Identification and classification of unmapped blanket bogs in the Cordillera Cantábrica, northern Spain

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SUMMARY

Blanket bogs are rare types of peatland that are recognised internationally for important habitat provision, and nationally and locally as important carbon stores and sinks. These ecosystems enjoy particular attention and protection within the European Union, but gaps highlighted in the Spanish national peatland inventory leave many areas of Spain's blanket bog habitat unprotected and exposed to anthropogenic pressures such as livestock or wind farm development. This research identifies and offers classification of four currently unmapped areas of blanket bog located in the Cordillera Cantábrica (north Spain) on the administrative boundaries between the regions of Cantabria and Castilla y León. Peat depth was surveyed on a 15 m spaced grid at all sites and mesotope units were defined from topography and hydrological flow patterns. Two sloping and two mound blanket bogs were identified containing a range of bog and fen mesotope units. Maximum peat depth at the five sites ranges from 1.78 to 2.82 m covering an area of 43 ha of blanket bog (> 30 cm peat depth). The survey also estimates that more than 300,000 m³ of peat has accumulated across all sites. This study adds significantly to the known global distribution of blanket mire and suggests that an urgent update of national peatland inventories is needed more widely, not least in Spain, to identify currently unmapped areas of blanket bog. The approach used here can be employed wherever blanket mires occur in the world to promote their designation and the preservation of peatland diversity and carbon storage.

KEY WORDS: blanket mire, fen, mesotope, peat depth, wind farms

INTRODUCTION

Blanket bogs are a comparatively rare form of rain-fed, or ombrotrophic, peatland habitat type that is internationally recognised as being of global significance (Lindsay *et al.* 1988, Tallis 1998). It is, for example, a 'Habitat of European Interest', requiring the best examples to be protected under the European Union Habitats Directive (92/43/EEC), particularly as the latest assessment of such habitats in the European Union indicates that bogs, mires and fens "have the highest proportion of unfavourable assessments" (European Topic Centre on Biological Diversity 2008). This ecosystem type is also important for its contribution to regional and national carbon budgets because peatlands represent the largest global store of terrestrial soil carbon (Limpens *et al.* 2008) and most undisturbed peat-forming systems act as ongoing carbon sinks, taking CO_2 from the atmosphere and storing it on potentially millennial timescales (Strack *et al*. 2008). However, such peatland systems also release CH_4 −a more powerful greenhouse gas but with a substantially shorter lifespan in the atmosphere than CO_2 (Lelieveld *et al.* 1998). On balance, therefore, peat bogs (*i.e.* ombrotrophic peatlands) are considered to be either climate neutral or mildly climate cooling when in their natural state (Frolking *et al.* 2006), but blanket bogs are widely recorded as being in degraded condition with a loss of keystone species (Heras & Infante 2003) and they may now be acting as substantial carbon sources (Yallop *et al.* 2010). The conservation and restoration of these areas is, therefore, key to preserving peatland biodiversity and may help to mitigate the impacts of climate change (Joosten *et al.* 2017).

A global inventory of blanket bogs is notoriously difficult to compile but based on climatic suitability and terrain the total may amount to around 10 million ha (Lindsay *et al.* 1988). Recognised areas of blanket bog exist predominantly in oceanic climates characterised by high atmospheric moisture content and precipitation (>1,000 mm yr^{-1}), low average temperatures (< 15 °C) and low seasonal temperature variability (Lindsay *et al.* 1988). In Europe, blanket

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bogs are found mainly in the United Kingdom, Ireland and Norway (Lindsay 1995), with some limited occurrence in Sweden, France and Spain (Joosten *et al.* 2017). The majority of the blanket bogs identified and classified in Spain are located in Galicia (Castillo *et al.* 2001) and Asturias (European Commission 2018, Pontevedra-Pombal *et al.* 2017). In the eastern part of the Cordillera Cantábrica there are currently only two designated blanket bogs: Zalama in the Basque Country (Heras 2002) and Montes de Valnera Site of Community Interest (SCI) in Castilla y León administrative region (European Commission 2018). However, a number of additional areas of blanket bog are indicated to be present on the boundaries between the administrative regions of Cantabria and Castilla y León (Ramil-Rego & Rodríguez-Guitián 2017, Heras & Infante 2018) but these are not shown in the most recent inventory of Iberian peatlands (Pontevedra-Pombal *et al.* 2017). As these areas lie on the boundary between two or more regions, the classification, designation and management of such areas requires inter-regional government agreement and collaboration. Regional administrations have different approaches to peatland habitat classification and there is often a lack of agreement in their protection and management. These areas also represent an extremely small proportion of the overall administrative regions and allocation of funding for these limited features is often not considered economically worthwhile. However, the restoration of Zalama blanket bog in Bizkaia (Basque Country) supported by the LIFE + project "Ordunte Sostenible" is an example of successful collaboration.

