# LIFE+ LIMNOPIRINEUS: CONSERVATION OF AQUATIC HABITATS AND SPECIES IN HIGH MOUNTAINS OF THE PYRENEES

TECHNICAL REPORT

LIFE13 NAT/ES/001210 LIMNOPIRINEUS

~ Sphagnum mires associated to a small water course, in the locality of Liat ~

# HABITATS OF COMMUNITY INTEREST IN THE MIRES OF AIGÜESTORTES AND ALT PALLARS: DISTRIBUTION, IMPACTS AND THREATS

Aaron PÉREZ-HAASE (1), Josep M. NINOT (1), Efrem BATRIU (1), Eulàlia PLADEVALL-IZARD (1), Jaume ESPUNY (1), Alba ANADON-ROSELL (1, 2), Arnau MERCADÉ (1), Albert FERRÉ (1) & Empar CARRILLO (1)

1. Institute for Research in Biodiversity (IRBio) and Department of Evolutionary Biology, Ecology and Environmental Sciences, University of Barcelona. Av. Diagonal 643, 08028 Barcelona, Catalonia, Spain.
2. Institute of Botany and Landscape Ecology, University of Greifswald, Soldmannstrasse 15, 17487 Greifswald, Germany.

## ABSTRACT

Here, we present the main results of a study of the wetland habitats found at the Sites of Community Interest (SCIs) Aigüestortes and Alt Pallars, aimed to create a solid basis for conservative management. This study includes three levels of approach: a general cartography of the wetland landscape units, larger than 1500 m$^2$; an extensive sampling of Habitats of Community Interest (HCIs) located among 15 main valleys distributed through the two SCIs; and an intensive sampling of 13 mire systems relevant in extent and complexity. Mostly from the results of the first two levels of approach, the mire HCIs are characterised in terms of geographic and ecological distribution, singularity and naturalistic interest, and affectations derived from anthropic activities.

The set of mires studied includes eight HCIs (as well as other water-related habitats) some of which are restricted to very few locations, hosting 19 plant species that are found in different threat categories or that are of high biogeographic and ecological interest. Among them, there are some species of *Carex* or *Sphagnum* found in very few Pyrenean locations. It should be noted that both rare HCIs and specialist species are often very scatered over the complex mosaic of Pyrenean ecosystems, which is a challenge to conservative management. In general, the conservation status of mires in these protected areas is good, although grazing represents a threat in some places where livestock are often concentrated. Frequenting by hikers and hydroelectric uses also cause damage to the mires, albeit in fewer locations.

## INTRODUCTION

High mountain wetlands, also extensively called mires, are ecosystems of particular conditions because the soil is waterlogged at least during most of the vegetative period. This supposes significant limitations for the plants and other organisms that live in the soil, which is in a state of hypoxia or anoxia. The vascular plants of mires are almost always perennial grasses, especially rhizome-forming *Cyperaceae* and more or less dense turf, and are ecological specialists of quite restricted habitats. The plant communities of mires usually include bryophytes, which are not adversely affected by the fact that the soil is waterlogged. In fact, this may favour them over vascular plants, so that different species of mosses can take a leading role in mires (Vigo, 2009; Vitt, 2006).

Another common fact in mires is the low concentration of mineral nutrients present in their waters, which are in fact a somewhere between moderately and extremely oligotrophic and acid, a situation that translates into plant growth rates between moderate and low. Although primary production is relatively low, the poor oxygenation of the soil causes plant remains that are incorporated into the soil (roots and fallen parts) and other organic remains decompose very slowly, and therefore organic matter is accumulated in the form of peat. When this peat forms a layer of more than 30-40 cm thick, the ecosystem is correctly referred to as a mire (Rydin & Jeglum, 2006).

