range was much greater in the fens (5–167 yr cm^{-1} *versus* 16–91 yr cm^{-1}).

The PARs were much more variable in the fens (Figure 3), with a median value of 33 yr cm^{-1}, although most of the values are concentrated in the first quartile, which starts at 20 yr cm^{-1}. The opposite was observed for raised bogs, with most values very close to the median (25 yr cm^{-1}) and the maximum and minimum values close to the first and third quartiles, respectively.

Outliers (mild and critical) in the accumulation rates data were identified for the three types of peatland (Figure 3). In all cases except one, the outlier PARs were significantly higher (i.e. the accumulation rates were lower) than for the whole class. Only the atypical value found for the Chao de Veiga Mol raised bog indicated a faster accumulation rate than that for the whole class.

Classification of the peatlands on the basis of the PARs (Figure 4) showed that the most common class (PAR range: 16–30 yr cm^{-1}) represented 41 % of all types. Combining this class with the second most abundant class (PAR range: 31–60 yr cm^{-1}) accounted for 74 % of all types. The class containing the peatlands with the lowest PARs (< 15 yr cm^{-1}) accounted for less than 11 % of the total.

However, in terms of sensitivity and establishment of an ideal environmental archive, the number of peatlands with high peat accumulation rates within this class decreased greatly with age (Table 2), and only one (the Chao Mol Veiga raised bog) had a mean PAR of less than 15 yr cm^{-1} for the entire Holocene. The results also indicated that only those peat-forming cycles associated with the LIA in five Iberian peatlands had PARs of less than a decade *per* centimetre (Table 3).

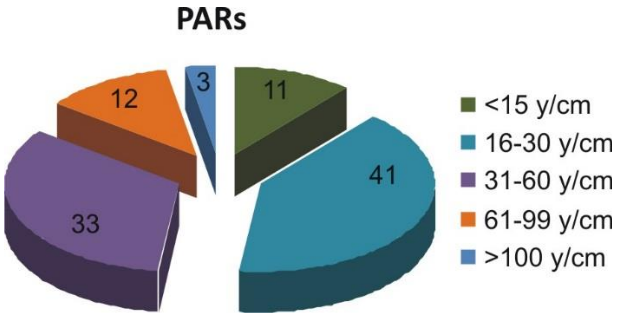

Figure 4. Distribution of the peatlands considered, grouped into different classes on the basis of vertical peat accumulation rates (PARs).

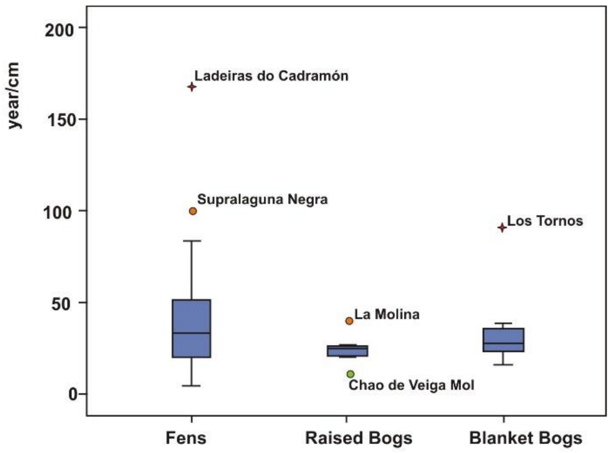

Figure 3. Vertical peat accumulation rates in the Iberian peatlands considered in this study. Stars indicate severe outliers. Circles indicate outliers with slightly higher (orange) and slightly lower (green) accumulation rates than the median.

Table 2. Number and percentage of all peatlands considered as belonging to Class 1 of vertical peat accumulation rates (< 15 yr cm^{-1}), grouped by different periods of the Holocene (yr cal BP).

PAR_Class1	Total number of peatlands	%
last 500 yr cal BP	12	11
last 1000 yr cal BP	5	5
last 2000 yr cal BP	5	5
last 5000 yr cal BP	3	3
last 10000 yr cal BP	1	0.9

Table 3. Iberian peatlands with PARs of one centimetre in less than a decade. LIA = Little Ice Age.

