ARTICLES

Mediterranean Botany
ISSNe 2603-9109

EDICIONES COMPLUTENSE

https://doi.org/10.5209/mbot.80170

Diversity and conservation of the Gredos Regional Park peatlands (Iberian Central System, Spain): Geomorphological and geobotanical characterisation and incoming threats

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Received: 28 January 2022 / Accepted: 24 January 2023 / Published online: 17 April 2023

Abstract. High-mountain peatlands are essential ecosystems for habitats, biodiversity, water, and carbon cycling, but there is little comprehensive information in central Iberia. We present results of research concerning the distribution, geormorphology, floristic, geobotany, and habitat diversity of peatlands in the Gredos Regional Park (Iberian Central System). We identified 72 peatlands covering 117 ha and ranging in size from 0.01 to 17.34 ha. Peatlands occur primarily in the upper orosubmediterranean bioclimatic belt at 1775–2230 m asl. From a geomorphological point of view, 9 different peatland typologies have been defined. Multivariate analyses (agglomerative cluster analysis and principal component analysis) of 103 relevés allowed us to classify the sampled peatland stands into 7 plant communities and 4 European habitats that formed along complex hydrogeomorphic conditions, and to propose a new subassociation of other community previously described (*Caricetum echinato-nigrae lycopodielletosum inundatae*). The main threat to Gredensean peatlands is pastoral pressure, which affects 15 of them intensively, mainly between the upper supramediterranean and the lower orosubmediterranean bioclimatic belts (~1314–1700 m asl). Seven bryophytes and three vascular plants documented in the Gredos Regional Park peatlands are included in the IUCN Red List. From the point of view of conservation priority, the most threatened correspond to transition mires communities (Habitat 7140) growing in oligotrophic and minerotrophic peatlands (*Caricion nigrae* vegetation). Particularly, the Iberian Central System endemic *Sedo lagascae-Eriophoretum latifolii* association is the one that has achieved the highest score in the five criteria considered in this regard because *Meesia triquetra*, a species with the category of "critically endangered", inhabits it.

Keywords: Wetland habitats, Phytosociology, Geobotany, Multivariate Analyses.

How to cite: López-Sáez, J.A., Luelmo-Lautenschlaeger, R., Carrasco, R.M., Pedraza, J., Sánchez-Mata, D. & Luengo Nicolau, E. 2023. Diversity and conservation of the Gredos Regional Park peatlands (Iberian Central System, Spain): Geomorphological and geobotanical characterisation and incoming threats. Mediterr. Bot. 44, e80170. https://doi.org/10.5209/mbot.80170

Introduction

Peatlands are among the most valuable ecosystems of the planet covering > 4 x 10^6 km^2, and comprising only 3% of Earth's land and freshwater surface (Joosten & Clarke, 2002; Page & Baird, 2016). They are characterized by the accumulation of organic matter in the form of layers of 'peat' which is mainly decaying plant material under waterlogged and low oxygen anoxic and nutrient-poor conditions, generally seen as comprising at least 30% dry mass of dead organic material and greater that 30 cm deep (Couwenberg & Joosten, 2005; Joosten *et al*., 2017). Moreover, these ecosystems are the largest natural terrestrial carbon store, sequestrating 0.37 gigatonnes (Gt) of carbon dioxide a year, thus storing more carbon (550 Gt) than all other vegetation types in the world altogether combined (Clymo *et al*., 1998; Yu *et al*., 2010). However, many peatlands are threatened by both human activities and climate change, and the result is that damaged peatlands contribute about 10% of greenhouse gas emissions, of which CO_2 emissions from drained ones are estimated at 1.3 Gt of carbon dioxide annually (Gorham, 1991; Yu *et al*., 2011).

Peatlands are critical for preserving global biodiversity, provide safe drinking water, minimise flood risk and help address climate change, and therefore they increasingly

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play a role in policy relating to climate change, biodiversity and ecosystem services (Gorham, 1991; Benavent-González *et al.*, 2014; Page & Baird, 2016; Joosten *et al.*, 2017). However, peatland ecosystems are highly sensitive to climatic conditions and human impact; therefore, they have been classified as a priority habitat of community interest by the European Union Habitats Directive 92/43/EEC, in order to establish protection areas and promote monitoring programs to ensure their conservation (Anon., 2013). Nevertheless, spatially explicit information on peatland distribution is needed to raise awareness of peatlands, to assess their ecosystem values, functions and losses, and to develop and implement strategies for peatland protection and wise use (Charman, 2002; Page & Baird, 2016; Tanneberger *et al.*, 2017). This is particularly important in south-western Mediterranean Europe, where their distribution is sparse and highly fragmented (Heras *et al.*, 2017; Joosten *et al.*, 2017; Pontevedra-Pombal *et al.*, 2017).

Peatland ecosystems are especially abundant in areas with excess moisture. Thus, as a consequence they are widespread over large parts of the mid-high latitudes of North America and Eurasia, especially in the boreal zone of Canada and Russia (Gorham, 1991; Finlayson & Milton, 2016). Surprisingly, no detailed and complete peatland map yet exists for Europe, probably the continent with the longest history of peatland and peat study and exploitation (Montanarella *et al.*, 2006; Tanneberger *et al.*, 2017). In temperate climates, such as those of the Iberian Peninsula, they are extensively developed in oceanic or highland areas of the Eurosiberian Region (Martínez-Cortizas & García-Rodeja, 2001; Pontevedra-Pombal *et al.*, 2006; Payne, 2016; Heras *et al.*, 2017). In Spain, with an approximate surface area of 505,992 km^2, the areas occupied by peatlands are estimated to be around 350 km^2, i.e. barely 0.07% of the national territory (Montanarella *et al.*, 2006; Heras *et al.*, 2017; Tanneberger *et al.*, 2017). In the Mediterranean Region, the generally arid and warm climate has a significant influence on the distribution and size of peatland ecosystems, which are typically small and scattered, although they are present in most countries and make a disproportionately large contribution to regional biodiversity with endemic species recorded for several sites (Payne, 2016). Iberian Mediterranean peatlands are poorly documented and increasingly threatened by human activity, in particular the increasing need for agricultural land and water resources (Martínez-Cortizas *et al.*, 2009a; López-Sáez *et al.*, 2014b; Joosten *et al.*, 2017; Pontevedra-Pombal *et al.*, 2017). They are mainly distributed in four mountain ranges (Heras *et al.*, 2017): the Iberian System, the Central System, the Toledo Mountains, and Sierra Nevada.

The Gredos range is the most prominent mountain range in the Iberian Central System and their summits were occupied by extensive glaciers during the last glaciation (Palacios *et al.*, 2011, 2012; Pedraza *et al.*, 2013; Carrasco *et al.*, 2020). Since this Mediterranean mountain runs in a W-E direction along the central sector of the Iberian Peninsula, the influence of the northern westerly winds enters easily through the mountains, which are considered a major component of the mid-latitude atmospheric circulation, thus favouring the development of peatland ecosystems (López-Sáez *et al.*, 2019). In the Gredos Regional Park, the continuous accumulation of peat over thousands of years provides one of the best records for landscape, fire history, palaeoecological, and climate reconstruction research (López-Sáez *et al.*, 2014a, 2018a, 2018b). Due to the uniqueness of peatland ecosystems within the Gredensean landscape, they have long attracted the attention of botanists, which has resulted in a thorough understanding of the regional distribution of the vascular and bryophyte floras (Rivas-Martínez, 1964, 1975; Rico, 1980; Castroviejo *et al.*, 1983; Luceño, 1985; Luceño & Vargas, 1986, 1987, 1991; Sánchez-Mata, 1986a, 1986b, 2015; Pizarro *et al.*, 1987; Sánchez-Rodríguez *et al.*, 1987; Casas, 1988; Elías, 1988a, 1988b, 1989a, 1989b; Sánchez-Mata *et al.*, 1988; Amor *et al.*, 1993; Sardinero, 1993, 1996; Escudero & Sánchez-Mata, 1996; Luceño *et al.*, 2000, 2015, 2016, 2017a, 2017b; Infante & Heras, 2001; Toro *et al.*, 2001; Baonza *et al.*, 2003; González-Canalejo *et al.*, 2004; Elías *et al.*, 2006; Sánchez-Villegas *et al.*, 2019, 2020), although references to the vegetation and phytosociological classification of the habitats present in these enclaves are scarcer (Rivas-Martínez, 1963; Pizarro *et al.*, 1987; Sánchez-Mata, 1989; Amor *et al.*, 1993; Sardinero, 2004; Sánchez-Mata *et al.*, 2017).

Numerous authors have shown that many factors are responsible for the geographical distribution of peatlands. Usually, the role of climate has been emphasised at global or continental scales, although the majority of authors also highlight the importance of the geomorphological and hydrological context (Charman, 2002; Montarella *et al.*, 2006; Yu *et al.*, 2010; Householder *et al.*, 2012; Cubizolle *et al.*, 2013; Page & Bird, 2016; Joosten *et al.*, 2017; Rocha-Campos *et al.*, 2017). Nevertheless, peatlands are difficult to classify because of their floristic diversity and their hydrological, geomorphological and even their stratigraphical and microtopographical variety (Graham *et al.*, 2020). Usually, they have been classified on the basis of origin, but the most widely used classifications are based either on vegetation or on water source (Boeye *et al.*, 1997; Godwin *et al.*, 2002; Cubizolle *et al.*, 2003; Cubizolle & Thebaud, 2014; Joosten *et al.*, 2017). This is logical, considering that most classifications based on vegetation studies are focused on plant ecology and conservation, although dominant species and associations are used in local studies.

Our study objectives were to: i) evaluate peatlands distribution, abundance, and geomorphological and phytosociological characteristics in the Gredos Regional Park (Iberian Central System), and ii) due to the degradation of some peatlands in the study area, typify disturbances to study their state of conservation.

Methods

Study area

The Gredos Regional Park (GRP) is a geologically complex from the Hercynian granitic basement reactivated during the Cenozoic in the Alpine orogeny (Pedraza, 1989, 1994), and finally shaped by Quaternary glacial processes (Palacios *et al*., 2011; Pedraza *et al*., 2013; Carrasco *et al.*, 2020). The GRP is the highest elevation range of the entire Iberian Central System (Figure 1), which is an east-west belt crossing the Iberian Peninsula, with some peaks reaching over 2500 m asl elevation (e.g. Almanzor 2592 m asl, La Galana 2568 m asl), and dozens over 2000 m asl. The streams of the southern flank drain to the Tiétar River and they belong to the Tagus fluvial system, while those of the northern slopes drain to the Tormes River and flows to the Douro fluvial system. With 86,235 ha, the GRP, within the province of Ávila, was created in 1996 with the aim of conserving its natural ecosystems and landscape values in harmony with traditional uses, rights and exploitation (Anon. 2003).

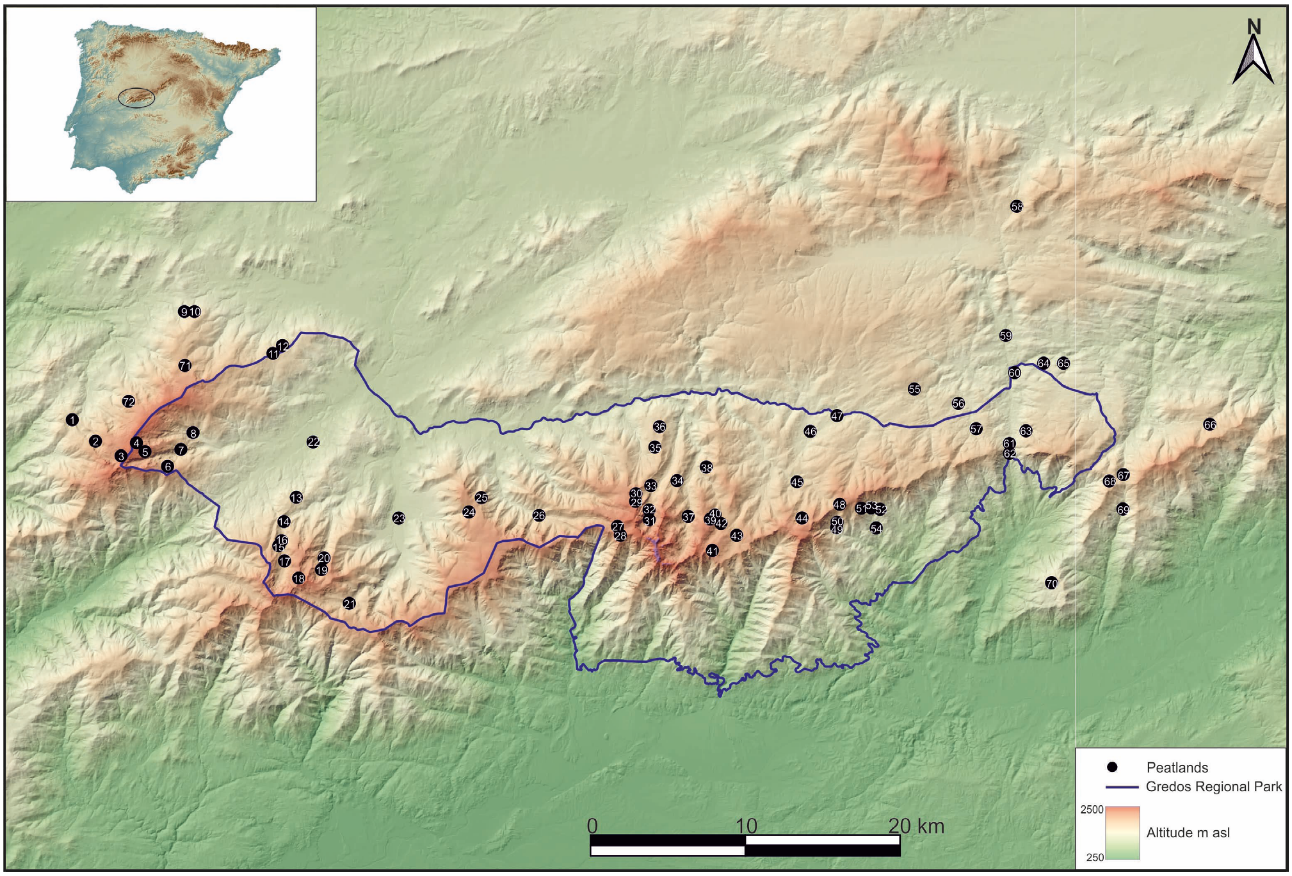

Figure 1. Distribution of peatlands in the Gredos Regional Park and close territories. Numbered locations are characterized further in Table 1.