Within the mires, the small variations that occur in the flood regime, in the chemical properties of the water, or derived from the vegetation's own dynamics favour the coexistence of quite different environments, formed by sometimes contrasting plant communities (Pérez-Haase & Ninot, 2017). Thus, the areas dominated by phreatic water, or water that has generally passed through the soil, carry minerotrophic plant communities, since these waters contain substantial amounts of dissolved minerals. They are usually flat or low-slope areas, which lead to plant communities dominated by *Cyperaceae*. On other

▲ **Figure 1.** Most Pyrenean mires appear in the form of small and irregular surfaces, generally following small water courses and associated flat areas, as at Estanyeres.

occasions, however, mires are fed directly by rainwater, thus called ombrogenous mires. There, the mosses of the *Sphagnum* genus take centre stage and, with their vertical growth, form bulging plant communities, which are always above the water table. These are highly oligotrophic communities, almost always with a good peat thickness, and that often experience certain desiccation in the upper parts, where plants less adapted to waterlogged soil take root (Bragazza & Gerdol, 1999; Rydin & Jeglum, 2006).

In the Alpine mountains, mires are mostly restricted to the high mountain levels. In the Pyrenees, they appear at altitudes between about 1000 m and 2500 m, and so they are more frequent and extensive in the subalpine area. Both from the point of view of their biological content and their function, these high mountain ecosystems correspond to mires that occupy large areas in many lower altitude landscapes of temperate and cold biomes (Casanovas, 1991; Bragazza & Gerdol, 1999; Damman *et al*., 1987). But in the Alpine mountains, because the physiography is very complex and abrupt, these ecosystems occupy much smaller areas, linked to the landscape units where the groundwater remains close to the ground surface, such as lake shores, former glacial beds, or the edges of rivulets or springs (Figure 1). This limitation in extension is particularly evident in the Pyrenees, given their border position between the mid-European and the Mediterranean regions. Thus, if mires can still be quite large in much of the Alps, in the Pyrenees they almost always occupy smaller areas, often just a few square metres (Ninot *et al*., 2017).

This reduction in the area that mires occupy in most of the Pyrenees, does not prevent the plant communities and other associated organisms from being completely comparable to those found in other Alpine landscapes and in more northern latitudes, with which they share a large part of the species (Jiménez-Alfaro *et al*., 2012). In this context, it is understood that mire ecosystems are susceptible to protection in the Alpine mountains, since a good part of the specialist species are found there in the form of very scattered populations, often in their geographical distribution limit towards the Mediterranean region. Mires also stand out for the important role they have as regulators of the water cycle in the mountains and as an organic carbon store.

Most mountain mires lay within protected natural areas. However, it should be considered that, even in protected areas, these unique ecosystems are subject to particular pressures and threats, such as hydroelectric exploitation (Catalan, 1997) which modifies surface watercourses and, therefore, ecological conditions of mires; grazing by domestic livestock, which is often particularly concentrated in mires; visitor frequenting, as mountain trails often run along streams and lakes; and also climate change, which manifests itself with increasingly frequent spring and summer droughts.