As well as being characteristically ombrotrophic with an acidophilous vegetation, blanket bogs are distinguished from other ombrotrophic peatland types by morphology. While the gross morphology of all other ombrotrophic peatland systems is determined almost solely by the accumulated mass of peat (in some cases combined with a core of frozen water), the gross morphology of a blanket bog is determined more by the shape of the underlying terrain than by depth of accumulated peat (Lindsay 1995). Specifically, blanket bog forms as a relatively extensive and continuous mantle of ombrotrophic peat draped over hill summits and slopes (Lindsay 2016). This may embrace whole landscapes, where distinct hydrological entities (mesotopes) fuse to form larger blanket mire complexes (macrotopes; Ivanov 1981) typically consisting of linked ombrotrophic bog and minerotrophic fen mesotopes. Blanket bogs are therefore often classified at mesotope level (watershed (i.e. hill summit), spur, valleyside, saddle mire, and watershed–valleyside; Ivanov 1981, Lindsay 2010) but macrotope classifications can also be adopted to describe the wider landscape units (*e.g.* sloping and mound blanket bog, and plane bog; Joosten *et al.* 2017).

Degradation of blanket bogs can arise from a combination of natural and anthropogenic factors including wildfire (Yeloff *et al.* 2006), peat extraction (Castillo *et al.* 2001), drainage (Holden *et al*. 2006), prescribed burning (Yallop & Clutterbuck, 2009), overgrazing (Castillo *et al.* 2001), commercial forestry (Lindsay *et al.* 1988) and wind farm infrastructure (Wawrzyczek *et al.* 2018). In northern Spain, peat extraction was widely undertaken in the last century and in some areas, such as Puerto de Tornos, entire accumulations of peat have been removed (Heras & Infante 2008). In addition, grazing livestock and associated management including drainage (Castillo *et al.* 2001) and vegetation burning present ongoing pressures (Heras 2002), while more recently there has been an increase in the installation of wind farms (Castillo *et al.* 2001, Heras & Infante 2008). For some blanket bogs in Galicia, wind farm infrastructure has resulted in altered vegetation structure as well as a degree of habitat loss (Fraga *et al.* 2008), whereas in the regions of Navarra and the Basque Country several blanket bogs have been entirely removed by such installations (Heras & Infante 2008).

Erosion of damaged peatland surfaces ultimately drives the loss of peat and at Zalama, despite its protected status, 50 % of the original peatland surface has been eroded, changing the morphology and functioning of the ecosystem (Heras 2002). While Zalama is now protected and undergoing restoration, non-designated and unprotected peatland areas located only 500 m from Zalama continue to be trampled by livestock and to erode. Rates of erosion measured over a period of two months in unprotected areas exposed to livestock (Chico *et al*. unpublished data) were greater than the annual mean rate of peat erosion reported from erosion pin studies across the UK (Evans & Warburton 2007).

Despite the importance of blanket bog, a number of areas in northern Spain currently remain unmapped and, without protection, face exposure to increased anthropogenic pressures. Identification of further areas of blanket bog is key to improving our understanding of the geographical range of this peatland habitat and also to enable protective and restorative measures to be instigated. This study aims to identify and classify four areas of currently unmapped blanket bog in the administrative regions of Cantabria and Castilla y León and updates the classification for Zalama blanket bog between the Basque Country and Castilla y León regions.

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METHODS

Study areas

The geographical scope of the present study focuses on a section of the Cordillera Cantábrica between the Montes de Ordunte and Puerto de Estacas de Trueba on the boundaries of the regions of Cantabria, Castilla y León and the Basque Country (Figure 1). The peaks of the mountain chain here typically range in altitude from 1,100 to 1,700 m above sea level (masl), with an annual mean temperature of 7.6 °C and annual precipitation > 1,600 mm (Heras 1990). Precipitation occurs on 200 days per year and there is no dry season as occult precipitation is consistent throughout the year from low cloud (Heras & Infante 2003).

Areas of the Cordillera Cantábrica with climate suitable for blanket bog were identified using climatic variables (Lindsay *et al*. 1988) obtained from the global climate data model WorldClim (Hijmans *et al*. 2005). Digital elevation models (DEM) at 27 m resolution and colour aerial photography from 2017 were acquired from Mapas Cantabria (2017) and Geoeuskadi (2017) and then used to identify areas of visible exposed peat and pools of water with likely ombrotrophic status based on topographical location. Areas identified with pools but no exposed peat visible in aerial photography were found on subsequent field survey to be non-peat habitats. No intact blanket bogs were identified in the area examined.