The GRP is characterized by a temperate continental climate influenced by Atlantic depressions from the southwest and the Azores anticyclone. Its climate is of a Mediterranean type, with a summer drought period lasting 3-5 months and heavy rainfall in autumn and winter. Annual precipitation ranges between 350 and 1400 mm, decreasing along a west-east gradient. Temperature varies between –4 and 3°C during winter and 22 and 32°C in summer; mean annual temperature is 13 °C (Ninyerola *et al.*, 2005). The southern slopes, especially along the Tiétar valley, feature warmer and wetter conditions due to their exposure to greater sunlight and to the predominant southwest humid winds (López-Sáez *et al.*, 2019). From a biogeographical point of view, the GRP belongs to the Mediterranean region, West Mediterranean subregion, West Iberian Mediterranean province, Carpetanian-Leonese subprovince, and Bejaran-Gredensean sector, which includes the subsectors Gredensean (with two districts: East Gredos Sierran and High Gredos Sierran) and Bejaran-Tormantos (also with two districts: Béjar Sierran and Tormantos Sierran) (Rivas-Martínez *et al*., 2007, 2014, 2017). The territories located south of the Gredos Regional Park, on the lower supramediterranean and mesomediterranean bioclimatic belts in the Tiétar valley, however, they belong to the Lusitan-Extremadurean subprovince, and although they have also been studied, they will hardly be mentioned as they lack peatlands.

Large areas of Quaternary deposits of glacial, periglacial, colluvial, and alluvial origin occur in valleys and on hillslopes (Carrasco *et al.*, 2020). Higher elevation areas have snowmelt driven hydrologic regimes, and lower elevation are rainfall driven. Glaciated high elevation valleys have broad U-shapes with numerous tarns, cirques, and moraines, while narrow lower elevation valleys have been cut by rivers (Palacios *et al.*, 2011, 2012; Pedraza *et al.*, 2013; Carrasco *et al.*, 2020). The development of glacial landforms and the altitude of the moraines indicate that on the north flank of the GRP the glaciations were more intense than those in the south flank (Pedraza & Carrasco, 2006; Pedraza *et al.*, 2013). Glaciers on the north flank of the GRP reach up to ~1400 m asl (Palacios *et al.*, 2011; Carrasco *et al.*, 2020).

Peatland identification and mapping

We mapped the GRP, as well as its eastern and western neighbouring areas in the provinces of Ávila and Salamanca (Figure 1). We firstly used natural colour aerial photograph stereo pairs and digital aerial imagery to identify wetlands with brownish colours and peat generated landforms typical of peatlands in our study area. We mapped and field verified peatlands to perfect methods for peatland identification. Then, we mapped and visited peatlands in randomly selected watersheds across the entire mountain range (Householder *et al*., 2012; Chimner *et al*., 2019). Later, the boundary of each peatland was delineated with the GIS software package ArcView 9.2 (ESRI, 2006; Cubizolle *et al*., 2013) and 3D imagery of the IBERPIX visor (IGN-IBERPIX 5.0). Finally, we verified out image interpretation in the field by investigating peaty soils and hydrologic regime, and corrected peatland polygon boundaries. We determined the elevation, occupied area, and exact location of each peatland from available GIS layers (Table 1).

Table 1. Site characteristics for the 72 peatlands on the Gredos Regional Park. Bioclimatic belts (BB): UO, upper orosubmediterranean; MO, middle orosubmediterranean, LO, lower orosubmediterranean, US, upper supramediterranean, MS, middle supramediterranean. Geomorphological typology (GT): Confined peatlands: RW, rock weathering; GC, glacial cirques; GV, glacial valleys; MD, moraine-dammed type; MGN, glacial or nival plugging moraine type; NC, nival cirque-type; NT, nava-type. Unconfined peatlands: S , springs; TT, torrent-type. AP; Anthropic pressure.

N.	Peatlands	Altitude	Latitude N	Longitude W	Area (ha)	BB	GT	AP
1	Navamuño	1505	40°19’17.41”	5°46’42.03”	14.00	LO	MD	0
2	Refugio Hoya de Cuevas	1858	40°18’31.08”	5°45’32.08”	2.40	UO	GV	0
3	Circo de Hoyamoros	2131	40°17’60.00”	5°44’15.91”	0.37	UO	GC	0
4	Supra-Lagunas del Trampal	2215	40°18’30.30”	5°43’31.93”	0.69	UO	GC	0
5	Trochagosta	2230	40°18’11.29”	5°43’06.14”	0.48	UO	GC	0
6	Hoyo Malillo	1900	40°17’39.61”	5°41’58.66”	12.04	UO	GC	1
7	Supra-Laguna del Duque	1651	40°18’18.61”	5°41’21.20”	0.46	MO	SP	1
8	Garganta del Trampal	1470	40°18’57.05”	5°40’47.12”	1.88	LO	GV	1
9	Puerto de la Hoya W	1475	40°23’28.20”	5°41’14.43”	0.57	LO	SP	2
10	Puerto de la Hoya E	1493	40°23’28.48”	5°40’59.27”	0.68	LO	SP	3
11	Puerto del Tremedal	1600	40°22’00.26”	5°36’59.57”	1.20	LO	NT	3
12	Los Pradillos	1555	40°22’18.42”	5°36’32.33”	1.81	LO	RW	4
13	Pico de los Trampales	1555	40°16’38.90”	5°35’38.64”	0.08	LO	RW	3
14	Valle de La Vega	1525	40°15’43.44”	5°36’12.73”	2.08	LO	GV	3
15	Silla del Zapatero S	1720	40°14’48.94”	5°36’25.74”	0.09	MO	GV	1
16	Silla del Zapatero N	1680	40°15’00.54”	5°36’18.09”	0.04	MO	GV	0
17	Circo del Barco	1775	40°14’15.34”	5°36’07.69”	6.29	UO	GV	2
18	Corral del Diablo	2208	40°13’37.76”	5°35’24.76”	0.08	UO	GC	0
19	Circo de la Nava	1878	40°13’58.39”	5°34’18.86”	0.56	UO	GC	1
20	Garganta de la Nava	1710	40°14’24.34”	5°34’12.15”	0.04	MO	GV	0
21	Fuente de Majá Baera	1653	40°12’44.38”	5°32’54.52”	0.26	MO	GV	1
22	Umbrías	1087	40°18’43.76”	5°34’54.21”	0.35	MS	RW	4
23	Navalonguilla	1140	40°15’58.70”	5°30’36.84”	0.64	MS	TT	1
24	Cuerda de los Canalizos	1815	40°16’16.82”	5°27’11.62”	0.06	UO	NC	1
25	Regajos de la Cruz	1865	40°16’49.83”	5°26’36.70”	0.22	UO	NC	0
26	Garganta de Bohoyo W	1535	40°16’13.67”	5°23’45.99”	0.28	LO	GV	0
27	Garganta de Bohoyo E	2125	40°15’53.39”	5°19’55.36”	0.13	UO	GC	0
28	Lagunilla del Corral	2215	40°15’34.14”	5°19’46.18”	0.20	UO	GC	0
29	Risco de las Hoces	2180	40°16’50.76”	5°19’04.21”	0.62	UO	GC	1
30	Lagunillas	1969	40°17’07.47”	5°19’03.81”	1.60	UO	GC	1
31	Hoya de las Berzas	1956	40°16’10.66”	5°18’22.83”	0.49	UO	MGN	0
32	Garganta del Pinar	1914	40°16’32.14”	5°18’23.94”	0.48	UO	GV	1
33	Cuerda del Barquillo	1820	40°17’27.14”	5°18’20.86”	0.18	UO	SP	1
34	Cervunal	1785	40°17’39.59”	5°17’04.37”	17.34	MO	MD	1
35	Refugio del Barquillo	1680	40°18’53.74”	5°18’11.77”	0.09	MO	SP	4

N.	Peatlands	Altitude	Latitude N	Longitude W	Area (ha)	BB	GT	AP
36	La Cepeda	1645	40°19’39.81”	5°17’59.66”	1.74	MO	SP	2
37	Gargantón	1740	40°16’20.22”	5°16’29.02”	4.04	MO	GV	0
38	Roncesvalles	1640	40°18’11.99”	5°15’39.45”	5.60	MO	MD	0
39	Fuente de los Cavadores W	2100	40°16’15.26”	5°15’23.94”	0.06	UO	TT	2
40	Fuente de los Cavadores E	2060	40°16’19.49”	5°15’14.18”	0.27	UO	SP	1
41	Refugio del Rey	2185	40°15’05.03”	5°15’15.52”	0.07	UO	SP	1
42	Prado de las Pozas	1925	40°16’05.95”	5°14’52.35”	3.41	UO	GV	2
43	Prado Puerto-Prado de Barbellido	1895	40°15’40.50”	5°14’05.50”	3.84	UO	GV	1
44	Los Conventos	1935	40°16’22.88”	5°10’55.35”	0.37	UO	GV	0
45	Corral de la Covacha	1545	40°17’43.86”	5°11’12.51”	0.65	LO	SP	3
46	Casas de la Isla	1402	40°19’37.93”	5°10’37.31”	0.52	US	SP	4
47	Chorreras del Tormes	1418	40°20’14.57”	5°09’19.96”	0.15	US	NT	3
48	Puerto del Peón	2020	40°16’55.72”	5°09’05.69”	0.07	UO	NC	2
49	Arroyo de los Herreros S	1495	40°16’09.99”	5°09’13.35”	0.01	US	TT	1
50	Arroyo de los Herreros N	1533	40°16’15.50”	5°09’12.18”	0.01	US	TT	1
51	La Hiruela	1667	40°16’48.21”	5°07’54.97”	0.22	LO	SP	1
52	La Cebedilla E	1403	40°16’46.48”	5°07’18.69”	0.05	US	TT	1
53	La Cebedilla W	1483	40°16’49.28”	5°07’33.53”	0.29	US	SP	1
54	Arroyo de Aguas Frías	1115	40°16’04.79”	5°07’17.08”	0.16	MS	TT	1
55	Navarredonda	1557	40°21’18.48”	5°05’34.88”	3.30	US	NT	4
56	Fuente de la Leche	1420	40°20’48.57”	5°03’24.71”	0.15	US	SP	4
57	Cañada de las Trampaleras	1477	40°19’52.61”	5°02’30.68”	0.25	US	NT	3
58	Puerto de Menga	1546	40°28’14.01”	5°00’46.60”	2.65	US	NT	4
59	Venta del Obispo	1233	40°23’23.40”	5°01’10.10”	0.04	MS	RW	4
60	Venta Rasquilla	1235	40°22’00.40”	5°00’41.73”	2.12	MS	RW	4
61	Puerto del Pico	1387	40°19’21.16”	5°00’52.28”	1.17	US	NT	4
62	Media Legua	1213	40°18’59.11”	5°00’51.77”	0.01	MS	TT	1
63	Hoya del Gallego	1455	40°19’50.53”	5°00’04.55”	0.19	US	RW	2
64	Arrelobo W	1314	40°22’23.09”	4°59’17.12”	5.50	US	RW	4
65	Arrelobo E	1297	40°22’23.99”	4°58’19.01”	2.45	US	RW	4
66	Collado Viejo	1640	40°20’14.07”	4°51’05.79”	0.35	LO	NT	4
67	Puerto del Lagarejo	1575	40°18’17.12”	4°55’16.42”	0.83	LO	NT	4
68	Puerto de Serranillos	1700	40°18’01.75”	4°55’56.94”	2.40	LO	NT	4
69	Manantial de las Queseras	1295	40°16’59.82”	4°55’15.28”	0.05	MS	SP	3
70	Fuente del Pino Blanco	1372	40°14’10.69”	4°58’39.46”	0.49	US	RW	3
71	La Covatilla	1945	40°21’27.15”	5°41’16.81”	4.15	UO	NT	1
72	El Quemal-Candelario	1850	40°20’02.74”	5°43’58.71”	0.79	UO	RW	1

A geomorphological and hydrological survey was also carried out with emphasis on the glacial landforms following previously published papers (Tejero *et al.*, 2006; Acaso *et al.*, 2009; Palacios *et al.*, 2011, 2012; Muñoz-Salinas *et al.*, 2013; Pedraza *et al.*, 2013; Carrasco *et al.*, 2020). We aimed to understand to what extend and in what manner local geomorphology contributed to peat accumulation and peatland development (Table 1; Figures 2-3). To map the geomorphological features and identify areas favourable to peatlands formation, we used images from the SRTM (Shuttle Radar Topography Mission) and Landsat 7. The images were processed in GIS. The drainage network was compiled from maps at a scale of 1:25.000 from the IGN.

Field assessments

A total of 72 peatlands were field sampled during March 2019-September 2021. To distinguish between peatlands and wet meadows, at each site a 50 cm long soil core was collected with a Russian peat sampler (GYK type, 50 cm length; 5 cm in diameter) to quantify soil organic matter content. We defined peatlands as wetlands with organic soils at least 30 cm thick and a carbon content of more than 15% (Martínez-Cortizas & Silva-Sánchez, 2019). Soil organic matter content was determined for all core sections by loss-on-ignition (LOI) at 550 ºC for 4 h (Heiri *et al.*, 2001). In all field verified peatlands, we determined location and overall site characteristic, condition and disturbances, and collected stand-level vegetation composition data.