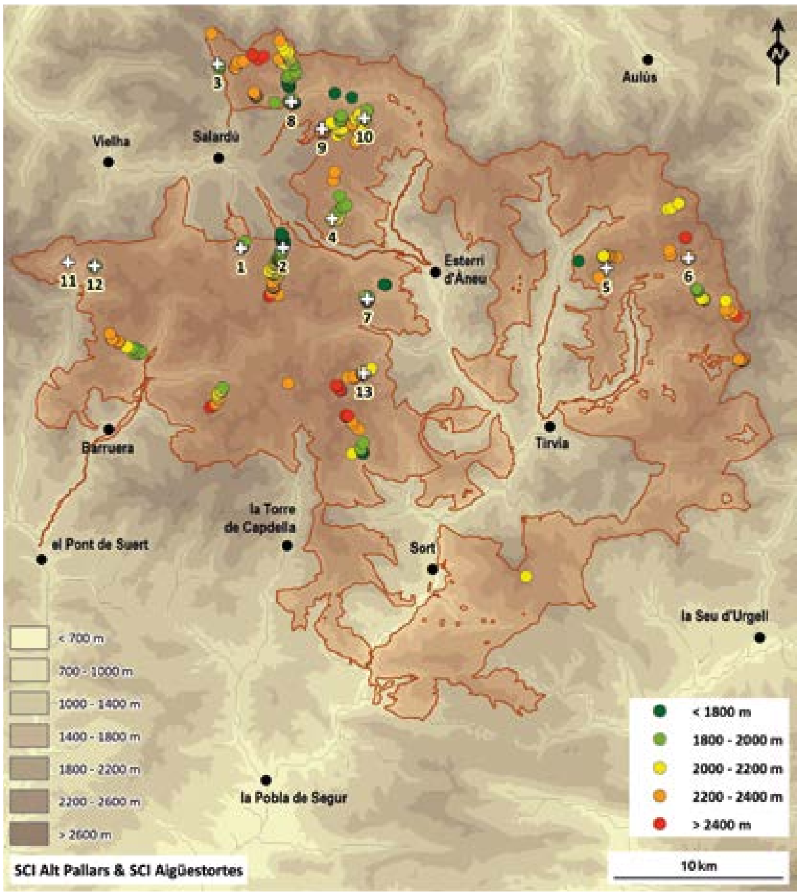
This is why, within the LIFE+ LimnoPirineus project, we approach a diagnostic study of the most unique mire habitats found at the Sites of Community Interest (hereinafter, SCIs) Aigüestortes and Alt Pallars, aimed to create a solid basis for conservative management..

## OBJECTIVES

The purpose of this work is to prepare a diagnosis of the Habitats of Community Interest (hereinafter, HCIs) of mires found in the Aigüestortes and Alt Pallars SCIs, from the points of view of their geographical and ecological distribution, their naturalistic and heritage interest, the anthropic alterations that affect them, and the threats to which they are subjected. The corresponding study is based on a large sampling conducted at different levels, which includes a general mapping of mire ecosystems; extensive sampling of mire HCIs across different valleys; and intensive sampling of these HCIs in a dozen particularly complex locations in terms of hydrography and the mosaic of mires hosted.

Given the volume and complexity of the data obtained, in this paper we present the most global results of this study, and mainly those derived from general mapping and extensive sampling of HCIs, while only partially using those of the intensive study.

**Figure 2.** Map of the study area (coloured), corresponding to the Aigüestortes and Alt Pallars SCIs. The points of the extensive study are represented, where HCIs have been georeferenced, in different colours according to altitude category; and the complex systems where intensive study has been conducted: 1, Bassa Nera-Era Planhòla; 2, Ruda-Locampo-Saboredo; 3, Plan de Tor; 4, Clots de Rialba; 5, Ribera de Boldís; 6, Plans de Sotllo; 7, Estanyeres; 8, Cabana de Parros; 9, Portilhon de Marimanha; 10, Ras de Bonabé; 11, Pleta de Molières; 12, Vall de Conangles; 13, Trescuro.




## MATERIAL AND METHODS

### Study Area

The study has been carried out at the Aigüestortes (ES0000022) and Alt Pallars (ES5130003) SCIs, both located in the northwest of Catalonia (Figure 2). The Aigüestortes SCI occupies an area of 56,033 ha, where the high mountain is very well represented; the altitude varies between 1200 and 3023 m. As for geological materials, there are mostly granite (which forms the core of the SCI and its most emblematic landscape) and slate, with limestone materials appearing in the eastern sector. The Alt Pallars SCI occupies a larger area, with a total of 77,112 ha, and extends from approximately 600 m to 3143 m in altitude. Shale and schist predominate in the high mountains, but other types of substrates (granite, limestone) are also present. Both natural areas, at high levels, have landscapes moulded by ancient glaciers, where tarn lakes and morainal deposits are common. These forms promote the appearance of wet areas, either directly by flooding or by the presence of springs.

### General cartography of mires

In order to locate the main sampling areas, throughout 2014 and 2015 we developed an extensive mapping of the high mountain wetlands of the two SCIs, which includes the mire systems of over approximately 1,500 m2. This mapping was done manually by interpretation of detailed orthoimages (scales 1:2,500 and 1:5,000), both in colour and infrared (ICGC, 2019; http://www.icc.cat/vissir3/index.html? 4v6vMyiv5). According to the slope and shape of the wetland, we assigned them to the category “Valley” when located in a valley floor (and it was noted if it coincided with a lake system), or “Spring” when it appeared in a spring or following a rivulet. This mapping is approximate and has not been subsequently validated in the field.