MIRE	Sector	Type	Holocene Period	PARs yr cm^{-1}
CHAO DE VEIGA MOL	Serras Septentrionais	Raised bog	LIA	5.9
TURBERA DE LA PIEDRA	Cordillera Cantábrica	Fen	LIA	4.5
TURBERA DE CULAZÓN	Cordillera Cantábrica	Fen	LIA	5.9
LAGUNA NAVA	Sistema Ibérico	Fen	LIA	5.6
TURBERA DE LAS LANCHAS	Montes de Toledo	Fen	LIA	7.7

DISCUSSION

Within the context of the northern hemisphere, in North America the origin of the geoforms of many peatlands is pre-Holocene, although stabilisation of cycles of peat formation and expansion of the peatlands were established between 10000 and 4000 yr BP (around 11500–4500 yr cal BP) (Gorham & Janssens 1992) with a peak between 8000 and 7000 yr cal BP (Gorham *et al.* 2007, MacDonald *et al.* 2006). In NW Europe, two periods of genesis and expansion of peatlands have also been established: between *ca*. 10200 and 8800 yr cal BP, coinciding with an increase in temperature and moisture, and between 7000 and 5500 yr cal BP, coinciding with a strong increase in moisture that favoured the expansion of raised bogs (Sjörs 1982, Averdieck *et al.* 1993, Laine *et al.* 1996, Mäkilä 1997, Hughes & Barber 2003). Chronological studies consistently establish the genesis of European blanket bogs within the period 7000 to 1500 yr cal BP (Malmer 1975, Moore *et al.* 1984, Gallego-Sala *et al.* 2015).

The findings of the present study show that the palaeoforms (landforms, soils, sediments, deposits) generated during the late-glacial (> 10000 years), the middle Holocene (8200 to 4200 years) and the late Holocene (4200 to 600 years) stimulated (in similar proportions) the genesis of most of the Iberian fens, with structures from the early Holocene (10000–8200 years) and the recent Holocene (< 600 years) being much more scarce. However, genesis of the bogs was more strongly influenced by periglacial and alluvial processes that generated gentler slopes and the formation of horizontal surfaces prone to paludification during the early Holocene and, to a lesser extent, the middle Holocene and the late-glacial.

The stabilisation of these inherited palaeoforms determined the subsequent development of peatlands. Peat formation was initiated immediately in some cases, whereas in others there was a delay of hundreds of years. Thus, peat formation in the Iberian peatlands may have involved a single continuous cycle extending until the present day. But it may also have taken place during resistaxia-biostaxia cycles (Erhart 1951), with erosive phases causing the loss or burial of pre-existing soils alternating with phases that reactivated soil formation processes that, in favourable environments, resulted in the initiation of new cycles of peat formation. The continuous, currently active peat-forming cycles identified in the bogs mainly originated from the early – middle Holocene. By contrast, the last peat-forming cycles in the fens predominantly (more than 75 % of the total) originated in the middle Holocene and the late Holocene, with very few cycles originating in the late-glacial, early Holocene or recent Holocene. The periodicity in the Iberian fens is similar to, although chronologically more variable than, that established by Cubizolle *et al.* (2003) for fens in the Massif Central (France).

Our analysis of Iberian peatlands revealed highly significant differences ($p < 0.01–0.005$) in peat thickness between peatland types. Average peat depth increased in the following order: sloping fens < glacial fens < endorheic fens < blanket bogs < raised bogs. Significant differences were also observed in the relationship between the total thickness of the deposit and the thickness of peat formed during one cycle, *i.e*. the delay in the initiation of peat formation. The delay was shortest in blanket bogs, followed by endorheic fens and raised bogs, then sloping fens and finally glacial fens.