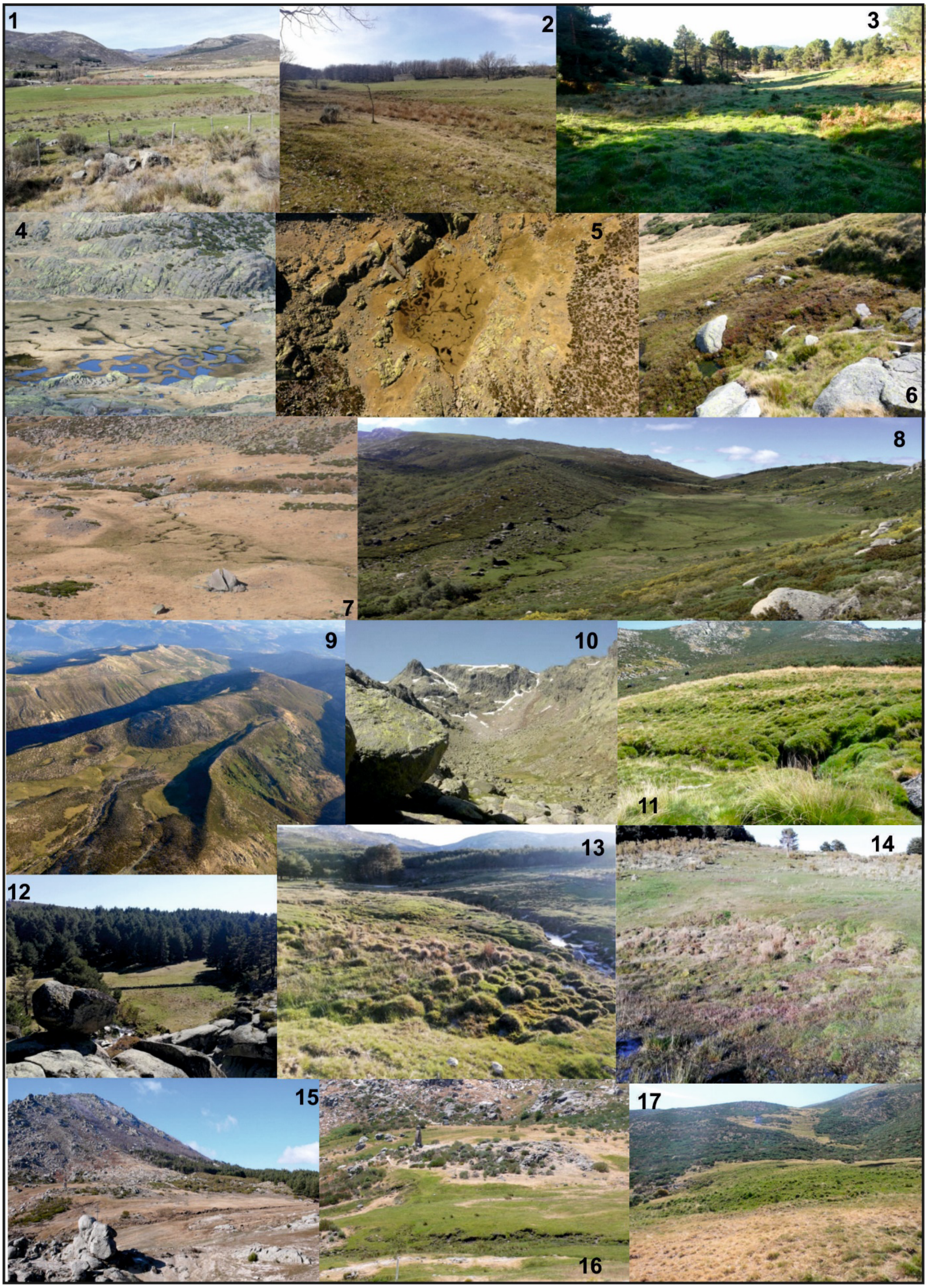

Figure 2. Confined peatland typological groups according to the r geomorphological location and the origin of the landform (see Table 1): RW-type (1, Venta del Obispo; 2, Arrelobo E; 3, Fuente del Pino Blanco); GC-type (4-5, Lagunillas); GV-type (6, Prado de las Pozas; 7, Prado Puerto-Prado de Barbellido); MD-type (8, Navamuño; 9, Cervunal); MGN-type (10, Hoya de las Berzas); NC-type (11, Puerto del Peón); NT-type (12, Chorreras del Tormes; 13-14, Cañada de las Trampaleras; 15-16, Puerto del Pico; 17, Collado Viejo).

A total of 103 relevés comprehending 72 different peatland ecosystems were obtained (Figure 1). The phytosociological approach (Braun-Blanquet, 1979) was used to obtain relevés, including topographic and other data of individual plots, such as altitude, longitude and latitude (Table 1). We chose homogenous sampling plots with an area of 10 m^2. When several relevés were conducted at the same site, they are referred to as "X"a, "X"b, "X"c, etc. (X = peatland number in Table 1).

Nomenclature

Taxonomic nomenclature and authorities for vascular plants mainly follow the published volumes of *Flora iberica* (Castroviejo *et al.*, 1986–2021) and *Flora Europaea* (Tutin *et al.*, 1964–1980); while Ros *et al.* (2013) and Söderström *et al.* (2016) were followed for the nomenclature of mosses and liverworts, respectively. Syntaxonomical scheme, nomenclature, and syntaxa authorities follow the compilations and proposals of Rivas-Martínez *et al.* (2001, 2002, 2011).

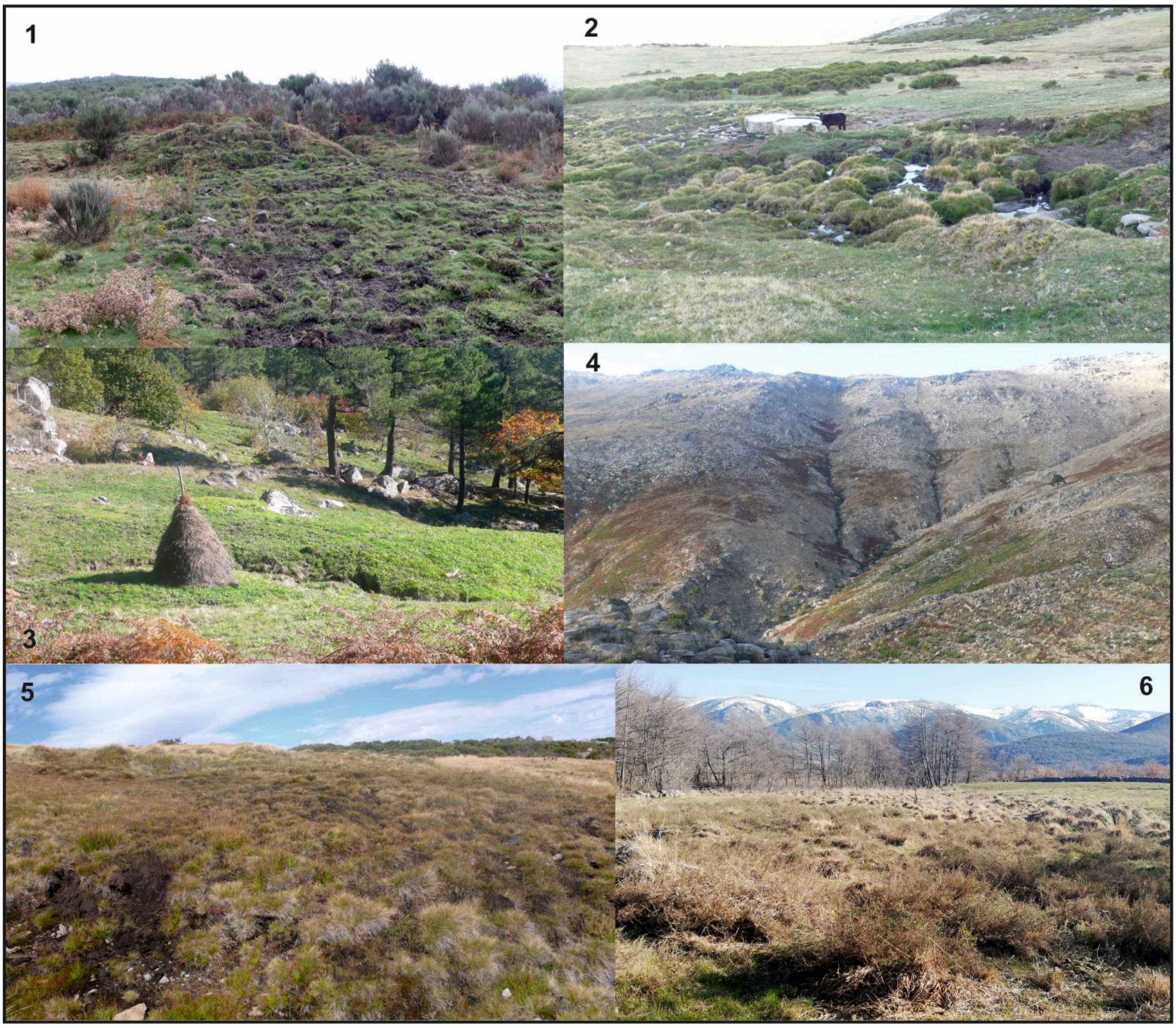

Figure 3. Unconfined peatland typological groups according to t eir geomorphological location and the origin of the landform (see Table 1): SP-type (1, Manantial de las Queseras; 2, Refugio del Barquillo); TT-type (3, Arroyo de Aguas Frías; 4, Arroyo de los Herreros S and N; 5, Fuente de los Cavadores W; 6, Navalonguilla).

Statistical analyses

Vegetation data from homogeneous stands were classified using agglomerative cluster analysis with the Euclidean distance and Ward's minimum variance method (Ward, 1963), which has been shown to optimize the internal homogeneity of clusters and to establish clearer dichotomies among them, as well as to classify continuous variables better (Wildi, 1989). The hierarchical relationships between clusters are illustrated by the dendrogram in Figure 4. Principal component analysis (PCA) was used as indirect gradient analysis (ter Braak, 1987) to provide a two-dimensional representation of high-dimensional geometric distances between each relevé and plant taxa (Figure 5). PCA was preferred to Detrended Canonical Correspondence Analysis (DCCA) because the short climatic gradient (< 3 S.D.) considered (Gavilán *et al.*, 1998) suggested linear instead of unimodal responses of taxa (Lepš & Šmilauer, 2003). Square-root transformation of the cover abundances of taxa and downweighting of rare species were applied. All analyses were performed with software PAST (Hammer *et al.*, 2001).

Biodiversity conservation and disturbances

We have also developed a conservation priority list based on peatland plant communities of the GRP following the criteria set out by Gautier *et al.* (2010) and Benavent-González *et al.* (2014), who considered four criteria to perform a cumulative point-scoring ranking: regional responsibility, local rarity, wealth of its endangered flora, and habitat vulnerability. Each plant community was assigned to a characteristic species list using our own data. In this context, a characteristic species is a species with a fidelity to a certain plant community in which it finds its ecological optimum (Braun-Blanquet, 1979). We introduced certain modifications into this method in order to adapt it to our plant communities and study area.

Regional Responsibility (RR) is a biogeographical criterion associated with distribution range. Plant communities with a wide distribution outside the GRP obtain a low regional responsibility value (RR = 1, if present outside the Iberian Peninsula; RR = 2, if present in other mountains of the Iberian Peninsula). In contrast, plant communities with restricted distribution will get high scores (RR = 3, if present only in the Iberian Central System), obtaining endemic plant communities the highest score (RR = 4, if present only in the Gredos range).

Local Rarity (LR) has been quantified as the number of Gredensean districts (Rivas-Martínez *et al.*, 2007, 2014, 2017) where a plant community is reported. It has a maximum score of 4. The lower the number of districts where a community type has been reported, the rarer the community type is in the study area and therefore the higher the score for this criterion. Obviously, the fact that a community can be present in several districts at the same time does not mean that it is abundant in these districts. For this reason, we have introduced a new criterion, called Local Abundance (LA), which refers to the number of localities where a plant community occurs within the 72 studied peatlands, scored as follows: 1–3 sites = 4, 4–5 sites = 3, 6–10 sites = 2, > 10 sites = 1.

Wealth of its Endangered Flora (WEF) assesses the value of the threatened flora contained by each plant community. This value was obtained by adding the content of habitual floristic composition species (Tables 2–10) mentioned into the Spanish red lists of vascular plants and bryophytes (Garilleti & Albertos, 2012; Moreno *et al.*, 2019), with the following scores: near threatened = 1, vulnerable = 2, endangered = 3, critically endangered = 4).

Habitat Vulnerability (HV) provides information on the likelihood of habitat loss for a plant community in the GRP. Bearing in mind that the main threat to the Gredensean peatlands is pastoral pressure (GP), both grazing and trampling and the development of livestock infrastructures (fences, watering troughs, etc.), we have considered this criterion mainly with regard to this threat. Nevertheless, other anthropogenic activities also threaten the peatlands of the GRP, such as drainage, roads and forest tracks, tourism, etc., which have also been considered. Thus, the level of severity of anthropic pressure was assessed by the proportion of peatland it impacted and the intensity of the impact on the relevant communities. Anthropic Pressure (AP) was ranked by severity, that which impacted <1% of the peatland was ranked as low (GP = 1), 1–5% as moderate (GP = 2), 5–15% as high (GP = 3), and >15% as very high (GP = 4). The AP value was estimated for all studied peatlands (Table 1), and the final HV value is the average of the AP values of those peatlands where a particular community is present.

The core of our classification is the equal weight of each criterion. We have attempted to avoid the interrelation among criteria as far as possible. The maximum possible score that may obtain a plant community in the ranking is 20. The gross value of each criterion has been weighted taking 4 as the maximum value. Finally, the combined value of the five criteria comprises the final scores of the ranking

Results and Discussion

Distribution and abundance

Through the mapping analysis and field work we identified 72 peatlands covering approximately 117 ha in the GRP and surrounding areas (Figure 1, Table 1). In the GRP there are many sites with similar characteristics, even with turfophilous vegetation, but they lack edaphic development of at least 30 cm of peat, so they should be classified as para-peaty habitats rather than peatlands (Martínez-Cortizas & Silva-Sánchez, 2019). Peatland area ranged from 0.01 to 17.34 ha with a mean size of 1.62 ha. Three peatlands exceeded 10 ha (Navamuño, Hoyo Malillo and Cervunal) and three others reach 5–10 ha. The vast majority (4) are peatlands of less than 1 ha, and 17 are between 1 and 5 ha 87.5 percent of the peatland area (63 peatlands) was restricted to the north side of the GRP (Figure 1), probably because the southern slope is warmer and to some extent limits the development of peatland ecosystems (López-Sáez *et al.*, 2014a, 2019). In addition, the landforms on the northern slope are more suitable for the formation of these deposits (Carrasco *et al*., 2020).

No peatlands have been documented in the mesomediterranean and lower supramediterranean bioclimatic belts below 1000 m asl, probably because temperature and rainfall conditions are not suitable for their formation (Pontevedra-Pombal *et al.*, 2017). Thus, evaporation is very important during several months by year (Gavilán, 2005), limiting peat inception. Neither in the criorosubmediterranean belt (> 2300 m asl), because at these altitudes the climate is xeric as they are covered by winter snow for at least 4–5 months (Gavilán, 2005). However, the presence of peatland ecosystems between the middle supramediterranean and the upper orosubmediterranean belts is probably related with favourable climate conditions for peat formation, with high annual rainfall combined with lower temperatures, especially in summer. Peatlands occur primarily in the upper orosubmediterranean bioclimatic belt at 1775–2230 m asl, where 25 peatlands have been identified (Table 1), while 12 appear in the middle orosubmediterranean (1640–1785 m asl) and 17 in the lower orosubmediterranean (1470–1700 m asl) ones. Only 18 peatlands have been identified on the supramediterranean bioclimatic belt, 8 at the upper level and 10 in the middle one.