## Extensive sampling of Habitats of Community Interest

To carry out this sampling, we selected 15 main valleys (Figure 2) based on the following criteria: 1, Proximity to mires mapped at scale 1:50,000 (Cartography of the Habitats of Catalonia; GEOVEG, 2019) and with the mapping prepared by us; 2, Presence of calcareous substrates (scarcer than siliceous ones); 3, Areas under Atlantic influence.

We started field sampling in 2014 and finished in 2019. During the field campaigns, all in summer to ensure the correct development of the vegetation, the mires in the 15 valleys were visited, and the GPS coordinates were recorded (accurate to within 10 m) for all the mire habitats that could be attributed to an HCI. At each point or coordinate, the following was noted: a) CORINE Habitat, b) HCI Code, c) Disturbances, d) Threats, and e) Endangered or endemic species.

The HCIs considered are the following (Carreras et al., 2015):

- 3160 Natural dystrophic lakes and ponds
- 4020* Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*
- 7110* Active raised bogs
- 7140 Transition mires (quaking bogs)
- 7220* Petrifying springs with tuf formation (*Cratoneurion*)
- 7230 Alkaline minerotrophic fens
- 7240* Alpine pioneer formations of *Caricion maritimae*
- 91D0* Bog woodland

The disturbances assessed correspond to those caused by large herbivores, mostly due to domestic livestock. We divided them into disturbance by trampling and disturbance by herbivory, and we assessed their intensity using a four-unit scale.

In the case of herbivory, the meaning of the scale is: 0, no herbivory; 1, low herbivory, presence of mild signs of herbivory; 2. medium herbivory, i.e. between 10 and 50% of plants showing signs of herbivory; and 3, high herbivory, i.e. more than 50% of the plants showing signs of herbivory at the time of the visit.

In the case of trampling, the meaning of the scale is: 0, no trampling; 1, low trampling, which causes soil compaction; 2, medium trampling, with compaction and onset of soil disorganization, with visible livestock tracks; 3, high trampling, with visible bare soil as a result pugging damage.

The threats considered were: 1, Bovine, equine and ovine grazing; 2, Hiking trails (tourism); 3, Presence of forest tracks; 4, Water catchments; 5, Spontaneous afforestation; 6, Erosion. More specifically, the simple presence of herds and tourists in the mire was considered a sign of potential threat, although it did not necessarily cause conservation problems at the time of sampling. We considered that the presence of trees (very often young) near the GPS point (within approximately 10 m) was a potential threat.

We also recorded the presence of species of interest, both vascular plants and bryophytes. Specifically, we considered the presence of species included in the Catalan government Order of threatened flora (Catalonia, 2008, 2015) or the "Red Book" of Sáez *et al.* (2010), and others because of their biogeographical or ecological interest, according to the authors criterium.

In order to know in more detail the ecological distribution of the mires, we characterised them considering the variables: 1, altitude (highly correlated with the average annual temperature); 2, geological substrate, from a simplified version of the "Map of lithological classes of forest importance" (Conesa *et al.*, 2010); 3, slope; and 4, continentality index, which is the average of the highest of the warmest month (July) minus the average of the minimum of the coldest month (January).

## Intensive sampling of complex mire systems

For this sampling we chose thirteen locations where mires form particularly complex systems, in order to analyse the ecological conditions of these ecosystems more completely and accurately (Figure 2). These are systems that stand out due to their expansion and for the fact that they include an interesting diversity of mire habitats, which respond to complex environmental gradients. For system one we prepared detailed mapping of habitats, based on areas and points. This mapping was done using orthophotography from 2017, where field annotations were recorded, both of habitat identity and georeferencing GPS. Finally, the map of each mire system was transferred to digital format, working on screen, with the help of other photography formats (infrared orthophotography, field photographs) and field annotations.