The development of many European peatlands is linked to paludification processes and their influence on pre-existing soils; this applies to several phases of the Holocene. These processes have been linked to strong anthropic effects on the landscape (Chambers

1988, Huang 2002), cyclic climatic crises (Taylor 1983, Tipping 2008, Gallego-Sala *et al*. 2015) and/or soil evolution processes (Mitchell 1972, Bennett *et al*. 1992). Initiation of the formation of most of the Iberian peatlands coincided with forest decline, increased numbers of erosion events in soils, increased inputs of inorganic material, and intensification of the formation of iron oxyhydroxide crusts (Törnqvist & Joosten 1988, Janssen 1994, Martínez Cortizas & Moares 1995, van der Knaap & van Leeuwen 1995, Pontevedra-Pombal 2002, Carrión *et al.* 2010, Pontevedra-Pombal *et al.* 2013, Castro *et al.* 2015).

Vertical peat accumulation rates are highly variable, depending on the type and location of the peatland. In the Florida Everglades (USA) the rate has been estimated to be 0.84 mm yr^{-1} (McDowell *et al.* 1969), while in some ombrotrophic bogs in Canada it has been reported to be 0.025 mm yr^{-1} (Boville *et al.* 1982). In raised bogs, mean rates have been calculated to be 0.56 mm yr^{-1} in *Carex* communities, 0.32 mm yr^{-1} in *Scheuchzeria-Cuspidata* communities and 0.76 mm yr^{-1} in *Sphagnum* communities (Mäkilä 1997). Vertical growth rates of 0.2–1.5 mm yr^{-1} (Silvola 1986) and 0.1–0.8 mm yr^{-1} (Ovenden 1990) have been proposed for subarctic and boreal peatlands. For ombrotrophic bogs, mean rates of 0.40 mm yr^{-1} (Iceland), 0.49 mm yr^{-1} (Estonia), 0.18 mm yr^{-1} (Norway) (Everett 1983) and 0.20–4.0 mm yr^{-1} (Finland) (Korhola & Tolonen 1996) have been estimated. For concentric raised bogs, rates of 0.52 mm yr^{-1} (Finland) (Mäkilä 1997), 0.48–0.50 mm yr^{-1} (Canada) (Gorham 1991) and 0.6–0.8 mm yr^{-1} (southern zone of the former USSR) (Botch *et al*. 1995) have been reported. On a worldwide scale, Gorham (1991) suggested a value of 0.5 mm yr^{-1} as a conservative but reasonable estimate of the vertical peat accumulation rate, and Blackford (2000) proposed a range of 0.2–2 mm yr^{-1}.

The mean vertical peat accumulation rate calculated for Iberian peatlands in the present study was 0.41 ± 0.35 mm yr^{-1}, with higher rates in raised bogs (0.47 ± 0.20 mm yr^{-1}) than in blanket bogs (0.36 ± 0.14 mm yr^{-1}) and fens (0.34 ± 0.18 mm yr^{-1}). If outliers are ignored, more than 90 % of these peatlands display accumulation rates of between 0.11 and 0.90 mm yr^{-1}, with a mean value of 0.33 mm yr^{-1}. The accumulation rates of the Iberian peatlands are, therefore, similar to those determined for peatlands located in more northerly areas, both for peatlands in general and for the different types. No significant differences in the rates were identified in relation to the geographical area, biogeographical region, altitude, or period of the Holocene when peat formation began.

Vertical peat accumulation rates of more than 1 mm yr^{-1} (1 cm *per* decade) for Iberian mires have been observed only during the peat-forming cycles that have taken place within the last 600 years. This high rate may be attributed to the combined effects of favourable climatic conditions during the LIA (Martínez Cortizas *et al.* 1999), the intensification of deforestation (Pontevedra-Pombal *et al.* 2012), and the apparent decrease in rate of accumulation as the age of the peat increases (Tolonen & Turunen 1996).

CONCLUSIONS

Based on this study of a group of representative (type and geographical distribution) acid peatlands on the Iberian Peninsula, it can be concluded that their chronologies, peat accumulation rates and formation processes were similar to those of other Atlantic peatlands in Europe. The distribution of these ecosystems is uneven. Fens are more widely represented and distributed throughout the Iberian Peninsula, while bogs are restricted to the N and, mainly, NW of the territory. There are also differences in the times when their formation commenced, which range from the late-glacial to the LIA in the case of fens and are confined to the early and late Holocene for bogs.