The presence of only a few peatlands in the supramediterranean belt could be also related to the fact that these areas were historically dedicated to ploughing and pasture land, particularly during the Medieval period (López-Sáez *et al.*, 2018c). Hence, some human responsibility can be invoked for both the establishment of peatlands and the presence of peaty soils, but also of their disappearance. The effects of deforestation by fire, and of grazing and farming pressure have combined to reduce the water deficit in the hydromorphic valley bottoms where trees have been felled, and thus to activate the peat accumulation process, or, on the contrary, erode away the peat and make it disappear (Cubizolle *et al*., 2012).

Our mapping (Figure 1) indicates that mountain peatlands are extensive in the GRP and its buffer zone with ~ 0.14% of the landscape mapped as peatlands. This is a much greater concentration of mountain peatlands that identified in the eastern Iberian Central System (Rivas-Martínez, 1963; Rivas-Martínez *et al*., 1990), and even in the Toledo Mountains, where they reach larger sizes, however (López-Sáez *et al*., 2014b). Nevertheless, this Gredensean peatlands cover smaller surfaces than those estimated from the Cantabrian and Galician mountains of northern Iberia (Martínez-Cortizas & García-Rodeja, 2001; Pontevedra-Pombal *et al*., 2006; Chico *et al*., 2019). The difference in the peatland abundance between the GRP and the other Iberian mountain ranges is likely due to climatic differences. The Cantabrian range and Galicia are located in the Eurosiberian region characterized by cool and wet conditions with no clear distinct dry season (Pontevedra-Pombal *et al*., 2017). In contrast, the GRP is characterized by stronger seasonality, with distinct wet and dry season, which limits to some extent the formation of peatlands (Gavilán, 2005; López-Sáez *et al*., 2019).

Geomorphological typology

The collected data revealed significant diversity in the geomorphological structure and related typology of peatlands in the GRP, although there is a lithological homogeneity of the documented deposits related to a granitic basement. The landscape of the GRP is basically dominated by both erosional (e.g. cirques, U-shaped valleys, streams and rivers) and depositional (e.g. moraine ridges) glacial features (Carrasco *et al*., 2020), which are clearly preserved between the supra- and the criorosubmediterranean bioclimatic belts ~1400–2400 m asl. Differences in topography could be another factor that may help explain the greater abundance of peatlands in the GRP, which has the greatest cover of glaciers of the Iberian Central System, and many of these glaciers have created broad U-shaped valleys with steep side slopes that influence peatlands by slope processes and mineral sediment inputs (Pedraza, 1989, 1994; Pedraza & Carrasco, 2006; Palacios *et al.*, 2011, 2012; Pedraza *et al.*, 2013). According to their geomorphological location and the origin of the landform, two peatland typological groups have been identified in the GRP (Figures 2, 3, Table 1).

The first group includes “confined peatlands”, so the typical acidic peatland or fens, which occupy terrain depressions (areas of endorheic tendency) whose genesis may have occurred by:

- (i) rock weathering granite (weathered or regolit) (RW);
- (ii) glacial activity, that is:
- (iia) overdeepening in glacial cirques or glacial plateau accumulation area and later sediment overfilling in former lacustrine basins (GC). This type also includes some small circus ‘navas’ hanging on slopes or shoulders (e.g. Trochagosta, Lagunilla del Corral, Risco de las Hoces);
- (iib) overdeepening in glacial valleys and later sediment overfilling in subglacial environments (basal moraine) or former lacustrine basins (GV). These peatlands are quite complex although they all develop at the bottom of glacial valleys. However, some have a very clear endorheic tendency, while others are associated with the current stream (convergent with the TT type) or with slope solifluxions (convergent with the SP type);
- (iic) morainic deposits of lateral moraines (moraine-dammed type) (MD);
- (iid) morainic deposits related to arcuate moraines (glacial or nival plugging moraine type), that is to crescent-shaped and frame a small closed depression related to glacial or periglacial deposits (MGN);
- (iie) nival weathering, rill wash, etc., that is in nival in flat-bottomed cirques by periglacial processes (NC);
- (iif) be structural (tectonic depressions usually related to fracture crossings -‘nava’-type-, which are also clogged with sediment) (NT).

The second group includes “unconfined peatlands”, which correspond to peatland types developed on landforms that are not clearly endorheic, in which water is circulating. They occupy valley or hillside positions. They may be associated with: (i) springs in hillside areas (SP); or, (ii) high-mountain streams and rivers (‘torrent’-type) with a nivo-pluvial regime, that is to fractures (NNE-SSE and, to a lesser extent, N-S and NNW-SSE) and erosion processes of the hydrological network on sandy granites, usually with a linear course (TT).

The majority of peatland types are related to glacial valleys (GV) and springs (SP) -14 cases each-, whereas those originating from rock weathering granite (RW), overdepening in glacial cirques (GC) and nava-type (NT) account for 10 occurrences each. Torrent-type peatlands (TT) accounts for 7 cases, while those of the moraine damme (MD) and nival cirque (NC) types account for only three. Finally, we have documented only one case of the glacial or nival plugging moraine type (MGN). Among the three largest peatlands in the GRP, two are of the MD type (Navamuño, Cervunal) and the other of the GC type (Hoyo Malillo).

Phytosociological characterization of peatland communities

During the field surveys, we recorded 103 phytosociological relevés (Tables 2-10) which contained 109 species in total. Based on the results of the agglomerative clustering analysis (Figure 4), we recognized twelve sample groups or communities, mostly interpreted as associations and even as subassociatons. The first division separates cluster A, which includes coenoses dominated by *Carex nigra*, *C. echinata* and *Sphaghum* spp. (cluster A), from cluster B, related to those dominated by other different species. In the group A are raised peatland communities (dominated by *Sphagnum denticulatum* and belonging to the *Erico tetralicis-Sphagnetalia papillosi* order, Aa2); and fla peatland communities with *Eriophorum latifolium* and *Sedum lagascae* (Aa1), or without these species (Ab) (both belonging to the *Caricetalia nigrae* order). Within the Ab grouping, different subdivisions can be distinguished, in smaller ranges, interpretable as subassociations of the *Caricetum echinato-nigrae* community, according to the characteristic species (*Carex demissa*, *Lycopodiella inundata*, *Parnassia palustris*). In group Ba are included heliophilous and pioneer coenoses living on altered and eroded peatlands (dominated by *Rhynchospora alba* and belonging to the *Scheuchzerietalia palustris* order, Ba1a), oligotrophic floating communities (with *Utricularia minor* and belonging to the *Utricularietalia intermedio-minoris* order, Ba1b), and *Myosotis stolonifera*-dominated mountain stream, spring and shallow peatland communities (*Montio-Cardaminetalia* order, Ba2); while group Bb includes xerophytic peaty communities dominated by *Trichophorum caespitosum* subsp. *germanicum*, belonging to the *Caricetalia nigrae* order like others mentioned in group A, from which it is clearly segregated. The clusters are further divided into some groups, which are described below from a syntaxonomical point of view based on floristic and ecological features.

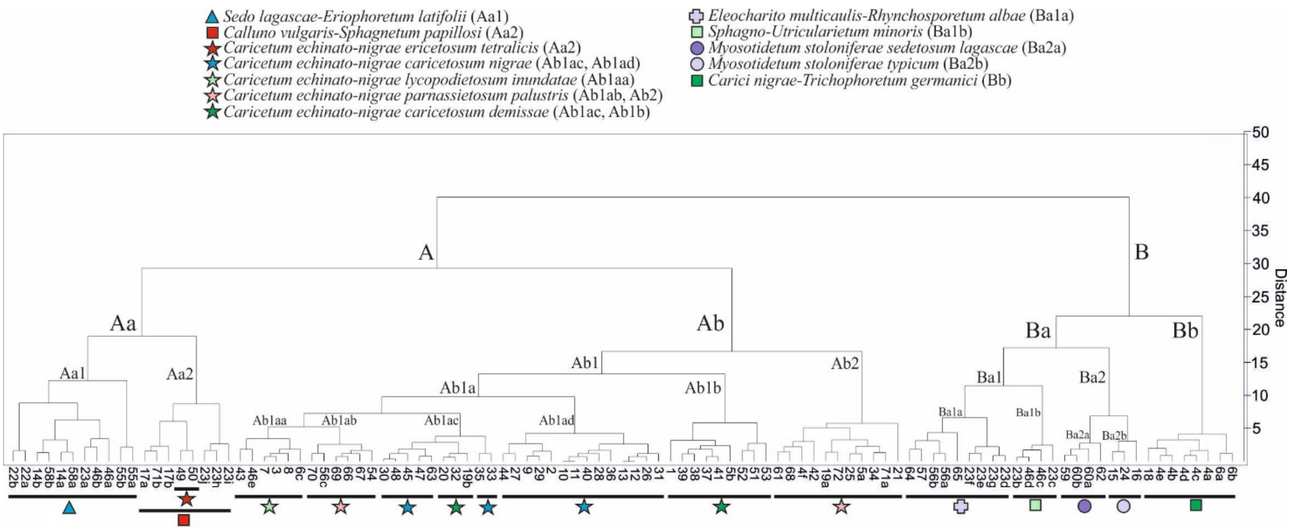

Figure 4. Dendrogram resulting from cluster analysis of the relevés.

A PCA biplot of the sample scores of individual relevés and loading (eigenvectors) for the plant species is shown in Figure 5. The first two principal component axes are significant, accounting for 32.6% and 27.3% of the variance, respectively. The first principal component axis separates samples into two groups. Samples from Aa (Aa1, Aa2) cluster have positive values on the firs axis while those from Ba (Ba1a, Ba1b, Ba2a, Ba2b) and Bb cluster show negative values. Samples from Ab cluster are arranged on both sides of the axis, showing low segregation, although they are preferentially located on the positive side of the axis. Accordingly, PCA axis 1 is probably discriminating between communities living on deep peatlands (positive side) versus those living on shallow and even eroded ones (negative side). The former would be characterised by species typical of well-developed peatlands with a dense moss cover such as *Carex echinata*, *C. nigra*, *Drosera rotundifolia*, *Eriophorum latifolium*, *Parnassia palustris*, *Sedum lagascae* and *Sphagnum denticulatum*, which are also located on the positive side of the axis; while the latter are generally related to heliophilous and pioneer species in peat-loving environments, as in the case of *Rhynchospora alba*, *Myosotis stolonifera* and *Trichophorum caespitosum* subsp. *germanicum*, or even oligrotrophic floating communities dominated by *Utricularia minor*, which are located on the negative side of the axis. The second principal component axis separates the relevés of clusters Aa and Ba (positive values) from those of clusters Ab and Bb (negative values) of the cluster analysis. This indicates that probably PCA axis 2 discriminates between samples (positive values) mainly belonging to middle and upper supramediterranean communities, while those with negative values belong to orosubmediterranean ones.

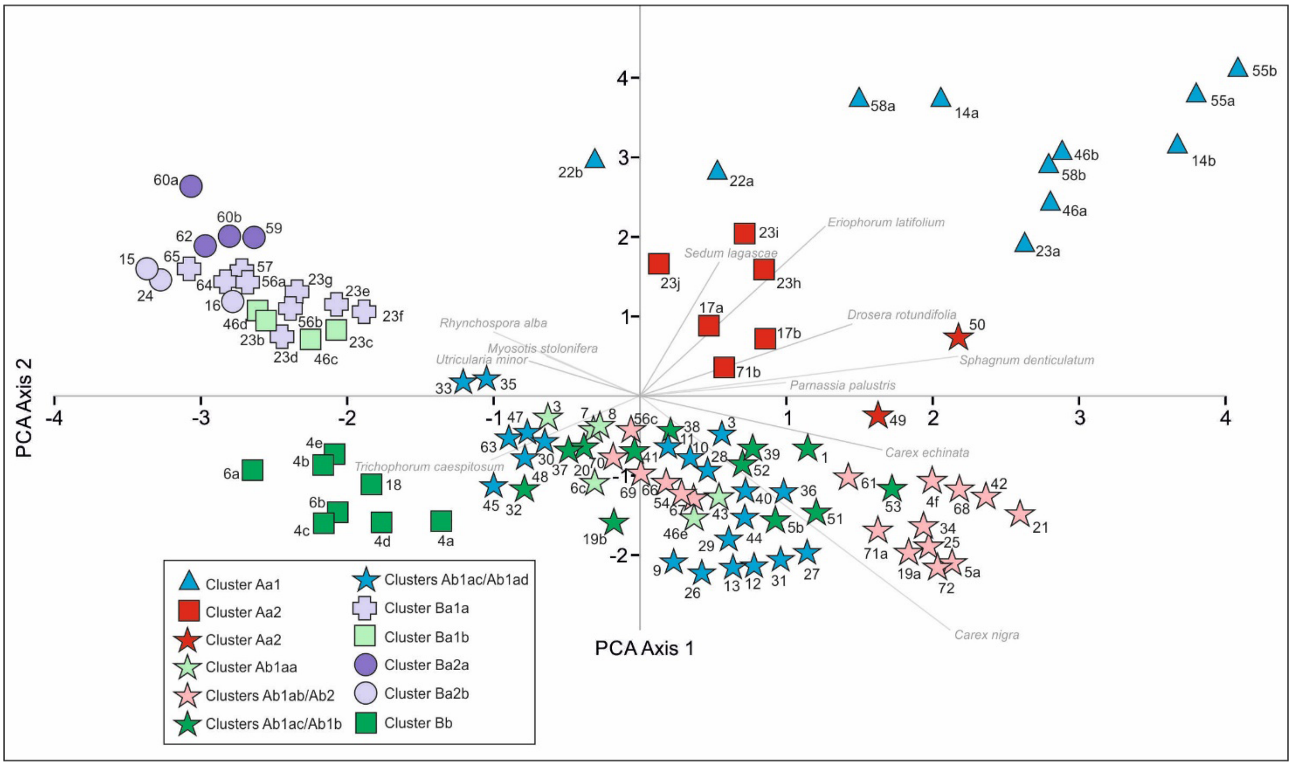

Figure 5. Ordination results of principal component analysis (PCA) for major plant taxa and 103 relevés. The first two axes explain 59.9% of the variance in the dataset (Axis 1 = 32.6%, Axis 2 = 27.3%).

Cluster Aa1 represents the *Sedo lagascae-Eriophoretum latifolii* association, which has its optimum in the middle and upper supramediterranean bioclimatic belts (1087–1587 m asl) of the GRP (Table 2), with a wide distribution in the study area in the East Gredos Sierran and Tormantos Sierran districts. It lives on well-developed, deep peaty soils (Sánchez-Mata, 1989; Sardinero, 2004), in a variety of geomorphological typologies, both in confined and unconfined peatlands. Above 1500 m asl this community is mainly found in NT and GV peatlands, while at lower altitudes it tends to occupy RW, SP and TT ones. It is an exclusively Iberian community, only also known in the Guadarrama range in the eastern part of the Iberian Central System (Rivas-Martínez, 1963; Rivas-Martínez *et al.*, 1990). It is characterized by *Eriophorum latifolium*, *Sedum lagascae*, *Parnassia palustris*, *Potentilla palustris*, *Menyanthes trifoliata*, and a dense cover of bryophytes (*Sphagnum* spp.).