From each habitat we chose a minimum of three sampling points, where we made two relevés of vegetation (vascular plants and bryophytes) of an area of 2.5 × 2.5 m, with an assessment of its coverage according to the 10 categories of the Domin scale. As environmental data associated with each relevé, in addition to physiographic and physiognomic descriptors, we extracted a soil sample (with half-round steel probe) to measure the underlying peat thickness and the depth of the water table. We also measured the pH and conductivity of the squeezed water from the upper part of the soil with a multiparameter field probe. Both from the edaphic water and the ground we preserved two fresh samples, which were later frozen for subsequent analyses.

# RESULTS

## Typology and Habitats of Community Interest

Through photointerpretation, we identified 921 mire systems larger than 1,500 $m^2$, which together occupy some 780 ha. However, each mapped mire system includes a significant portion of wet habitats, in addition to those that are strictly mires, with which they are dynamically related (such as the hygrophilous meadows of *Nardus stricta*). According to our estimates, the mire habitats occupy about 342 ha if we apply a correction based on the intensively visited locations (see below, Spatial complexity of the mires). Considering the area studied, the density of mires is approximately 18 m$^2$ per hectare of territory, i.e. 0.18% of the territory is covered by mires.

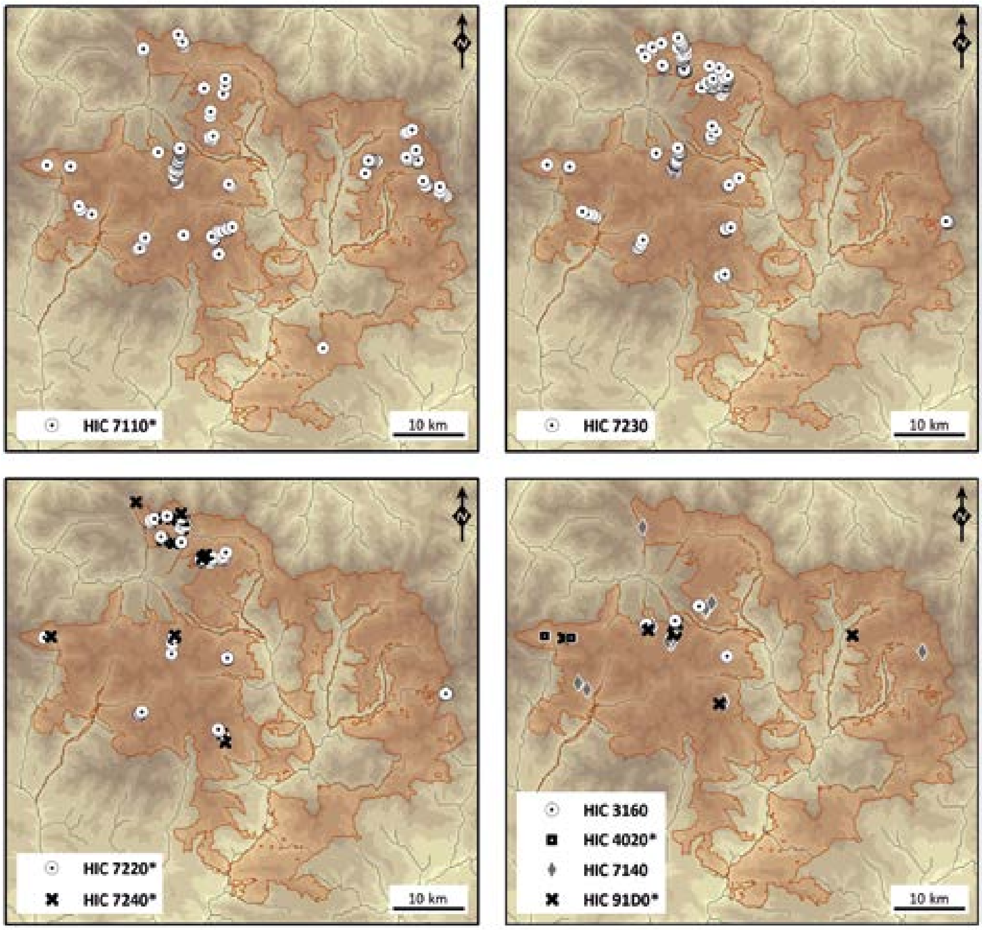
The cartography also shows a classification of mires related to springs and rivulets, or with valley floors, whether associated with lakes or not. The most frequent typology are mires associated with springs and rivulets, of which there are 557, while those associated with valley floors amount to 364 (among these, 97 are linked to lake shores). The mire systems associated with springs and rivulets occupy about 492 hectares, a value that allows us to estimate the total area of these mires as 197 hectares. The systems associated with valley floors occupy some 290 ha, of which 145 ha are strictly mires. Thus, the mapped mires occupy about 0.37 ha on average each (0.35 those of springs and rivulets and 0.40 those of valley floors).