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Author for correspondence:
Dr Xabier Pontevedra-Pombal, Group of Environmental Studies Applied to the Natural and Cultural Heritage (GEMAP), Department of Soil Science and Agricultural Chemistry, Faculty of Biology, University of Santiago de Compostela, Campus Vida, 15782 Santiago de Compostela, Galicia, Spain.
Tel: + 34-981563100 ext. 13238; Fax: + 34-881813195; E-mail: xabier.pombal@usc.es

Appendix: List and brief details of peatlands on the Iberian Peninsula that were considered in this study (see also Figure 1).

Number	Peatland	Type	Sector	N2000 Network Bioclimatic Zone	Altitude (m a.s.l.)	Reference
1	*CHAO DE VEIGA MOL*	Raised bog	Serras Septentrionais	Atlantic	695	Present study
2	*TREMOAL DE CHAO DE LAMOSO*	Blanket bog	Serras Septentrionais	Atlantic	1039	Ramil-Rego *et al*. 1994
3	*TREMOAL DE PENIDO VELLO*	Blanket bog	Serras Septentrionais	Atlantic	793	Pontevedra-Pombal 2002
4	*TREMOAL DE PENA DA CADELA*	Blanket bog	Serras Septentrionais	Atlantic	972	Pontevedra-Pombal *et al*. 2013
5	*CHARCA DE CHAN DA CRUZ*	Raised bog	Serras Septentrionais	Atlantic	800	Ramil-Rego 1992
6	*TREMOAL DO PEDRIDO*	Raised bog	Serras Septentrionais	Atlantic	695	Peiteado-Varela 2017
7	*BARREIRAS DO LAGO*	Blanket bog	Serras Septentrionais	Atlantic	932	Present study
8	*TREMOAL DE LADEIRAS DO CADRAMÓN*	Fen	Serras Septentrionais	Atlantic	700	Sá-Otero *et al*. 2005
9	*BORRALLEIRAS DA CAL GRANDE*	Blanket bog	Serras Septentrionais	Atlantic	670	Present study; Pontevedra-Pombal *et al*. 2013
10	*TREMOAL DOS MONTES DO BUIO*	Blanket bog	Serras Septentrionais	Atlantic	580	Menéndez Amor & Florschütz 1961
11	*TREMOAL DE VIVEIRO*	Blanket bog	Serras Septentrionais	Atlantic	620	Van Mourik 1986
12	*CHAO DE LAGOZAS*	Fen	Serras Septentrionais	Atlantic	520	Sá-Otero *et al*. 2005
13	*TREMOAL DE LOBEIRAS*	Fen	Serras Septentrionais	Atlantic	660	Sá-Otero *et al*. 2005