Cluster Aa2 includes two peatland communities (Figure 4), which are clearly segregated in the PCA biplot (Figure 5). The first one corresponds to the *Calluno vulgaris-Sphagnetum capillifolii* community, typical of raised peatlands with an ombrotrophic tendency although they are minerotrophic in nature, where the water table is relatively high (Martínez-Cortizas *et al.*, 2009c). It is very rich in bryophytes, especially of the genus *Sphagnum*, as well as in species of Ericaceae (*Calluna vulgaris*, *Erica tetralix*). In our territory, it is distributed only in the Bejaran-Gredensean sector, both in the Béjar Sierran and Tormantos Sierran districts, occupying a wide altitudinal range (1140–1775 m asl) between the middle supramediterranean and the upper orosubmediterranean bioclimatic belts (Table 3). This endemic Iberian community has been reported in northern Iberian mountains as well as in the southwestern slopes of the Gredos range in Extremadura (García-Alonso *et al*., 2009; Díaz-González & Penas, 2017).

All samples of the large cluster Ab, as well as two samples of the cluster Aa2, correspond to the *Caricetum echinato-nigrae* association (Figure 4), typical of relatively flat, oligotrophic peat bogs (fens) on deep peaty deposits, although water flows on the surface. It is the most widespread community in the GRP, with an enormous syntaxonomic variety; hence its segregation in the PCA biplot is rather low (Figure 5). The community is made up of small sedges (*Carex nigra*, *C. echinata*) and bryophytes, especially of the genus *Sphagnum* (Tables 4-5). These acid peatlands are widely distributed throughout the Iberian mountains, where they are endemic (Martínez-Cortizas *et al*., 2009a; Loidi, 2017; Pontevedra-Pombal *et al.*, 2017), including the Iberian Central System (Rivas-Martínez, 1963; Sánchez-Mata, 1989; Rivas-Martínez *et al.*, 1990; Sardinero, 2004; Sánchez-Mata *et al.*, 2017).

Table 2
Sedo lagascae-Eriophoretum latifolii Rivas-Martínez in Rivas-Martínez, Fernández-González & Sánchez-Mata 1986
(*Caricion nigrae*, *Caricetalia nigrae*, *Scheuchzerio palustris-Caricetea nigrae*)

Altitude (m asl)	1087	1087	1546	1546	1525	1525	1557	1557	1402	1402	1140
N. species	17	19	20	21	21	23	29	29	31	32	24
Peatland site	22b	22a	58a	58b	14a	14b	55a	55b	46a	46b	23a
Relevé N.	1	2	3	4	5	6	7	8	9	10	11
Characteristics											
Eriophorum latifolium	4	4	4	3	4	3	3	4	2	3	2
Carex echinata	1	2	2	2	2	3	2	3	1	2	2
Drosera rotundifolia	+	+	2	1	2	2	2	3	2	2	1
Carex echinata	1	2	2	2	2	3	2	3	1	2	2
Drosera rotundifolia	+	+	2	1	2	2	2	3	2	2	1
Carex nigra	·	+	+	2	1	2	2	2	2	1	2
Sedum lagascae	·	·	2	3	3	3	2	3	2	1	1
Parnassia palustris	·	·	1	1	1	1	1	1	1	1	2
Epilobium palustre	·	·	1	+	+	1	3	3	1	1	1
Potentilla palustris	·	·	+	1	+	1	3	3	1	+	1
Carex demissa	1	1	+	+	·	+	·	·	+	+	+
Menyanthes trifoliata	·	·	·	·	·	·	4	3	·	·	1
Carex limosa	·	·	·	·	·	·	+	+	·	·	·
Lobelia urens	+	1	·	·	·	·	·	·	·	·	·
Viola palustris	·	·	·	·	·	·	+	+	·	·	·
Sphagnum denticulatum	·	·	·	2	1	2	4	3	3	3	2
Meesia triquetra	·	·	·	·	·	·	1	1	2	1	·
Sphagnum teres	·	·	·	·	·	·	·	·	+	+	·
Sphagnum auriculatum	·	·	·	·	·	·	·	·	+	+	·
Other species											
Hypericum undulatum	+	+	1	+	+	1	1	+	+	+	+
Potentilla erecta	·	·	+	1	+	1	+	+	+	1	+
Holcus mollis subsp. *reuteri*	·	+	1	1	+	1	2	1	1	1	+
Holcus lanatus	1	1	·	·	·	·	·	·	·	·	·
Carum verticillatum	+	+	+	1	+	1	1	+	+	+	+
Anthoxanthum aristatum	+	·	1	1	1	1	+	+	+	1	1
Wahlenbergia hederacea	+	·	+	·	+	+	2	2	+	+	+
Dactylorhiza elata	·	·	·	+	+	+	1	+	+	+	·
Veronica scutellata	·	·	·	·	·	·	+	+	+	·	·
Succisa pratensis	·	+	1	+	1	1	1	+	1	+	+
Luzula multiflor	+	1	·	·	·	·	+	+	·	·	·
Scilla verna subsp. *ramburii*	·	·	·	·	·	·	+	+	·	·	·
Molinia caerulea	1	1	·	·	·	·	·	·	·	·	·
Juncus acutifloru	1	2	·	·	·	·	·	+	·	·	·
Juncus effusus	+	+	·	·	·	·	+	·	·	·	·
Carex binervis	1	1	+	+	+	+	·	·	+	+	+
Nardus stricta	+	+	+	1	+	1	+	+	·	·	+
Briza media	+	·	1	+	+	1	·	·	·	+	·
Prunella vulgaris	+	+	·	·	·	+	·	+	·	·	·
Scorzoneroides carpetana	·	·	·	·	·	·	+	·	·	·	·
Aulacomnium palustre	·	·	+	+	+	+	3	3	2	1	+
Calliergonella cuspidata	·	·	·	·	·	·	·	+	+	+	+
Philonotis tomentella	·	·	·	·	·	·	+	·	+	+	·
Bryum pseudotriquetrum	·	·	·	·	·	·	·	·	+	+	+
Tomentypnum nitens	·	·	·	·	·	·	·	·	+	+	·
Depranocladus aduncus	·	·	·	·	·	·	·	·	+	+	·
Philonotis fontana	·	·	·	·	·	·	·	·	·	+	+

Other species: *Danthonia decumbens* + in 2, *Hamatocaulis vernicosus* and *Aneura pinguis* + in 9, *Plagiomnium ellipticum* and *Lophozia ventricosa* + in 10.
Localities: 1, 2: Umbrías (22a, 22b); 3, 4: Puerto de Menga (58a, 58b); 5, 6: Valle de La Vega (14a, 14b); 7, 8: Navarredonda (55a, 55b); 9, 10: Casas de la Isla (46a, 46b); 11: Navalonguilla (23a).

Table 3
Calluno vulgaris-Sphagnetum capillifolii F. Prieto, M.C. Fernández & Collado 1987
(*Trichophorenion germanici*, *Erico tetralicis-Sphagnetalia papillosi*, *Oxycocco-Sphagnetea*)

Altitude (m asl)	1775	1775	1140	1945	1140	1140
N. species	8	10	12	11	14	15
Peatland site	17b	17a	23j	71b	23h	23i
Relevé N.	1	2	3	4	5	6
Characteristics						
Sphagnum denticulatum	4	3	3	3	4	3
Sphagnum angustifolium	1	+	1	·	2	3
Sphagnum compactum	·	·	·	1	·	·
Sphagnum fimbriatu	·	·	·	1	·	·
Other species						
Drosera rotundifolia	1	2	1	1	1	2
Potentilla erecta	1	+	+	+	+	1
Nardus stricta	2	1	·	2	·	·
Viola palustris	1	+	·	+	·	·
Gentiana boryi	+	1	·	1	·	·
Molinia caerulea	·	·	2	·	2	1
Calluna vulgaris	·	·	2	·	1	2
Betula celtiberica (seedlings)	·	·	1	·	+	1
Erica tetralix	·	·	2	·	2	3
Holcus lanatus	·	·	+	·	1	+
Wahlenbergia hederacea	·	·	1	·	+	1
Genista anglica	·	·	1	·	1	1
Pedicularis sylvatica	·	+	·	+	·	·
Agrostis canina	·	+	·	+	·	·
Juncus acutifloru	·	·	·	·	+	+
Menyanthes trifoliata	·	·	·	·	1	+
Carex binervis	·	·	·	·	·	+
Aulacomnium palustre	1	+	1	1	1	1

Localities: 1, 2: Circo del Barco (17a, 17b); 4: La Covatilla (71b); 3-6: Navalonguilla (23h, 23i, 23j).

The *caricetosum nigrae* subassociation (Ab1ac and Ab1ad clusters) represents the initial facies of the community colonising shallow peaty soils, while the *parnassietosum palustris* subassociation (*typicum*; Ab1ab and Ab2 clusters) is consolidated in stable peatland ecosystems on deeper soils, and has a very important moss cover. The typical subassociation has a wide altitudinal distribution between the middle supramediterranean and the upper orosubmediterranean bioclimatic belts (1115–2230 m asl), and is found in the four Gredensean districts (Table 4), as well as the *caricetosum nigrae* subassociation (Table 5; 1418–2215 m asl). Both are abundant in glacial typology landforms above 1800 m asl, while at lower altitudes they occur in SP, RW and NT-type peatlands.

The *caricetosum demissae* subassociation (Ab1ac and Ab1b clusters), characterized by the constant presence of *Carex demissa* (Table 6), is typical of sites with a certain slope and less developed soil on glacial landforms (GC, GV and MD types), where water flows constantly, between the upper supramediterranean and the upper orosubmediterranean bioclimatic belts (1403–2230 m asl), being founded in the four Gredensean districts. On the other hand, the *ericetosum tetralicis* subassociation (Aa2 cluster) is typical of more xeric upper supramediterranean sites (1495–1533 m asl) on the East Gredos Sierran district, which may even suffer from a certain summer drought, being its differential species *Erica tetralix*, *Calluna vulgaris*, *Anagallis tenella* and *Carex binervis* (Table 6). This subassociation is clearly separated from the rest in both the dendrogram and the PCA biplot (Figures 3, 4), and has only been found in TT-type peatlands.

Finally, within the *Caricetum echinato-nigrae* association we describe the new *lycopodielletosum inundatae* subassociaton (rel. 17 of Table 6, Prado Puerto-Prado de Barbellido at 1895 m asl) −clearly individualised in the dendrogram within cluster Ab1aa− (Figure 4), with a pioneer character and the constant presence of *Lycopodiella inundata* (Table 6), colonising eroded and even bare peat areas in peatlands, i.e. less hygrophilous characteristics than those of the *caricetosum nigrae* subassociation, between the upper supramediterranean and the upper orosubmediterranean bioclimatic belts (1402–2131 m asl) in the Béjar Sierran, East Gredos Sierran and High Gredos Sierran districts.

Table 4
Caricetum echinato-nigrae Rivas-Martínez (1964) 2002 in Rivas-Martínez et al. 2002
parnassietosum palustris Rivas-Martínez 1964
(*Caricion nigrae, Caricetalia nigrae, Scheuchzerio palustris-Caricetea nigrae*)

Altitude (m asl)	1575	1295	1115	1420	1640	1372	1387	1878	1865	1850	1945	1700	1785	2230	1654	2215	1925
N. species	5	5	7	7	8	8	9	10	10	11	12	12	13	14	16	19	19
Peatland site	67	69	54	56c	66	70	61	19a	25	72	71a	68	34	5a	21	4f	42
Relevé N.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Characteristics																	
Carex nigra	3	3	3	2	3	2	3	4	4	4	4	3	4	4	4	3	3
Carex echinata	2	1	2	1	1	2	2	2	3	3	2	3	2	3	2	2	3
Sphagnum denticulatum	1	+	+	1	1	+	2	2	2	2	2	3	2	2	2	3	3
Parnassia palustris	+	+	1	1	+	+	1	1	+	+	+	1	1	+	1	1	+
Drosera rotundifolia	+	+	+	+	+	·	1	1	+	+	+	1	1	+	3	1	1
Agrostis canina	·	·	1	·	+	+	·	2	+	2	+	+	1	1	+	1	+
Viola palustris	·	·	+	·	·	·	+	·	·	+	+	+	·	·	+	·	·
Gentiana boryi	·	·	·	·	·	·	·	+	·	·	·	·	+	·	+	·	·
Eleocharis quinqueflor	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	+	+
Aulacomnium palustre	·	·	·	+	·	+	1	+	+	1	+	+	1	1	1	1	1
Sphagnum compactum	·	·	·	·	·	·	·	2	+	1	+	+	1	1	2	1	2
Sphagnum fimbriatu	·	·	·	·	·	·	·	1	·	+	+	·	·	1	1	+	·
Sphagnum subsecundum	·	·	·	+	·	+	·	·	+	·	·	·	·	+	+	+	+
Sphagnum teres	·	·	·	·	·	·	·	·	+	·	·	·	·	+	+	·	+
Other species																	
Ranunculus peltatus	·	·	·	·	·	·	+	·	·	·	·	·	+	·	·	+	·
Juncus tenageia	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	+	·
Glyceria fluitan	·	·	·	·	+	·	·	·	·	·	·	·	+	·	·	·	·
Philonotis tomentella	·	·	·	·	·	·	·	·	·	·	+	+	·	+	+	+	+
Fontinalis antipyretica	·	·	·	·	·	·	·	·	·	·	·	+	+	+	+	+	+
Philonotis fontana	·	·	·	·	+	·	·	·	·	·	·	+	·	·	·	·	+
Bryum latifolium	·	·	·	·	·	·	·	·	·	+	·	·	·	·	·	+	·
Bryum alpinum	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	+	·

Other species: Characteristics: *Epilobium palustre* 1 in 1, *Sphagnum russowii* + in 17. Other species: *Juncus squarrosus* 1 in 6; *Selinum pyrenaeum* and *Calliergon stramineum* + in 16; *Gymnocolea inflat* , *Tomentypnum nitens*, *Philonotis seriata* and *Nardia scalaris* + in 17.
Localities: 1: Puerto del Lagarejo (67); 2: Manantial de las Queseras (69); 3: Arroyo de Aguas Frías (54); 4: Fuente de la Leche (56c); 5: Collado Viejo (66); 6: Fuente del Pino Blanco (70); 7: Puerto del Pico (61); 8: Circo de la Nava (19a); 9: Regajos de la Cruz (25); 10: El Quemal-Candelario (72); 11: La Covatilla (71a); 12: Puerto de Serranillos (68); 13: Cervunal (34); 14: Trochagosta (5a); 15: Fuente de Majá Baera (21); 16: Supra-Lagunas del Trampal (4f); 17: Prado de las Pozas (42).