Four currently unmapped areas of potential blanket bog were identified at Ilsos de Zalama, Motas del Pardo, Collado de Hornaza and La Marruya (Figure 1). The designated Zalama blanket bog (Heras 2002; Figure 1) was also included in the present study and the peatland classification of the site was updated. The common peat-forming species *Eriophorum vaginatum, Eriophorum angustifolium* and *Sphagnum* spp. are present at all four sites within a more diverse vegetation including *Calluna* spp., *Erica* spp. and *Vaccinium myrtillus,* but with the exception of Zalama which is under restoration management, all sites have significant areas of exposed and visibly eroding peat (Figure 2).

Peat depth and extent

A 15 m systematic square grid of points was created for each of the areas of peatland extending 50 m beyond the limit of visible exposed peat. Peat depth was measured at all points (Table 1) in July 2017 using 1 m long sections of connectable, threaded steel rod (8 mm in diameter). The location of survey points was identified in the field using a Garmin GPSMAP64 handheld GNSS reporting an accuracy of ± 3 m, and additional 15 m survey grid locations were added where peat was found to extend beyond the sample locations. Peat cores were collected from each site and the depth determined using the auger was typically within 2 cm of the depth estimated using a rod prior to core extraction.

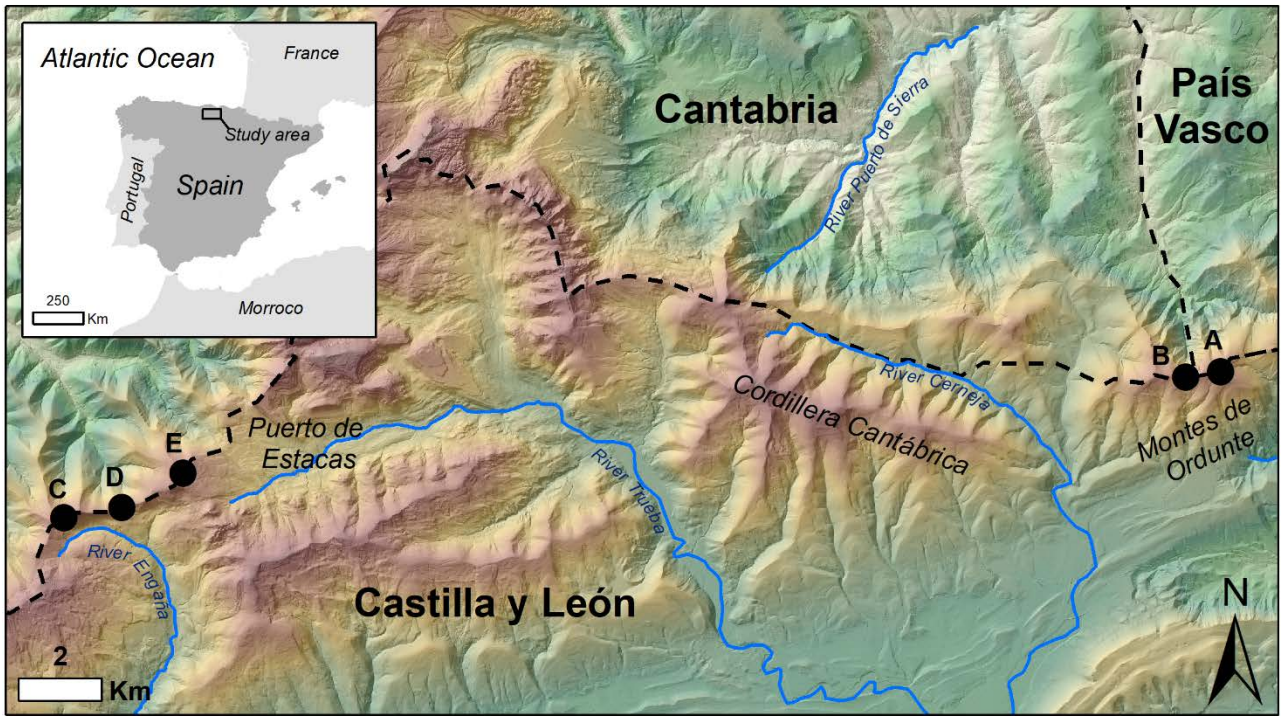

Figure 1. Location of study areas in Cantabria, Basque Country and Castilla y León administrative regions: A) Zalama; B) Ilsos de Zalama; C) La Marruya; D) Collado de Hornaza; E) Motas del Pardo.