In addition, as a result of extensive field sampling, we georeferenced a total of 604 points corresponding to mire habitats (Figure 2). Of these, 573 points could be attributed to some mire HCI; one HCI (4020* Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*) was not represented given its rarity (Table 1). Considering only the hydrological basins (main valleys), we obtained data from 18 basins with more than five HCI points recorded, in addition to eight more basins where the number of points was lower.

Considering the 573 points recorded, the most abundant HCIs were the 7230 Alkaline fens (with 249 points) and the 7110* -Active raised bogs (with 194 points; Figure 3). The majority of these HCIs correspond to the CORINE 51.1117 *Sphagnum capillifolium* hummocks (23.0%) and 54.24 Pyrenean rich fens (22.0%).

Regarding the distribution according to the geological substrates (Table 2), all HCIs can occur on acidic materials, but only 7230 Alkaline fens, 7220* Petrifying springs and 7240* Alpine pioneer formations are well represented on carbonate substrates. These three HCIs, although typically calcium, are also found on acidic substrates, especially in soligenous mires on granites.

The environmental descriptors in Table 3 express how all recognised habitats are typically located in high mountain levels and have an optimal distribution in the




▲ **Figure 3.** Distribution of the different mire HCIs in the studied area (Aigüestortes and Alt Pallars SCIs) from the 573 points recorded in the extensive study and the 13 locations of the intensive study. The HCI codes correspond to: 3160, Natural dystrohpic lakes and ponds; 4020*, Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*; 7110*, Active raised bogs; 7140, Transition mires (quaking bogs); 7220*, Petrifying springs with tuf formation (*Cratoneurion*); 7230, Alkaline minerotrophic fens; 7240*, Alpine pioner formations of *Caricion maritimae*; 91D0*, Bog woodland.

| HCC | Number of points | Percentage of points |
|---|---|---|
| 3016 Dystrophic lakes | 4 | 0.70 % |
| 7110* Active raised bogs | 194 | 33.86 % |
| 7140 Transition mires | 31 | 5.41 % |
| 7220* Petrifying springs | 54 | 9.42 % |
| 7230 Alkaline fens | 249 | 43.46 % |
| 7240* Alpine pioneer formations | 30 | 5.24 % |
| 91D0* Bog woodland | 11 | 1.92 % |

▲ **Table 1**. Number of points and percentage of the total where the different mire HCIs were recorded..

| HCI | Acid schist and shale | Other acid siliceous materials | Carbonate materials | Calcium-rich schist |
|---|---|---|---|---|
| 3016 Dystrophic lakes | 0.00 % | 75.00 % | 0.00 % | 25.00 % |
| 7110* Active raised bogs | 33.52 % | 52.75 % | 7.14 % | 6.59 % |
| 7140 Transition mires | 13.04 % | 86.96 % | 0.00 % | 0.00 % |
| 7220* Petrifying springs | 1.85 % | 22.22 % | 53.70 % | 22.22 % |
| 7230 Alkaline fens | 3.29 % | 32.51 % | 53.50 % | 10.70 % |
| 7240* Alpine pioneer formations | 3.33 % | 16.67 % | 80.00 % | 0.00 % |
| 91D0* Bog woodland | 9.09 % | 90.91 % | 0.00 % | 0.00 % |
| **Total** | **13.71 %** | **41.13 %** | **35.83 %** | **9.32 %** |