Cluster Ba1a represents the *Eleocharito multicaulis-Rhynchosporetum albae* community, which has its optimum in the middle and upper supramediterranean bioclimatic belts (1140–1477 m asl) of the GRP (Table 7), with a restricted distribution to five peatlands in the East Gredos Sierran and Tormantos Sierran districts. This community is known from other Iberian mountains, always sporadically, both in the north and northwest and in the south −Toledo Mountains−, and seems to be exclusive to the Iberian Peninsula (Corriol, 2014; López-Sáez *et al.*, 2014b; Loidi, 2017). It is characterized by the presence of *Rhynchospora alba*. This association occurs in fragmentary stands, usually as a microhabitat within other more extensive communities (e.g. *Caricetum echinato-nigrae* and *Calluno vulgaris-Sphagnetum capillifolii*). The bryophyte layer is always thin or absent and only one *Sphagnum* species (*S. angustifolium*) can develop sparsely but always in mixtures. This pioneer acid and heliophilous community often inhabits on humid exposed peat or peaty sand, on naturally seepage-eroded areas on eroded peatlands, which also favour the presence of other heliophilous species typical of sandy substrates such as *Scirpoides holoschoenus* (Martínez-Cortizas *et al.*, 2009a). It is always present in much waterlogged peaty soils although with little vegetation, where water moves slowly but steadily, and whose chemical composition differs from nearby habitats being charged with mineral compounds. Interestingly, the areas it occupies in the GRP peatlands are subject to periodic disturbance (e.g. Arrelobo E and W, Cañada de las Trampaleras, Fuente de la Leche), mainly grazing and trampling by domestic livestock that maintain an open habitat with small herbaceous species that do not compete with *Rhynchospora alba*, which is a shade-intolerant species. Ultimately, the survival of this community seems to be related to the maintenance of the grazing regime on the GRP peatlands.

Table 5
Caricetum echinato-nigrae Rivas-Martínez (1964) 2002 in Rivas-Martínez et al. 2002
caricetosum nigrae Fernández-González & Sánchez Mata 1989
(*Caricion nigrae*, *Caricetalia nigrae*, *Scheuchzerio palustris*-*Caricetea nigrae*)

Altitude (1:10 m asl)	155	154	202	146	197	156	156	218	168	160	149	148	142	222	182	213	165	206	196	186	194
N. species	5	5	5	6	6	6	6	7	7	7	7	7	7	8	8	8	9	9	9	10	13
Peatland site	45	26	48	63	30	12	13	29	35	11	10	9	47	28	33	27	36	40	31	2	44
Relevé N.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Characteristics																					
Carex nigra	2	4	2	2	2	4	4	4	1	3	3	4	2	3	1	4	3	3	4	3	3
Carex echinata	1	2	1	1	1	2	2	1	1	2	2	1	+	2	1	2	3	2	2	1	2
Viola palustris	+	·	·	·	·	+	+	1	1	+	+	+	·	1	·	+	+	+	+	+	+
Drosera rotundifolia	·	·	·	·	·	+	+	1	+	+	+	+	+	1	·	+	+	+	+	1	+
Aulacomnium palustre	·	+	+	+	+	+	+	1	·	+	+	+	+	1	+	2	+	1	1	1	2
Sphagnum denticulatum	+	+	+	·	+	+	+	+	·	+	+	+	+	+	·	+	+	1	+	+	+
Myosotis stolonifera	.	.	.	·	.	.	.	.	·	.	.	.	.	+	·	.	.	.	.	.	.
Sphagnum contortum	.	.	.	·	.	.	.	.	·	.	.	.	.	.	·	.	.	.	.	.	+
Other species																					
Nardus stricta	·	·	1	+	1	·	·	+	·	·	·	·	1	+	1	+	·	+	+	+	+
Carum verticillatum	·	+	·	1	·	·	·	·	+	+	+	+	1	·	+	·	+	+	·	+	+
Anthoxanthum aristatum	·	·	·	·	+	·	·	·	1	·	·	·	·	·	1	·	+	·	+	1	+
Carex flacc	+	·	·	·	·	·	·	·	+	·	·	·	·	·	+	·	+	·	+	·	·
Hypericum undulatum	·	·	·	+	·	·	·	·	·	·	·	·	·	·	+	·	·	·	·	+	·

Other species: *Campylopus introflexus* + in 16; *Nardia scalaris*, *Gymnocolea inflat* and *Dichodontium pellucidum* + in 21.
Localities: 1: Corral de la Covacha (45); 2: Garganta de Bohoyo W (26); 3: Puerto del Peón (48); 4: Hoya del Gallego (63); 5: Lagunillas (30); 6: Los Pradillos (12); 7: Pico de los Trampales (13); 8: Risco de las Hoces (29); 9: Refugio del Barquillo (35); 10: Puerto del Tremedal (11); 11: Puerto de la Hoya E (10); 12: Puerto de la Hoya W (9); 13: Chorreras del Tormes (47); 14: Lagunilla del Corral (28); 15: Cuerda del Barquillo (33); 16: Garganta de Bohoyo E (27); 17: La Cepeda (36); 18: Fuente de los Cavadores E (40); 19: Hoya de las Berzas (31); 20: Refugio Hoya de Cuevas (2); 21: Los Conventos (44).

Cluster Ba1b is related to the *Sphagno-Utricularietum minoris* community, which has its optimum in the middle and upper supramediterranean bioclimatic belts (1140-1402 m asl) of the GRP (Table 8), with a very restricted distribution to a few peatlands in the East Gredos Sierran and Tormantos Sierran districts. It corresponds to distrophic and oligotrophic floating communities usually growing in small marshy ponds, although occasionally in the GRP it appears in the middle of peatlands with *Sphagnum* in the association *Caricetum echinato-nigrae* in SP and TT-type peatlands. Its presence has been reported in the Cantabrian Mountains and the Iberian range, although it is also known in central and eastern Europe (Díaz-González & Penas, 2017). It is characterized by the presence of *Utricularia minor*.

Cluster Ba2 represents the *Myosotidetum stoloniferae* association, which has been documented both in the middle and upper supramediterranean (1213–1387 m asl) and the middle and upper orosubmediterranean (1680–1815 m asl) bioclimatic belts of the GRP (Table 9), usually developing in mountain brooks, springs and shallow peatlands in the East Gredos Sierran and Tormantos Sierran districts. It has also been cited, outside the GRP, on its southern slopes in the province of Cáceres, on the same bioclimatic belts from 900 m asl onwards (Amor *et al*., 1993), and within the Iberian Central System both in its western (Serra da Estrela in Portugal) and eastern (Guadarrama range) sectors (Braun-Blanquet *et al*., 1952; Rivas-Martínez, 1963; Rivas-Martínez *et al*., 1990). This association is exclusive to the Iberian Peninsula and it is also known from other Iberian mountains such as the Iberian System and the Cantabrian Mountains (Molina, 2001). The *sedetosum lagascae* subassociation (Ba2a cluster) has its optimum in the supramediterranean belt in peatlands of the eastern sector of the GRP (Venta Rasquilla, Venta del Obispo, Media Legua), characterized by the presence of *Sedum lagascae* and the absence of some elements such as *Veronica nevadensis*, *Viola palustris*, *Epilobium obscurum*, *Festuca rivularis* or *Sagina saginoides*, which, in turn, appear in peatlands on the central sector of the GRP (Cuerda de los Canalizos, Silla del Zapatero N and S) related to the *myosotidetosum stoloniferae* (typical subassociation; Ba2b cluster) on the middle and upper orosubmediterranean belts (Table 9).

Table 6
Caricetum echinato-nigrae Rivas-Martínez (1964) 2002 in Rivas-Martínez et al. 2002
caricetosum demissae Rivas-Martínez 1964 (1–12)
ericetosum tetralicis (Rivas-Martínez 1964) Fernández-González & Sánchez Mata 1989 (13–14)
lycopodielletosum inundatae Sánchez-Mata & López-Sáez *subass. nova* (15–20)
(*Caricion nigrae, Caricetalia nigrae, Scheuchzerio palustris-Caricetea nigrae*)

Altitude (1=10 m asl)	223	219	210	191	188	174	171	167	164	151	148	140	153	150	213	190	190	165	147	140
N. species	8	8	9	6	7	8	7	13	10	13	17	13	21	20	11	6	17	15	12	12
Peatland site	5b	41	39	32	19b	37	20	51	38	1	53	52	50	49	3	6c	43	7	8	46e
Relevé N.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Characteristics																				
Carex nigra	3	2	2	2	3	2	2	3	2	2	3	3	2	3	2	3	3	2	2	4
Carex echinata	3	2	3	+	1	2	1	3	2	3	3	2	1	1	1	+	2	1	1	1
Parnassia palustris	·	·	·	·	·	·	·	+	+	·	1	1	2	1	+	+	+	+	+	·
Drosera rotundifolia	+	+	1	+	·	+	+	·	+	1	·	·	3	2	+	·	+	+	+	1
Agrostis canina	1	+	+	·	+	·	+	·	·	1	·	·	·	·	·	·	·	·	·	·
Viola palustris	+	·	+	·	+	+	·	+	+	1	+	+	+	+	·	·	+	·	+	·
Sphagnum denticulatum	+	+	1	+	+	1	+	1	+	2	2	1	3	2	+	+	+	+	+	·
Aulacomnium palustre	+	+	+	·	·	+	·	·	+	+	+	·	+	+	+	·	·	+	+	·
Sphagnum teres	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	+	·
Sphagnum subsecundum	·	·	·	·	·	·	·	·	·	·	·	·	·	·	+	·	·	+	·	·
Differential of *caricetosum demissae*																				
Carex demissa	2	1	2	1	1	1	1	3	2	1	2	4	+	1	·	·	·	·	·	·
Differential of *lycopodielletosum inundatae*																				
Lycopodiella inundata	·	·	·	·	·	·	·	·	·	·	·	·	·	·	1	1	2	1	1	1
Anagallis tenella	·	·	·	·	·	·	·	·	·	·	·	·	+	1	·	·	·	+	·	·
Calluna vulgaris	·	·	·	·	·	·	·	·	·	+	·	·	1	1	·	·	·	·	·	·
Carex binervis	·	·	·	·	·	·	·	·	·	·	·	·	1	1	·	·	·	·	·	·
Other species																				
Nardus stricta	·	+	1	1	1	1	+	1	+	1	2	1	+	+	1	1	+	1	+	+
Potentilla erecta	·	·	·	·	·	·	·	1	+	1	+	1	1	1	+	+	+	+	+	+
Anthoxanthum aristatum	·	·	·	·	·	·	·	+	·	·	1	·	·	·	+	·	+	+	·	+
Wahlenbergia hederacea	·	·	·	·	·	·	·	·	·	·	+	·	+	+	·	+	+	·	·	+
Juncus squarrosus	·	·	·	·	·	·	·	+	·	·	+	+	+	+	·	·	·	·	+	·
Luzula multiflor	·	·	·	·	·	·	·	+	·	·	1	1	+	·	·	·	·	·	·	·
Hypericum undulatum	·	·	·	·	·	·	·	·	·	·	1	·	+	+	·	·	·	·	·	+
Pedicularis sylvatica	·	·	·	·	·	·	·	·	·	·	+	+	+	+	·	·	·	·	·	·
Dactylorhiza incarnata	·	·	·	·	·	·	·	·	·	·	·	·	+	1	·	·	+	·	·	·
Carex leporina	·	·	·	·	·	·	·	+	·	·	1	2	·	·	·	·	·	·	·	·
Festuca rivularis	·	·	·	·	·	·	·	+	·	·	+	+	·	·	·	·	·	·	·	·
Gentiana pneumonanthe	·	·	·	·	·	·	·	·	·	·	·	·	1	+	·	·	·	·	·	·

More species: Characteristics: *Trichophorum caespitosum* subsp. *germanicum* + in 5; *Menyanthes trifoliata, Sphagnum angustifolium* and *S. russowii* + in 6; *Gentiana boryi* + in 16. Other species: *Betula celtiberica*, *Scutellaria minor* and *Genista anglica* + in 4; *Nardia scalaris* and *Gymnocolea inflat* + in 6; *Eleocharis quinqueflor* + in 10.

Localities: 1: Trochagosta (5b); 2: Refugio del Rey (41); 3: Fuente de los Cavadores W (39); 4: Garganta del Pinar (32); 5: Circo de la Nava (19b); 6: Gargantón (37); 7: Garganta de la Nava (20); 8: La Hiruela (51); 9: Roncesvalles (38); 10: Navamuño (1); 11: La Cebedilla W (53); 12: La Cebedilla E (52); 13: Arroyo de los Herreros N (50); 14: Arroyo de los Herreros S (49); 15: Circo de Hoyamoros (3); 16: Hoyo Malillo (6c); 17: Prado Puerto-Prado de Barbellido (43), *holotypus subass*.; 18: Supra-Laguna del Duque (7); 19: Garganta del Trampal (8); 20: Casas de la Isla (46e).

Finally, cluster BB represents the *Gentiano boryi-Trichophoretum germanici* association, very well discriminated in both the dendrogram and the PCA biplot (Figures 4, 5). This is an endemic community of the western sector of the GRP (Béjar Sierran and Tormantos Sierran districts), on the upper orosubmediterranean bioclimatic belt (1990-2215 m asl), restricted only to three peatlands (Table 10). It is characterized by the constant presence of *Trichophorum caespitosum* subsp. *germanicum* and *Carex nigra*, as part of the *Caricetum echinato-nigrae* geoseries (Sardinero, 2004; Rivas-Martínez *et al*., 2011). It is similar to the *Erico tetralicis-Trichophoretum germanici* association described in the orocantabrian supra-orotemperate peatlands of the Cantabrian Mountains (Díaz-González & Penas, 2017) in its xerophytic character, although it lacks some elements that characterise the north Iberian community (*Erica tetralix* and *Narthecium ossifragum*), and even to the *Carici echinatae-Trichophoretum caespitosae* described by Rivas-Martínez *et al.* (2002) in the Pyrenees, in which, unlike our association, the presence of *Carex echinata* is constant and that of *C. nigra* sporadic.