14	*TREMOAL DA PENA VEIRA*	Fen	Serras Septentrionais	Atlantic	731	Ramil-Rego 1992
15	*PENA VELLA*	Fen	Serras Septentrionais	Atlantic	700	Ramil-Rego *et al*. 1994
16	*TREMOAL DA GAÑIDOIRA*	Fen	Serras Septentrionais	Atlantic	720	Ramil-Rego *et al*. 1993
17	*TURBERA DE SEVER*	Fen	Serras Septentrionais	Atlantic	719	Ramil-Rego & Aira Rodríguez 1993b
18	*BRAÑA DE BRINS*	Fen	Macizo Central	Atlantic	350	Van Mourik 1986
19	*TURBERA DE A INSUA*	Fen	Macizo Central	Atlantic	740	Taboada Castro *et al*. 1993
20	*TURBERA DE AMENEIROS*	Fen	Macizo Central	Atlantic	700	Taboada Castro *et al*. 1993
21	*TURBERA DE CRUZ DO BOCELO*	Fen	Macizo Central	Atlantic	730	Silva-Sánchez *et al*. 2014
22	*TURBERA DE MUIÑO*	Fen	Macizo Central	Atlantic	690	Taboada Castro *et al*. 1993
23	*TURBERA DE A LAGOA*	Fen	Macizo Central	Atlantic	700	Taboada Castro *et al*. 1993
24	*TURBERA DE SUÁRBOL*	Fen	Serras Orientais	Atlantic	1080	Pontevedra-Pombal 2002
25	*BRAÑA DE LAMELAS*	Fen	Serras Orientais	Atlantic	1280	Pontevedra-Pombal 2002
26	*BRAÑA DE PORTO ANCARES*	Fen	Serras Orientais	Atlantic	1580	Pontevedra-Pombal 2002
27	*CAMPA DA CESPEDOSA*	Fen	Serras Orientais	Atlantic	1415	Pontevedra-Pombal 2002
28	*LAGOA DE LUCENZA*	Fen	Serras Orientais	Atlantic	1375	Muñoz Sobrino *et al*. 2001
29	*LAGOA DE ANTELA*	Fen	Depresión de Xinzo de Limia	Atlantic	611	Van Mourik 1986
30	*TURBERA DE TOIRIZ*	Fen	Depresión de Monforte	Atlantic	530	Van Mourik 1986
31	*CHAIRA DE PEDRAFITA*	Fen	Serras Surorientais	Atlantic	1300	Menéndez Amor 1971
32	*TURBERA DE AS AGUILLADAS*	Fen	Serras Surorientais	Atlantic	1580	Santos 2004
33	*LAGOA DO MARINHO*	Fen	Serra do Geres	Atlantic-Mediterranean	1150	Muñoz Sobrino 2001
34	*CHARCA DE SANGUIJUELAS* o *LLEGUNA*	Fen	Montes de León	Mediterranean	1100	Menéndez Amor & Florschütz 1961
35	*LAGUNA DE SANGUIJUELAS*	Fen	Montes de León	Mediterranean	1080	Muñoz Sobrino *et al*. 2004