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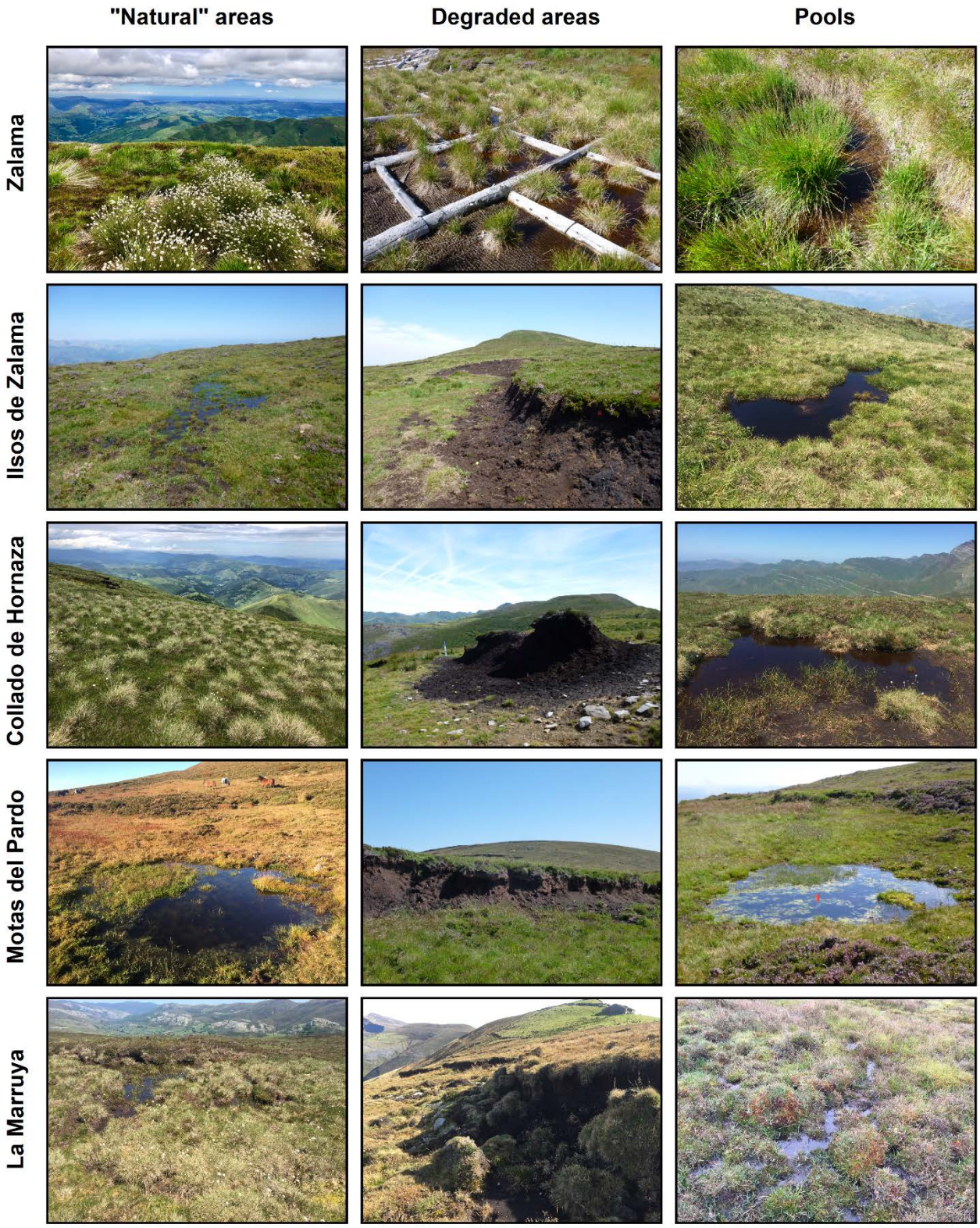

Figure 2. Ground level photographs of each site showing the “natural” area, degraded area and pools.

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Peat depth measurements were interpolated at each site using a spline algorithm in ArcGIS. A minimum peat depth of 40 cm was used to delineate the main body of the peatland (Cruickshank & Tomlinson 1990) and peat depth 30–40 cm was categorised as the peatland margin. The volume of peat mapped at each site was calculated from all interpolated data (i.e. from all areas where peat depth > 0 cm).

Macrotope and mesotope classification

Each peatland was defined initially at macrotope level (Ivanov 1981), the macrotope being defined and delimited by the landscape expanse possessing a continuous extent of peat over 40 cm. Hydrology tools in ArcGIS were then used to derive water surface flow from the digital elevation model (DEM) which enabled interpretation of individual mesotope units (Ivanov 1981, Lindsay 2010) within the overall macrotope complex from hydrological patterns. All GIS analyses were undertaken using ArcGIS 10.3.1.