Table 7
Eleocharito multicaulis-Rhynchosporetum albae
C. Valle & F. Navarro ex Rivas-Martínez in Rivas-Martínez et al. 2002
(*Rhynchosporion albae*, *Scheuchzerietalia palustris*, *Scheuchzerio palustris-Caricetea nigrae*)

Altitude (m asl)	1140	1140	1297	1420	1140	1140	1420	1314	1477
N. species	6	7	7	8	9	9	10	11	12
Peatland site	23d	23g	65	56b	23e	23f	56a	64	57
Relevé N.	1	2	3	4	5	6	7	8	9
Characteristics									
Rhynchospora alba	4	4	3	2	4	3	3	2	2
Carex echinata	1	1	·	+	2	2	+	+	·
Agrostis canina	1	·	·	+	1	+	·	+	+
Drosera rotundifolia	+	+	·	·	+	·	·	·	·
Menyanthes trifoliata	·	·	·	·	+	+	·	·	·
Other species									
Scirpoides holoschoenus	+	+	2	1	·	·	1	3	1
Carum verticillatum	+	+	1	+	+	1	1	1	2
Juncus effusus	·	·	3	+	·	+	+	2	2
Juncus acutifloru	·	·	3	·	+	·	+	1	+
Lysimachia tenella	·	·	+	·	·	+	+	+	+
Wahlenbergia hederacea	·	·	·	+	·	+	+	·	1
Montia fontana subsp. *amporitana*	·	·	·	·	+	·	+	+	+
Calluna vulgaris	·	·	+	·	·	·	·	+	+
Sphagnum angustifolium	·	·	·	+	+	+	·	·	·
Nardus stricta	·	·	·	·	·	·	+	+	+
Potentilla erecta	·	+	·	·	·	·	·	·	·
Dactylorhiza elata	·	+	·	·	·	·	·	·	·
Juncus squarrosus	·	·	·	·	·	·	·	·	+

Localities: 1,2,5,6: Navalonguilla (23d–23g); 3: Arrelobo E (65); 4,7: Fuente de la Leche (56a, 56b); 8: Arrelobo W (64); 9: Cañada de las Trampaleras (57).

Conservation priority of peatland communities and threats

Table 11 shows the cumulative point-scoring ranking of peatland plant-communities in the GRP after application of the five criteria (RR regional responsibility, LR local rarity, LA local abundance, WEF wealth of its endangered flora, HV habitat vulnerability). We considered peatland plant-communities as being those formed on peaty sediments at least 30 cm deep and a carbon content of more than 15% (Martínez-Cortizas & Silva-Sánchez, 2019). Thus, a definitive list of 7 plant communities belonging to 4 phytosociological classes was considered (see the syntaxonomical scheme). In the GRP, most peatland systems are restricted to topographically favourable reliefs such as flat bottoms of high-mountain cirques, moraine ridgnes, streams and rivers (Table 1). As a result, these ecosystems occupy just a few tens of square metres at each site, and even less on the southern side of the Gredos range (Tiétar valley). However, diversity remains high at the plant community level (Sánchez-Mata, 1989; Sardinero, 2004) and also in terms of bryophyte and plant species richness (e.g. Elías *et al.*, 2006; Luceño *et al.*, 2016, 2017a, 2017b). In this regard, Gredensean peatland systems are unique ecosystems with exclusive species -such as *Meesia triquetra*, *Hamatocaulis vernicosus*, and *Senecio coincyi*- that are rare at the landscape and regional scales, in most cases occurring there in its southernmost or near-southernmost location.

The current Spanish classification idetifies a series of peatland habitat types on the basis of ecological gradients related to nutrient status and water supply, pH, lithology, characteristic species and geomorphological position (Camacho *et al.*, 2009; Martínez-Cortizas *et al.*, 2009a, 2009b, 2009c). In view of the above, as well as the scarce literature on the subject (Pizarro *et al.*, 1987; Sánchez-Mata, 1989; Sardinero, 2004; Benavent-González *et al.*, 2014; Cano *et al.*, 2017; Sánchez-Mata *et al.*, 2017), four types of acidic, minerotrophic, and oligotrophic peatland European habitats have been distinguished in the GRP (Table 11): i) transition mires, “trampales” or “tremedales” (Habitat 7140;

Caricion nigrae); ii) primocolonising communities of oligotrophic peaty soils of the *Rhynchosporion albae* (Habitat 7150); iii) supra-orotemperate raised peatlands with peat mosses (*Sphagnum* spp.) and common heather (*Calluna vulgaris*) (Habitat 7130; *Trichophorenion germanici*); an, iv) aquatic plant communities (*Sphagno-Utricularion*) with *Utricularia minor* (Habitat 3160) in small dystrophic ponds on peaty soils. All these communities and habitats are of great ecological importance, both from the standpoint of phytosociological knowledge and to determine their current state of conservation. The oligotrophic spring vegetation constituted by communities of *Myosotis stolonifera* on permanently waterlogged and peaty soils, and waters that flow at a relatively constant rate and cold temperature throughout the year (*Myosotidion stoloniferae*) could not be assigned to any specific European habitat.

Table 8
Sphagno-Utricularietum minoris Fijalkowski 1960
(*Sphagno-Utricularion, Utricularietalia intermedio-minoris, Utricularietea intermedio-minoris*)

Altitude (m asl)	1140	1402	1140	1402
N. species	8	9	9	10
Peatland site	23c	46d	23b	46c
Relevé N.	1	2	3	4
Characteristics				
Utricularia minor	2	3	3	4
Other species				
Ranunculus hederaceus	1	2	2	1
Ranunculus flammul	2	1	1	2
Lythrum portula	1	1	+	1
Juncus tenageia	1	+	+	1
Sedum lagascae	1	+	+	1
Isolepis setacea	+	+	1	+
Glyceria declinata	·	1	+	1
Veronica scutellata	·	+	+	+
Carex nigra	+	·	·	+

Localities: 1,3: Navalonguilla (23b, 23c); 2,4: Casas de la Isla (46c; 46d).

Among the species documented in the GRP peatlands, 7 bryophytes and 3 vascular plants are included in the IUCN Red List (Garilleti & Albertos, 2012; Moreno *et al*., 2019): 1 with the "critically endangered" category (CR), the aforementioned *Meesia triquetra*; *Hamatocaulis vernicosus* within "endangered" (EN) species; 4 in the "vulnerable" (VU) category, *Senecio coincyi*, *Gentiana boryi*, *Sphagnum contortum*, and *Tomentypnum nitens*; and, finall , 4 (*Aneura pinguis*, *Bryum pseudotriquetrum*, *Spiranthes aestivalis* and *Philonotis fontana*) as "near threatened" (NT). Table 11 shows that the first two Gredensean peatland plant-communities obtained in the ranking accumulate over 65% of the maximum score and correspond to transition mires communities (Habitat 7140) growing in oligotrophic and minerotrophic peatlands (*Caricion nigrae* vegetation).

The *Sedo lagascae-Eriophoretum latifolii* association has the highest score (15.3), which represents 76.5% of the maximum score. Its higher scores are achieved thanks to being an endemic community of the Iberian Central System (RR = 3) that is present only in two biogeographical Gredensean districts (LR = 3), but above all because its flora is home to species whose conservation is threatened, being classified as "critically endangered" (WEF = 4). Indeed, a moss species that characterises very well this community in the GRP is *Meesia triquetra*, typical of these nutrient-rich minerotrophic peatlands, where it usually occupies the more waterlogged central areas. However, this species has only been found in two peatlands despite 11 relevés (Table 2). This is not strange considering that its only known Iberian population until not long ago was that of Casas de la Isla (Figure 6) in the municipality of Hoyos del Espino (Infante & Heras, 2001), until Luceño *et al.* (2017a) recently contributed 4 new populations in the Gredos mountains, one of them within the GRP in the Navarredonda peatland (Figure 6). In the Iberian Peninsula, another population is known in the Aragonese Pyrenees, more than 400 km from the Gredesean ones, which in turn is aroud 700 km from the nearest European populations in the Alps (Garilleti & Albertos, 2012). Both populations of this species in the GRP are therefore threatened. In fact, *Meesia triquetra* is included in the IUCN Red List with the CR category as "critically endangered" (IUCN, 2012; Garilleti & Albertos, 2012). Bearing in mind that the population of Navarredonda is relatively large, with numerous individuals occupying an area of almost 400 m^2 (Luceño *et al.*, 2017a), it is likely that this species lived in the past in other peatlands of the GRP from which it became extinct, as in other Iberian territories (Infante & Heras, 2001). The reasons for its potential extinction could be found in the high pastoral pressure suffered by the Gredensean peatlands, as well as the associated livestock infrastructures (water troughs), the effect of cattle grazing and trampling, and even the existence of water drains (Infante & Heras, 2012). The presence of all these threats together, such as those where the *Sedo lagascae-Eriophoretum latifolii* association has been inventoried but not *Meesia triquetra* (Valle de La Vega, Umbrías, Puerto de Menga), increases the mineralisation of the water and its nutrient concentration (Boeye *et al.*, 1997), which favours certain species (e.g. *Eriophorum latifolium*) to the detriment of *Sphagnum* spp. and *Meesia triquetra*. Navarredonda and Casas de la Isla peatlands (Figure 6) suffer similar pastoral pressure (Table 1), even with important drainage in the former, so the survival of this species in both peatlands is strongly threatened (HV = 3.3).

The second position in the ranking is held by the *Gentiano boryi-Trichophoretum germanici* association (66.5% of the maximum score), which is endemic to two Gredensean mountain districts (RR = 4, LR = 3), having been reported in only 3 upper orosubmediterranean localities (Table 10; LA = 4) and hosting a species considered in the "vulnerable" category (*Gentiana boryi*; WEF = 2). Fortunately, the habitats where it is found are not very threatened (HV = 0.3) by its inaccessibility (Figure 1). Other high scores (56.5-52.5% of the

Table 9
Myosotidetum stoloniferae Br.-Bl., P. Silva, Rozeira & Fontes 1952
(*Myosotidion stoloniferae*, *Montio-Cardaminetalia*, *Montio-Cardaminetea*)

Altitude (m asl)	1387	1387	1233	1213	1815	1720	1680
N. species	6	7	7	9	12	12	13
Peatland site	60a	60b	59	62	24	15	16
Relevé N.	1	2	3	4	5	6	7
Characteristics							
Myosotis stolonifera	3	2	2	1	3	2	3
Stellaria alsine	1	1	1	+	2	+	1
Montia fontana subsp. *amporitana*	4	3	3	4	3	4	2
Carex echinata	·	·	+	·	+	+	1
Epilobium obscurum	·	·	·	·	3	3	+
Veronica nevadensis	·	·	·	·	1	2	2
Viola palustris	·	·	·	·	2	2	1
Sagina saginoides	·	·	·	·	1	+	+
Festuca rivularis	·	·	·	·	+	·	+
Lobelia urens	·	·	·	+	·	·	·
Differential *sedetosum lagascae*							
Sedum lagascae	3	2	2	1	·	·	·
Other species							
Glyceria declinata	·	·	1	+	+	+	+
Nardus stricta	+	·	·	·	1	1	+
Sagina procumbens	1	+	+	·	·	·	·
Bryum argenteum	·	·	·	·	1	1	+
Galium broterianum	·	+	·	+	·	·	·
Epilobium collinum	·	+	·	+	·	·	·
Poa supina		·	·	·	·	1	+
Hypericum undulatum	·	·	·	+	·	·	·

Localities: 1,2: Venta Rasquilla (60a, 60b); 3: Venta del Obispo (59); 4: Media Legua (62); 5: Cuerda de los Canalizos (24); 6: Silla del Zapatero S (15); 7. Silla del Zapatero N (16).

maximum score) correspond to three associations for different reasons: i) the *Calluno vulgaris-Sphagnetum capillifolii* community (Habitat 7130) limited to three localities (Table 3; LA = 3); ii) the *Eleocharito multicaulis-Rhynchosporetum albae* association (Habitat 7150) present in only five peatlands and two biogeographical districts (Table 7; LR = 3, LA = 3); and, iii) the *Sphagno-Utricularietum minoris* community (Habitat 3160), which, like the previous one, is present in two districts but in only two peatlands (Table 8; LR = 3, LA = 4). The lowest-ranked community in the ranking is the *Caricetum echinato-nigrae* association (Habitat 7140), by far the most abundant in the GRP peatlands.

The main conservation problem of Gredensean peatlands is related to livestock (Figure 6). The maximum Anthropic Pressure (AP) values are reached in 15 peatlands (Table 1), mostly between the upper supramediterranean and lower orosubmediterranean bioclimatic belts (1314–1700 m asl), with the exception of 3 in the middle supramediterranean (1087–1235 m asl) and 1 in the middle orosubmediterranean (1680 m asl). With AP values of 3 there are 9 peatlands, with the same altitudinal distribution as the above-mentioned ones (Table 1).

Most peatlands have been subjected to excessive grazing by both domestic stock and wild bovids such as the Iberian wild goat (*Capra pyrenaica* subsp. *victoriae*), which probably leads to the disappearance of some species. It has been argued that high ungulate densities mediate an impoverishment of habitat quality, decreasing shrub cover and increasing the exposure of peatland ecosystems to further perturbances (Martínez, 1989). In the GRP the densities of Iberian wild goat are high in the areas where many peatlands are located (Pérez *et al.*, 2002). Most damage by bovids -domestic and wild- occurs in summer, when the animals even sleep in peatlands, mainly affecting the aerial parts of the peatland plants (Figure 6).

Although most studies have neglected other types of ungulate damage such as trampling, this is probably the greatest problem that threatens Gredensean peatlands, especially those located in the supramediterranean belt (e.g. Corral de la Covacha, Chorreras del Tormes, Navarredonda, Puerto de Menga, Venta del Obispo, Venta Rasquilla, Arrelobo E, Casas de la Isla), in which, being wetlands, pastures are abundant and they are usually fenced off for private or communal use for livestock (Figure 6). This type of management has a very high impact on peatland ecosystems through trampling and grazing, which seriously threatens their future conservation (Perrino *et al*., 2021). All this is clearly evidenced by the limited distributions of *Drosera rotundifolia*, *Erica tetralix*, *Gentiana boryi*, *Menyanthes trifoliata*, *Sphagnum* spp., *Trichophorum caespitosum* subsp. *germanicum* and *Utricularia minor*, among others, which require oligotrophic conditions rather than the eutrophic conditions often found in Gredensean peatlands.