Number	Peatland	Type	Sector	N2000 Network Bioclimatic Zone	Altitude (m a.s.l.)	Reference
36	*TURBERA DE BRAÑULAS*	Fen	Montes de León	Mediterranean	1000	Muñoz Sobrino 2001
37	*TURBERA DE XAN DE LLAMAS*	Fen	Montes de León	Mediterranean	1500	Morales-Molino *et al*. 2011
38	*TURBERA DE AYOÓ*	Fen	Meseta Septentrional	Mediterranean	78	Morales-Molino & García-Antón 2014
39	*TURBERA DE CAMPORREDONDO*	Fen	Meseta Septentrional	Mediterranean	800	García-Antón *et al*. 2011
40	*TURBERA DE MONTE AREO*	Fen	Cantábrica Prelitoral	Atlantic	200	López-Merino *et al*. 2010
41	*TURBERA DE ROÑANZAS*	Raised bog	Cantábrica Prelitoral	Atlantic	250	Moreno *et al*. 2009
42	*TURBERA DE LAS CONCHAS*	Fen	Cantábrica Prelitoral	Atlantic	363	Ortiz *et al*. 2016
43	*TURBERA DE HUELGA DE BAYAS*	Fen	Cantábrica Prelitoral	Atlantic	110	López-Días *et al*. 2010
44	*TURBERA DE LA MOLINA*	Raised bog	Cantábrica Prelitoral	Atlantic	650	Martínez Cortizas *et al*. 2016
45	*TURBERA DE LA MOLINA DE VIESGO*	Raised bog	Cantábrica Prelitoral	Atlantic	484	Pérez-Obiol *et al*. 2016
46	*TURBERA DE PINAR DE LILLO*	Fen	Cordillera Cantábrica Sur	Atlantic-Mediterranean	1360	García-Antón *et al*. 1997
47	*TURBERA DE LILLO*	Fen	Cordillera Cantábrica Sur	Atlantic-Mediterranean	1500	Muñoz Sobrino 2001
48	*TURBERA DE LA PIEDRA*	Fen	Cordillera Cantábrica Sur	Atlantic-Mediterranean	950	Muñoz Sobrino 2001
49	*TURBERA DE HERBOSA*	Fen	Cordillera Cantábrica Sur	Atlantic-Mediterranean	847	Menéndez Amor 1968
50	*TURBERA DE LOS TORNOS*	Blanket bog	Cordillera Cantábrica Norte	Atlantic	920	Peñalba 1994
51	*TURBERA DE ALSA*	Fen	Cordillera Cantábrica Norte	Atlantic	560	Mariscal 1993
52	*TURBERA DE CUETO DE LA AVELLANOSA*	Blanket bog	Cordillera Cantábrica Norte	Atlantic	1320	J.A. López-Sáez (unpublished data)
53	*TURBERA DE CULAZÓN*	Fen	Cordillera Cantábrica Norte	Atlantic	592	López-Sáez *et al*. 2013
54	*TURBERA DE PENA VELOSA*	Fen	Cordillera Cantábrica Norte	Atlantic	1350	Muñoz Sobrino *et al*. 2012
55	*TURBERA DE COMELLA*	Fen	Cordillera Cantábrica Norte	Atlantic	834	Ruiz Zapata *et al*. 2002
56	*TURBERA DE SALDROPO*	Raised bog	Montes Vascos	Atlantic	625	García-Antón *et al*. 1989.
57	*TURBERA DE ZALAMA*	Blanket bog	Montes Vascos	Atlantic	1330	Pérez-Díaz *et al*. 2016
58	*TURBERA DE USABELARTZA*	Fen	Montes Vascos	Atlantic	620	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
59	*TURBERA DE LAZAGORRIA*	Fen	Montes Vascos	Atlantic-Mediterranean	770	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
60	*TURBERA DE GALBANITURRI*	Fen	Montes Vascos	Atlantic-Mediterranean	750	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
61	*TURBERA DE ARRIZULO*	Fen	Montes Vascos	Atlantic-Mediterranean	760	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
62	*TURBERA DE VERDEOSPESOA-1*	Fen	Montes Vascos	Atlantic	980	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
63	*TURBERA DE VERDEOSPESOA-2*	Fen	Montes Vascos	Atlantic	100	S. Pérez-Díaz & J.A. López-Sáez (unpublished data)
64	*TURBERA DE QUINTO REAL*	Fen	Pirineos	Alpine	910	Galop *et al*. 2001
65	*TURBERA DE ATXURI*	Fen	Pirineos	Alpine	500	Galop *et al*. 2004
66	*TURBERA DE BELATE*	Fen	Pirineos	Alpine	847	Peñalba 1994
67	*TURBERA DE GESALETA*	Fen	Pirineos	Alpine	900	Present study
68	*TURBERA DE EL PORTALET*	Fen	Pirineos	Alpine	1802	González-Sampériz *et al*. 2006
69	*TURBERA DE RIU DELS ORRIS*	Fen	Pirineos	Alpine	2390	Ejarque *et al*. 2010
70	*TURBERA DE BOSC DELS ESTANYONS*	Fen	Pirineos	Alpine	2180	Miras *et al*. 2007
71	*TURBERA DEL LAGO BURG*	Fen	Pirineos	Alpine	1821	Pèlachs *et al*. 2007
72	*TURBERA DEL PRADELL*	Fen	Pirineos	Alpine	1975	Ejarque *et al*. 2009