RESULTS

Peat depth and extent

The maximum peat depth measured across all sites ranged from 1.73 m at La Marruya to 2.82 m at Zalama, and the collective expanse of peat greater than 40 cm deep covers a total area of 25.8 ha (Table 1, Figure 3). If areas with a minimum of 30 cm of peat are included, the total area increases to 43 ha, and the total volume of peat accumulated across all sites collectively is greater than 300,000 m^3 (Table 1).

Macrotopes and mesotopes

For Zalama and Motas del Pardo, the topographical location of the main peat body (macrotope) is characteristic of mound blanket bog, and Collado de Hornaza and La Marruya are characteristic of sloping blanket bog. All four of these blanket bogs have hill summits (watershed components at mesotope level; Figure 4), clearly indicating ombrotrophic status.

Table 1. Characteristics of the studied blanket bogs

Site	Zalama	Ilsos de Zalama	Collado de Hornaza	Motas del Pardo	La Marruya
Characteristics					
Altitude (masl)	1,330	1,280	1,280	1,390	1,360
Maximum peat depth (m)	2.82	2.16	2.75	2.65	1.73
Survey area (ha)	21.37	7.16	7.28	49.50	11.30
Survey points	225	81	84	516	125
Peat extent (ha; >40 cm depth)	6.5	3.2	3.1	10.9	2.1
Peat extent (ha; >30 cm depth)	9.9	4.3	4.2	20	4.6
Peat volume (m^3)	74,341	40,127	34,747	153,198	35,850
Macrotopes	Mound blanket bog	Blanket bog	Sloping blanket bog	Mound blanket bog	Sloping blanket bog
Mesotopes					
Watershed	√		√	√	√
Spur	√				√
Saddle mire	√	√			
Valleyshed				√	
Fen	√	√	√	√	
Status and anthropogenic pressures					
Designated	√				
Restored	√				
Unprotected		√	√	√	√
Prescribed burning			√	√	√
Livestock type	None	Cattle, horses, goats	Cattle, horses	Cattle, horses	Cattle, horses

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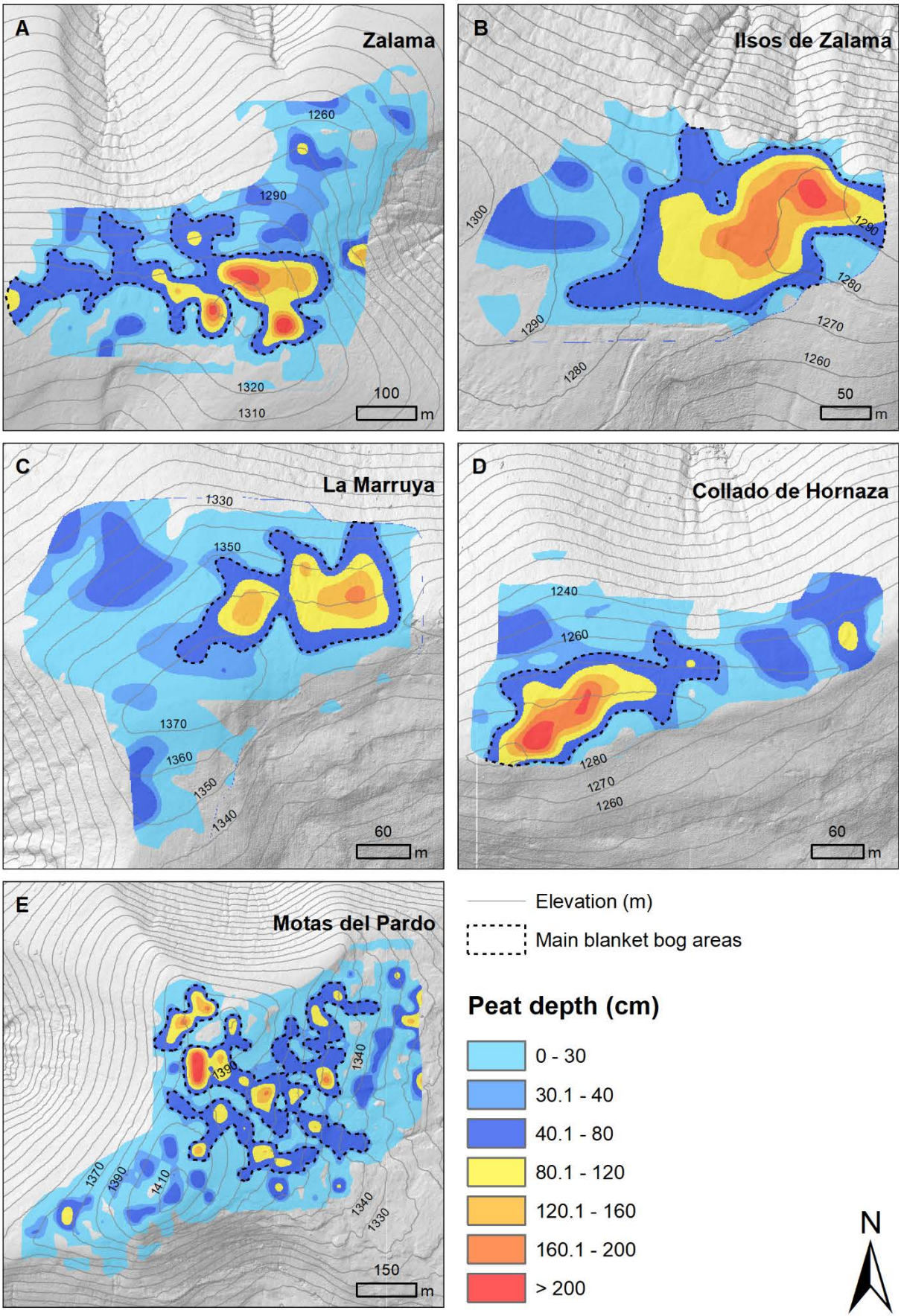