Table 10
Gentiano boryi-Trichophoretum germanici Sardinero & Rivas-Martínez 2011
(*Caricion nigrae*, *Caricetalia nigrae*, *Scheuchzerio palustris-Caricetea nigrae*)

Altitude (m asl)	2215	2215	2215	2215	2215	1990	1990	2208
N. species	7	8	8	9	9	9	9	10
Peatland site	4c	4a	4e	4b	4d	6a	6b	18
Relevé N.	1	2	3	4	5	6	7	8
Characteristics								
Trichophorum caespitosum subsp. *germanicum*	5	4	4	4	5	5	5	3
Carex nigra	2	2	1	1	2	1	2	2
Carex echinata	+	2	1	1	1	+	+	·
Gentiana boryi	1	+	·	1	1	2	1	1
Agrostis canina	1	1	+	+	1	·	·	+
Viola palustris	·	·	·	·	·	+	+	·
Other species								
Nardus stricta	1	1	2	2	1	+	1	1
Bryum latifolium	+	+	·	+	+	+	·	+
Aulacomnium palustre	·	+	+	+	1	·	+	+
Narcissus bulbocodium s.l.	·	·	+	·	·	1	+	+
Polytrichum juniperinum	·	·	+	+	+	·	·	+
Festuca iberica	·	·	·	·	·	+	+	·
Sphagnum teres	·	·	·	·	·	·	·	+

Localities: 1-5: Above Lagunas del Trampal (4a-4e); 6-7: Hoyo Malillo (6a, 6b); 8: Corral del Diablo (18).

Of all studied peatlands, we would highlight two: Casas de la Isla and Navalonguilla, where 3 and 4 of the associations described in this work have been recorded, respectively. This may be due to two reasons. Firstly, it may be due to the age of the peatlands. Table 12 shows the date of peat inception in the 10 peatland for which radiocarbon dating has been carried out. Casas de la Isla is the oldest, having been formed almost 7 millennia ago, with a peaty deposit of almost 2 m. This age would have allowed the development of a very diverse and evolved peatland ecosystem in the upper supramediterranean belt (1402 m asl). Garganta del Trampal is a similar peatland, with a slightly younger age (6 thousand years), although its location on the lower orosubmediterranean belt (1470 m asl) probably limited the development of certain plant associations with a supramediterranean optimum. Therefore, the formation of both peatlands occurred during the mid-Holocene thermal maximum, while Fuente de la Leche peatland was formed during the early late Holocene ~3000 cal BP in a relatively humid stable period (López-Sáez *et al.*, 2014a). On the other hand, Puerto de Serranillos and Navarredonda peatlands were formed ~1860 and 1660 cal BP, respectively, the former in the middle orosubmediterranean belt and the latter in the upper supramediterranean one. Subsequently, Puerto del Pico and Fuente del Pino Blanco were formed ~600 cal BP coinciding with warm and humid conditions associated with the Late Medieval Warm Episode, while those of Manantial de las Queseras and Arroyo de Aguas Frías ~389 and 207 cal BP, respectively, in relation with cooler and wetter conditions within the Little Ice Age (López-Sáez *et al.*, 2018a, 2019).

Secondly, Navalonguilla peatland was formed at a similar date to that of Puerto de Serranillos, although on the middle supramediterranean belt (1140 m asl), and therefore it is home to plant communities with an optimum on this belt like Casas de la Isla. Although Navalonguilla peatland is not as old as the previous one and its peaty deposit is smaller (100 cm), it suffers less pastoral pressure than many other peatlands at the same altitude, and in fact its environment is sustainably managed. Ultimately, Casas de la Isla and Navalonguilla peatlands can be considered as "peatland complexes" as they are home to diverse vegetation communities (mesotopes) that are part of larger spatial units that are interconnected by a hydrological circuit of surface waters (Martínez-Cortizas & Silva-Sánchez, 2019).

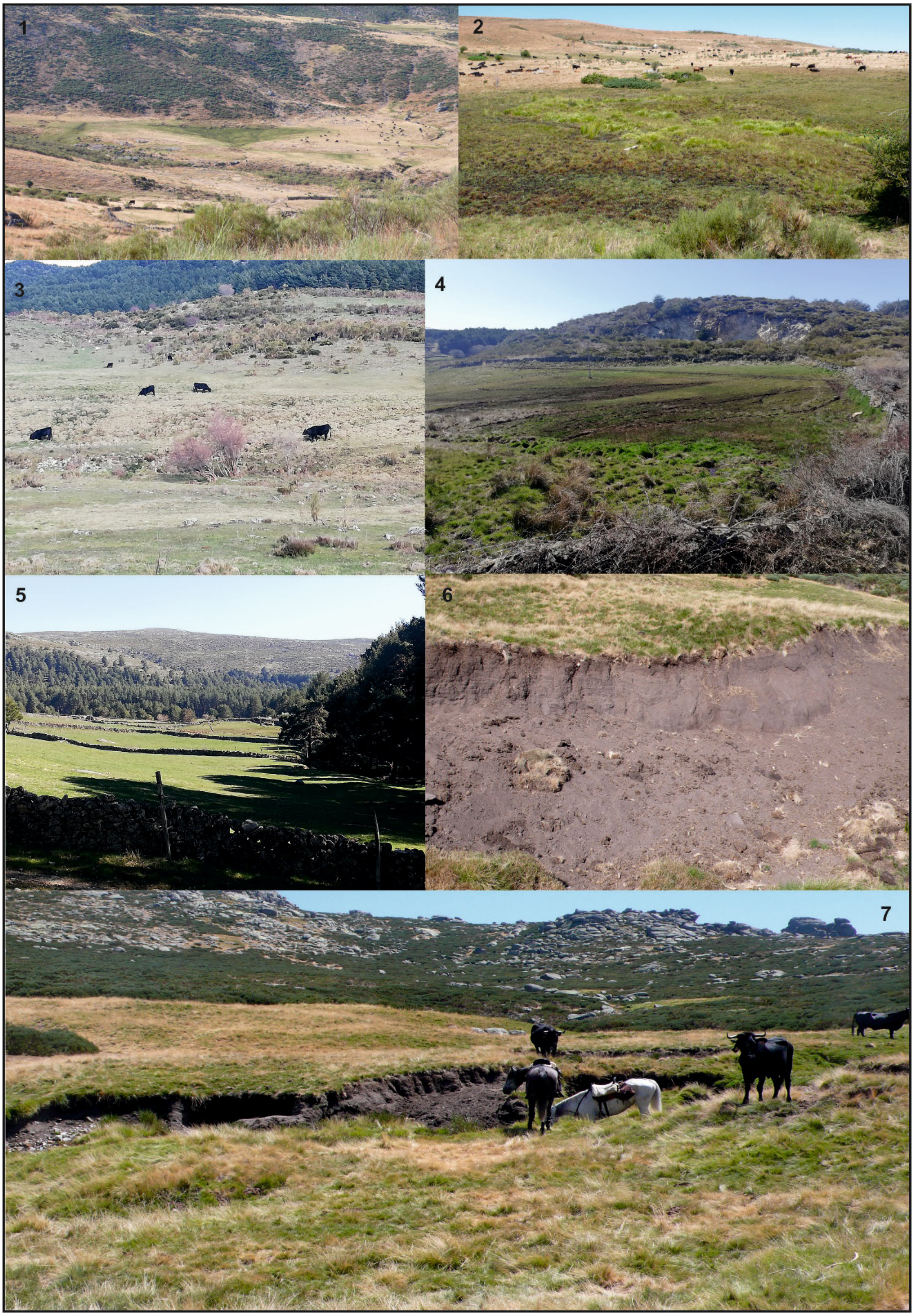

Figure 6. Some examples of the main threats to the peatlands of the Gredos Regional Park: a) Overgrazing and floristic impoverishment (1, Corral de la Covacha; 2, Fuente de la Leche; 3, Venta Rasquilla); b) Navarredonda (4) and Casas de la Isla (5) peatlands are home to one of the few known populations of *Meesia triquetra* in the GRP, a species included in the IUCN Red List with the CR category as "critically endangered". Both are subject to very high pastoral pressure in the form of grazing and trampling by domestic livestock, which puts this species at serious risk. The second of the two peatlands is also drained; c) erosion and exposure of extensive areas of bare peat (6, Collado Viejo; 7, Puerto del Peón).

Table 11. Cumulative point-scoring ranking of peatland plant-communities in the Gredos Regional Park after application of the five criteria (RR regional responsibility; LR local rarity; LA local abundance; WEF wealth of its endangered flora; H habitat vulnerability) and their adscription to habitat codes from Habitat Directive (HD).

Order	Plant community	RR	LR	LA	WEF	HV	Total	HD
1	*Sedo lagascae-Eriophoretum latifolii*	3	3	2	4	3.3	15.3	7140
2	*Gentiano boryi-Trichophoretum germanici*	4	3	4	2	0.3	13.3	7140
3	*Calluno vulgaris-Sphagnetum capillifolii*	2	2	4	2	1.3	11.3	7130
4	*Eleocharito multicaulis-Rhynchosporetum albae*	2	3	3	0	3.2	11.2	7150
5	*Sphagno-Utricularietum minoris*	1	3	4	0	2.5	10.5	3160
6	*Myosotidetum stoloniferae*	2	3	2	0	1.8	8.8	-
7	*Caricetum echinato-nigrae*	2	1	1	2	1.5	7.5	7140

Table 12. Estimated date of peat inception in peatlands of the GRP. ^{14}C data (Age BP / Before Present) for the deepest peat (cm) level were calibrated (cal BP) using CALIB 8.2 software with the INTCAL20 curve. Calibrated radiocarbon dates are given as cal BP.

Peatland	^{14}C Age BP	Calibrated range (cal BP)	Median probability (cal BP)	Depth (cm)	Reference
Casas de la Isla	5960 ± 70	6976–6635	6795	194	Franco-Múgica (1995)
Garganta del Trampal	5270 ± 90	6283–5777	6064	115	Atienza (1993)
Fuente de la Leche	2875 ± 35	3144–2878	3001	125	Robles-López *et al.* (2018)
Puerto de Serranillos	1938 ± 35	1973–1743	1860	120	López-Merino *et al.*(2009)
Navalonguilla	1920 ± 90	2098–1611	1842	100	Franco-Múgica (1995)
Navarredonda	1770 ± 80	1870–1420	1660	360	Franco-Múgica (1995)
Puerto del Pico	575 ± 30	644–529	601	114	López-Sáez *et al.* (2016)
Fuente del Pino Blanco	635 ± 30	661–554	600	98	Robles-López *et al.* (2018)
Manantial de las Queseras	318 ± 25	458–307	389	39	López-Sáez *et al.* (2021)
Arroyo de Aguas Frías	230 ± 30	420–146	207	50	Camarero *et al.* (2019)

Syntaxonomical scheme

MONTIO-CARDAMINETEA Br.-Bl. & Tüxen ex Br.-Bl. 1948
Montio-Cardaminetalia Pawlowski in Pawlowski, Sokolowski & Wallisch 1928
Myosotidion stoloniferae Rivas-Martínez, T.E. Díaz, F. Prieto, Loidi & Penas 1984
Myosotidetum stoloniferae Br.-Bl., P. Silva, Rozeira & Fontes 1952
myosotidetosum stoloniferae
sedetosum lagascae Rivas-Martínez & Sánchez-Mata 1989

OXYCOCCO-SPHAGNETEA Br.-Bl. & Tüxen ex Westhoff, Dijk & Passchier 1946
Erico tetralicis-Sphagnetalia papillosi Schwickerath 1940 em. Br.-Bl. 1949
Trichophorenion germanici Rivas-Martínez, T.E. Díaz, F. Prieto, Loidi & Penas 1984
Calluno vulgaris-Sphagnetum capillifolii F. Prieto, M.C. Fernández & Collado 1987

SCHEUCHZERIO PALUSTRIS-CARICETEA NIGRAE Tüxen 1937 Rivas-Martínez & al. 2002 nom. mut. propos.
Scheuchzerietalia palustris Nordhagen 1936
Rhynchosporion albae Koch 1926
Eleocharito multicaulis-Rhynchosporetum albae C. Valle & F. Navarro ex Rivas-Martínez in Rivas-Martínez et al. 2002
Caricetalia nigrae Koch 1926 em. Br.-Bl. 1949 Rivas-Martínez et al. 2002 nom. mut. propos.
Caricion nigrae Koch 1926 em. Klika 1934 Rivas-Martínez et al. 2002 nom. mut. propos.
Caricetum echinato-nigrae Rivas-Martínez (1964) 2002 in Rivas-Martínez et al. 2002
parnassietosum palustris Rivas-Martínez 1964
caricetosum nigrae Fernández-González & Sánchez Mata 1989
caricetosum demissae Rivas-Martínez 1964
ericetosum tetralicis (Rivas-Martínez 1964) Fernández-González & Sánchez Mata 1989
lycopodielletosum inundatae Sánchez-Mata & López-Sáez *subass. nova*
Sedo lagascae-Eriophoretum latifolii Rivas-Martínez in Rivas-Martínez, Fernández-González & Sánchez-Mata 1986
Gentiano boryi-Trichophoretum germanici Sardinero & Rivas-Martínez 2011

UTRICULARIETEA INTERMEDIO-MINORIS Pietsch 1965
Utricularietalia intermedio-minoris Pietsch 1965

Sphagno-Utricularion Müller & Görs 1960
Sphagno-Utricularietum minoris Fijalkowski 1960

Floristic appendix

Those species not recognized in the reference floras above mentioned (Nomenclature subchapter) are listed here, including the protologue.

Betula celtiberica Rothm. & Vasc. in Bol. Soc. Brot. ser 2, 14: 147 (1940)
Trichophorum caespitosum subsp. *germanicum* (Pallas) Hegi in Ill. Fl. Mitt.-Eur. 2: 25 (1908)

Acknowledgements

This work was funded by the projects FINICES-PID2020-117685, LATESICE-CGL2016-78380-P and MED-REFUGIA-RTI2018-101714-B-I00 (Plan Nacional I+D+I, Spanish Ministry of Economy and Competitiveness), as well as by the Research Grants Program from the Diputacion of Ávila (Institucion Gran Duque de Alba, 2020). R. Luelmo-Lautenschlaeger is funded by a Formación del Profesorado Universitario (FPU) grant (Spanish Ministry of Education, Culture, and Sports).

Authorship contribution

JALS: Conceptualization, Data curation, Formal analysis, Research, Methodology, Management of the project, Resources, Software, Visualization, Writing (first draft, review and editing).
RLL: Formal analysis, Research, Visualization, Writing (review and editing).
RMC: Conceptualization, Data curation, Methodology, Resources, Writing (first draft, review and editing)
JP: Data curation, Methodology, Writing (review and editing).
DSM: Conceptualization, Supervision, Writing (first draft, review and editing).
ELN: Research, Writing (review and editing).

Conflict of interest

None.

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