Number	Peatland	Type	Sector	N2000 Network Bioclimatic Zone	Altitude (m a.s.l.)	Reference
73	*TURBERA DE OJOS DEL TREMEDAL*	Fen	Montes Universales	Mediterranean	1650	Stevenson 2000
74	*TURBERA DE HOYOS DE IREGUA*	Fen	Sistema Ibérico	Mediterranean	1780	Gil García *et al*. 2002
75	*LAGUNA NAVA*	Fen	Sistema Ibérico	Mediterranean	1190	Gil García *et al*. 1996
76	*TRAMPAL DE NIEVA*	Fen	Sistema Ibérico	Mediterranean	1100	Gil García *et al*. 2001
77	*TURBERA DE LAGUNA DE LAS PARDILLAS*	Fen	Sistema Ibérico	Mediterranean	1850	Sánchez-Goñi & Hannon 1999
78	*NEILA HOLLOW*	Fen	Sistema Ibérico	Mediterranean	1480	Von Engelbrechten 1998
79	*SUPRALAGUNA NEGRA*	Fen	Sistema Ibérico	Mediterranean	1840	Gómez-Lobo 1993
80	*TURBERA DE PELAGALLINAS*	Fen	Sistema Central	Mediterranean	1340	Franco-Múgica *et al*. 2001
81	*TURBERA DE RASCAFRÍA*	Fen	Sistema Central	Mediterranean	1113	Franco-Múgica *et al*. 1998
82	*TURBERA DE NAVACERRADA*	Fen	Sistema Central	Mediterranean	1340	Franco-Múgica 1995
83	*TURBERA DEL PUERTO DEL PICO*	Fen	Sistema Central	Mediterranean	1395	López-Sáez *et al*. 2016
84	*TURBERA DE PUERTO DE SERRANILLOS*	Fen	Sistema Central	Mediterranean	1700	López-Merino *et al*. 2009
85	*TURBERA DE NAVARREDONDA*	Fen	Sistema Central	Mediterranean	1550	Franco-Múgica *et al*. 1997
86	*TURBERA DE HOYOS DEL ESPINO*	Fen	Sistema Central	Mediterranean	1450	Franco-Múgica 1995
87	*TURBERA DE NAVALGUIJO*	Fen	Sistema Central	Mediterranean	1200	Franco-Múgica 1995
88	*TURBERA DE OJOS ALBOS*	Fen	Sistema Central	Mediterranean	1483	Blanco-González *et al*. 2009.
89	*TURBERA DE LANZAHÍTA*	Fen	Sistema Central	Mediterranean	588	López-Sáez *et al*. 2010
90	*TURBERA DE PRADO DE LAS ZORRAS*	Fen	Sistema Central	Mediterranean	1650	Andrade 1994
91	*TURBERA DE PEÑA NEGRA*	Fen	Sistema Central	Mediterranean	1000	Abel-Schaad & López-Sáez 2013
92	*TURBERA DE GARGANTA DEL TRAMPAL*	Fen	Sistema Central	Mediterranean	1440	Atienza Ballano 1993
93	*TURBERA DE LA MESEGUERA*	Fen	Sistema Central	Mediterranean	900	Abel-Schaad *et al*. 2014
94	*TURBERA DEL MAÍLLO*	Fen	Sistema Central	Mediterranean	1100	Morales-Molino *et al*. 2013
95	*TURBERA DEL PAYO*	Fen	Sistema Central	Mediterranean	1000	Silva-Sánchez *et al*. 2016
96	*LAGOA COMPRIDA 1*	Fen	Serra da Estrela	Mediterranean	1600	Janssen & Woldringh 1981
97	*TURBERA DE PATATEROS*	Fen	Montes de Toledo	Mediterranean	700	Dorado-Valiño *et al*. 2014a
98	*TURBERA DE VALDEYERNOS*	Fen	Montes de Toledo	Mediterranean	850	Dorado-Valiño *et al*. 2014b
99	*TURBERA DE GARGANTA DEL MESTO*	Fen	Montes de Toledo	Mediterranean	1000	Gil-Romera *et al*. 2008
100	*TURBERA DE BERMÚ*	Fen	Montes de Toledo	Mediterranean	787	J.A. López-Sáez (unpublished data)
101	*TURBERA DE LA BOTIJA*	Fen	Montes de Toledo	Mediterranean	745	J.A. López-Sáez (unpublished data)
102	*TURBERA DE LAS LANCHAS*	Fen	Montes de Toledo	Mediterranean	757	J.A. López-Sáez (unpublished data)
103	*LAGOA TRAVESSA*	Fen	Depresión Atlántica	Mediterranean	10	Mateus 1989
104	*TURBERA DE TORREBLANCA*	Fen	Costa del Azahar	Mediterranean	0	Menéndez Amor & Florschütz 1961
105	*TURBERA TU DE TORREBLANCA*	Fen	Costa del Azahar	Mediterranean	0	Dupré-Ollivier *et al*. 1994
106	*TURBERA DE PADUL*	Fen	Sistema Penibético	Mediterranean	1900	Carrión *et al*. 2007
107	*TURBERA DEL ACEBRÓN*	Fen	Depresión Bética	Mediterranean	25	Stevenson & Moore 1988
108	*LAGUNA DE LAS MADRES*	Fen	Depresión Bética	Mediterranean	7	Stevenson 1985