▲ **Table 2**. Percentage of presence of each mire HCI in the different geological materials (according to the simplified map of Conesa *et al*., 2010), evaluated as a percentage of points over the total.

subalpine belt. However, neither the dystrophic lakes (3160) nor the bog woodland (91D0*) are found above 2300 m and, therefore, do not reach the alpine area. As for gradients, the vegetation linked to springs and rivulets (HCIs 7230 Alkaline fens, 7220* Petrifying springs and 7240* Alpine pioneer formations), has the highest values, followed by 91D0* Bog woodland, which often occupies relatively soft, but steep slopes, where water flows diffusely. Finally, since the continentality index was correlated with altitude, the HCIs that appear at higher altitude have the lowest values of this index.

| HCI | Minimum altitude (m) | Average altitude (m) | Maximum altitude (m) | Average slope | Continentality index |
|---|---|---|---|---|---|
| 3016 Dystrophic lakes | 1783 | 1828.25 | 1958 | 5.16 | 25.15 |
| 7110* Active raised bogs | 1751 | 2144.77 | 2498 | 6.54 | 23.7 |
| 7140 Transition mires | 1810 | 2032.35 | 2257 | 1.69 | 24.41 |
| 7220* Petrifying springs | 1802 | 2156.54 | 2431 | 16.65 | 23.31 |
| 7230 Alkaline fens | 1555 | 1986.96 | 2564 | 12.65 | 24.12 |
| 7240*Alpine pioneer formations | 1798 | 2161.17 | 2434 | 22.7 | 22.72 |
| 91D0* Bog woodland | 1754 | 1859.55 | 1990 | 11.99 | 24.76 |
| **Total** | **1555** | **2064.39** | **2564** | **10.83** | **23.87** |

▲ **Table 3**. Average values of the environmental variables considered for each HCI, and for the whole.

## Spatial complexity of mires

Pyrenean mires that occupy larger areas, either because they are found in lake areas, or because they depend on wide seepage systems, form systems with strong variations in environmental properties and in biological content, and thus they take the form of complex landscape mosaics. This is evident in the systems intensively studied, where the relationship between environmental parameters and habitats was analysed. In this section we will comment on general aspects observed in these complex systems, while for the more specific results we refer to other works (cf. Pérez-Haase & Ninot, 2017; Colomer *et al*., 2019).

These mire systems are mostly found in the lower half of the subalpine belt, linked to bottoms of glacial valleys or circuses (Table 4). Sometimes they clearly correspond to sediment-filled lakes or wide margins of lake infilling (Figure 4), others to seepage systems on gentle slopes (such as Cabana de Parros) and others to the combination of these situations, as occurs in the most extensive system

▲ **Figure 4.** . In some appropriate places, such as Plans de Sotllo, there are systems formed by complex mosaics, where different types of mires and other non-hydrophilic habitats are combined.