Figure 3. Peat depth and extent of main blanket bog area in each study site.

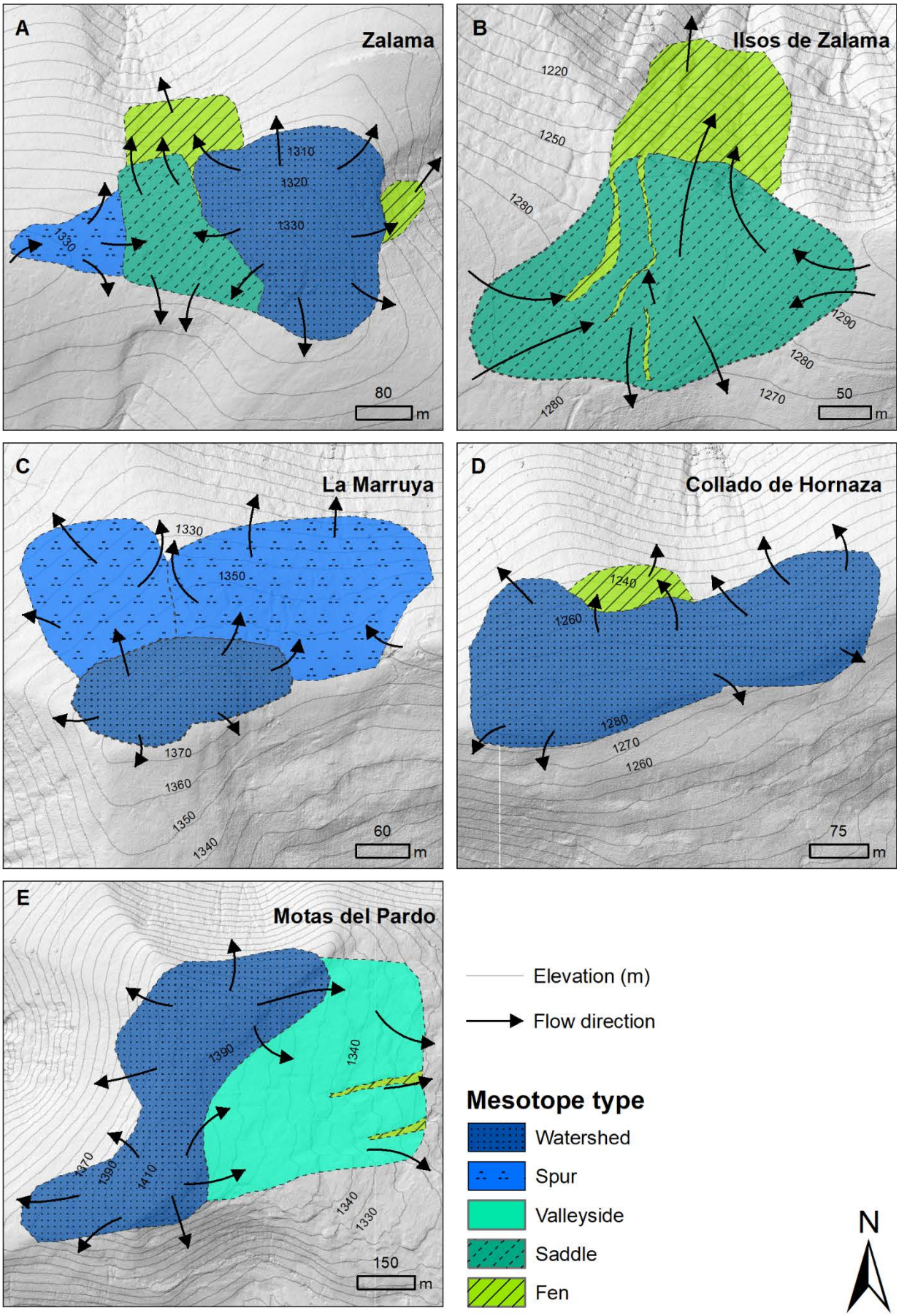

Figure 4. Mesotope units in the new blanket bogs and Zalama.

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Ilsos de Zalama is a saddle mire where a single mesotope predominates and thus the macrotope and mesotope are almost interchangeable (Figure 4).

With the exception of Zalama which is protected by a fence, numerous livestock graze each site, and at Motas del Pardo, Collado de Hornaza and La Marruya recent prescribed burn scars (occurring since aerial photographic capture in 2014) were visible on the surrounding slopes in 2017.

DISCUSSION

This study has identified and classified four new areas of blanket bog on the borders of Cantabria and Castilla y León in the Cordillera Cantábrica. In addition, new information concerning the extent, depth of peat, and mesotopes at Zalama blanket bog on the boundary between the Basque Country and Castilla y León administrative regions has been provided. For Spain, where peatlands cover only 0.07 % of the land surface (Tannerberger *et al.* 2017), the area of blanket bog mapped (43 ha) highlights the importance of the Cordillera Cantábrica for admittedly small, but geographically highly significant, examples of a globally rare and important habitat. If edge-of-range examples of a habitat or species are lost, the impact on the total natural range and perception of that range is arguably much greater than loss of an example lying within the main centre of distribution. This is a particularly important factor to consider given that 'favourable conservation status' within the European Union (EU) Habitats Directive (92/43/EEC) requires that the *natural range* of a listed habitat is stable or increasing.

Loss of the albeit small area of Spanish blanket bogs would represent a major reduction in the apparent natural range of this habitat within Europe, shifting the perceived southern limit of Atlantic blanket bog as far north as Brittany in north–west France (Julve & Muller 2017). As such, Spain's blanket bogs have a significance which belies their limited scale. They provide highly distinctive ecotones which display gradients from tundra-like conditions to habitats more typical of the Iberian Peninsula and thus result in particularly unusual species assemblages (Heras 1990). In addition, given that wholesale loss of peatland habitat is acknowledged to have taken place at various localities across the Cordillera Cantábrica (Heras & Infante 2008), the remaining sites may provide the only supply of appropriate vegetation for any further attempts at habitat restoration.

Furthermore, their isolated nature offers the potential for development of localised genotypes within otherwise more widespread blanket bog species, thus highlighting the need to consider use of local vegetation for restoration works while also potentially adding to overall genetic diversity within the otherwise relatively limited range of species characteristic of Atlantic blanket bog. The unique nature of any peat archive also means that these isolated sites, sitting as they do at what is probably the edge-of-range for Atlantic blanket bog habitat, most likely store the best available, and irreplaceable, record of vegetation history for the local and regional landscape (e.g. Zalama; Souto *et al*. 2014). These potentially edge-of-range sites also highlight that existing climate-envelope models for blanket bog require further work, as do associated models forecasting the likely effect of climate change on blanket bog distribution (Gallego-Sala & Prentice 2013).

At a regional level this study provides clear evidence for the existence of blanket bogs in Cantabria. If recorded under Natura 2000, these sites would be the first such designated blanket bogs in the region. Natura 2000 designation would highlight the important contribution of Cantabria as well as Castilla y León to the Spanish and European inventory of peatlands, and would help to emphasise the incomplete status of the peatland inventory in the Atlantic region of Spain (Pontevedra-Pombal *et al.* 2009, Ramil-Rego & Rodríguez-Guitián 2017, Heras & Infante 2018). The present study also adds significantly to our understanding of the distribution – and limits to that distribution – of blanket mire globally.

The maximum depth of peat recorded at Zalama in this study (2.82 m) is greater than previous reported measurements (2.32 m; Souto *et al*. 2014) and this study provides the first map of the extent and distribution of peat at this site. The volume of peat recorded across all sites described in the present paper (>300,000 m^3) indicates that the potential long-term carbon storage held in these ecosystems may be as important as that stored in the O Xistral blanket bog complex in Galicia (Gómez-Orellana *et al.* 2014). However, Zalama is the only designated and protected study area in this research where livestock exclusion and restoration of bare peat surfaces is being undertaken. At all other sites, bare peat is not only exposed to fluvial and aeolian erosion processes but grazing livestock continue to trample across expanses of bare peat. Native ungulates, including the Iberian red deer (*Cervus elaphus hispanicus*) and roe deer (*Capreolus capreolus*) are also reported in the region (Gobierno Vasco 1985) and although numbers are unknown their impact may be contributing to the degradation.

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Terrestrial laser scanning in May and July 2017 indicated that erosion rates in unrestored and unprotected blanket bogs in the regions were higher than the estimated annual mean rate of peat erosion across the UK, while at Zalama blanket bog (restored) these rates were significantly lower (Chico *et al*. unpublished data). This highlights the significance and impact of livestock pressure on these peatland surfaces. Uncontrolled burning by farmers to improve grazing for livestock takes place every year in the Cantabria region and affects the peatland surface of Motas del Pardo, Collado de Hornaza and La Marruya. The effects of vegetation burning on erosion in these regions has not yet been quantified, but desiccation of exposed peat following fire combined with livestock trampling has been indicated as a key driver of peat loss prior to restoration at Zalama (Heras 2002).

While all four new areas of blanket bog identified here are exposed to ongoing pressures from livestock and associated management, additional anthropogenic pressures such as wind farm developments are more site-specific. The infrastructure of wind farm installations, including tracks 'floated' across the peat, cable trenches and turbine foundations, can, but may not always, result in significant impacts on the stability of peat and its accumulation by altering key hydrological functioning (Wawrzyczek *et al.* 2018, Heras & Infante 2008). Some wind farm developments have in the past adopted the approach of simply extracting peat prior to construction, and a number of peatlands in the Basque Country and Navarra no longer exist as a result (Heras & Infante 2008). Without designation and protection there is little in the way of statutory or official procedural process to oppose wind farm installations, and of particular concern here is that in 2017 a new wind farm installation was proposed for construction across Ilsos de Zalama (BOC 2017). The peat depth data recorded in this study show that the proposed wind farm includes construction of a turbine on part of the main body of blanket bog, and the data collected in our study (Figure 3) were employed in assembling a case to oppose the installation.

In addition to the likely impact on the currently unprotected blanket bog at Ilsos de Zalama, the resulting public debate and published case opposing the development (BOC 2017) created a conflict between the regions of Cantabria and Basque Country owing to the proximity of the protected and restored blanket bog in Zalama (500 m east). This conflict highlights the importance of regional boundaries in the conservation of blanket bogs in this area of the Cordillera Cantábrica, and it is worth noting that all blanket bogs identified here are located on the boundary between two administrative regions. Administrative boundaries often follow catchment (water divide) boundaries and blanket bog typically forms across such water divides. Restoration and protection of these blanket bogs will undoubtedly require inter-regional government collaboration if real progress is to be made in terms of long-term protection and restoration of these important areas. As the Habitats Directive requires that designated areas are in favourable or recovering status, the EU could request that regional governments designate these areas as a matter of urgency. This would create a beneficial situation whereby the EU would subsequently be able to provide financial support for restoration activities as occurred at Zalama blanket bog in Bizkaia.

It is also worth noting that fen ecosystems and associated peat accumulation downslope from these blanket bogs may rely on the hydrological function of the blanket bog components and may also be at risk if the associated blanket bogs were to disappear. Loss of such linked fen systems, as well as the often-narrow fen systems which form the essential linkages between blanket bog mesotopes, would not only represent a substantial additional loss of biodiversity but also loss of key components for any sustainable grazing regime – a factor often overlooked when contemplating changes to blanket mire landscapes.

CONCLUSION

All of the new blanket bogs identified in this research are degraded with clear evidence of peat erosion. They are not only exposed to a range of anthropogenic pressures including livestock-trampling and burning but are under threat of wind farm construction. However, Zalama represents an example of restoration that could be followed to improve the condition of these and other currently unprotected areas of blanket bog in the regions. Given the evident value of these sites within both a regional and European context, and the fact that their existence was not even known when the original EU Biogeographic Workshop for the Atlantic Region set out expected designation obligations for EU Member States within the Region, we would (a) impress on the European Commission the significance of these sites for their potential contribution to the Natura 2000 network; (b) urge both the European Commission and regional administrations to act now to prevent further degradation of these identified sites; and (c) urge both the European Commission and regional administrations to support further

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survey of the Cordillera Cantábrica in order to identify any additional unmapped blanket bogs within the Cordillera Cantábrica. Inter-regional government action is crucial to instigate protection of blanket bogs in north Spain. Finally, it is worth highlighting that the approach used here to identify and classify blanket bog can be employed wherever blanket mires occur in the world.

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