| Location | HCIs | Typology | Altitude (m) | Area (ha) | Threats | Status | Species of interest |
|---|---|---|---|---|---|---|---|
| 1. Bassa Nera-Era Planhòla | 3160<br>7110*<br>7140<br>7230<br>91D0* | Lake and valley floor mire | 1840-1900 | 16.19 | Afforestation (M)<br>Grazing (B-M)<br>Trampling (B) | Very good | *Carex lasiocarpa*<br>*C. limosa*<br>*C. diandra*<br>*Comarum palustre*<br>*Menyanthes trifoliata*<br>*Utricularia minor*<br>*Sphagnum magellanicum* |
| 2. Ruda-Locampo-Saboredo | 3160<br>7110*<br>7140<br>7220*<br>7230<br>91D0* | Lake and valley floor mire | 1720-2190 | 4.39 | Grazing (B)<br>Hydroelectric activity (B) | Very good | *Drosera anglica*<br>*Menyanthes trifoliata*<br>*Utricularia minor* |
| 3. Plan de Tor | 7110*<br>7140<br>7230 | Valley floor mire | 1960-2005 | 5.95 | Grazing (B-M)<br>Tourism (B-M) | Good | *Sphagnum fuscum* |
| 4. Clots de Rialba | 3160<br>7110*<br>7140<br>7230 | Lake mire | 2070-2090 | 2.81 | Grazing (B)<br>Winter sports (M) | Very good | *Carex limosa*<br>*Comarum palustre*<br>*Drosera anglica* |
| 5. Ribera de Boldís | 7110* | Glacier floor mire | 2190-2200 | 1.40 | Grazing (M) | Good | *Eriophorm vaginatum*<br>*Sphagnum russowii* |
| 6. Plans de Sotllo | 7110* | Glacier floor mire | 2183-2190 | 1.67 | Grazing (M-A) | Good | *Sphagnum papillosum* |
| 7. Estanyeres | 7110*<br>7220*<br>7230 | Carbonate source mires | 1930-1950 | 2.62 | Grazing (A)<br>Trampling (A) | Average | *Cochlearia pyrenaica*<br>*Utricularia australis* |
| 8. Cabana de Parros | 7220*<br>7230 | Carbonate source mires | 1750-1850 | 1.98 | Grazing (M) | Average | *Eriophorum latifolium* |
| 9. Portilhon de Marimanha | 7220*<br>7230<br>7240* | Carbonate source mires | 2220-2350 | 2.31 | Grazing (M) | Average | *Carex frigida*<br>*Sphagnum warnstorfii* |
| 10. Ras de Bonabé | 7220*<br>7230 | Carbonate source mires | 2000-2100 | 4.94 | Grazing (M) | Average | *Juncus balticus*<br>*Equisetum variegatum*<br>*Sphagnum warnstorfii* |
| 11. Pleta de Molières | 4020*<br>7110*<br>7220*<br>7230<br>7240* | Valley floor mire | 1600-1650 | 6.23 | Tourism (M) | Average | *Erica tetralix* |
| 12. Vall de Conangles | 7110*<br>7230<br>91D0* | Valley floor mire | 1820-1840 | 1.13 | Grazing (B)<br>Avalanches (B)<br>Afforestation (B) | Good | *Erica tetralix*<br>*Saxifraga aquatica* |
| 13. Trescuro | 7110*<br>7140<br>7230<br>91D0* | Lake and valley floor mire | 2045 | 1.42 | Grazing (B)<br>Hydroelectric activity (B) | Very good | *Sphagnum magellanicum* |

▲ **Table 4.** Characterisation of the 13 intensive study locations (located in figure 2) based on the mire HCIs present, the geomorphological and hydrological status, altitude, the area occupied by the mire habitats (including HCIs and other mire habitats, but not free bodies of water), an assessment of potential threats (B, low; M, medium; A, high) as well as conservation status and the species of interest observed (vascular plants and bryophytes).

of all at Bassa Nera-Era Planhòla.

Some of these systems are formed by a few different mire habitats, notably those found in acid schistose substrates and also those derived from seepage systems in some carbonate-rich slopes (Figure 5). However, those that include diverse hydrological situations (lake shores, rivulets, gentle slopes) and also different substrates are much more diverse, as is the case of Clots de Rialba, Pleta de Molières and Trescuro.

## Impacts caused by large herbivores

Throughout the extensive sampling we found that the majority of mire HCIs had been affected by domestic livestock (Tables 5 and 6). Only 11.6% of the points showed no signs of grazing. Although in most cases the degree of herbivory was low (43.9%), the medium trampling levels was the most frequent (37.8%). Considering each HCI separately, we detected a medium or high level of grazing in more than half of the points of HCIs 7240* Alpine pioneer formations (61.9%), 7230 Alkaline fens (59.7%) and 7220* Petrifying springs (58.8%). These were also the three habitats with the highest affectation percentages in terms of medium and high trampling levels (47.1%, 67.2% and 61.8% respectively).

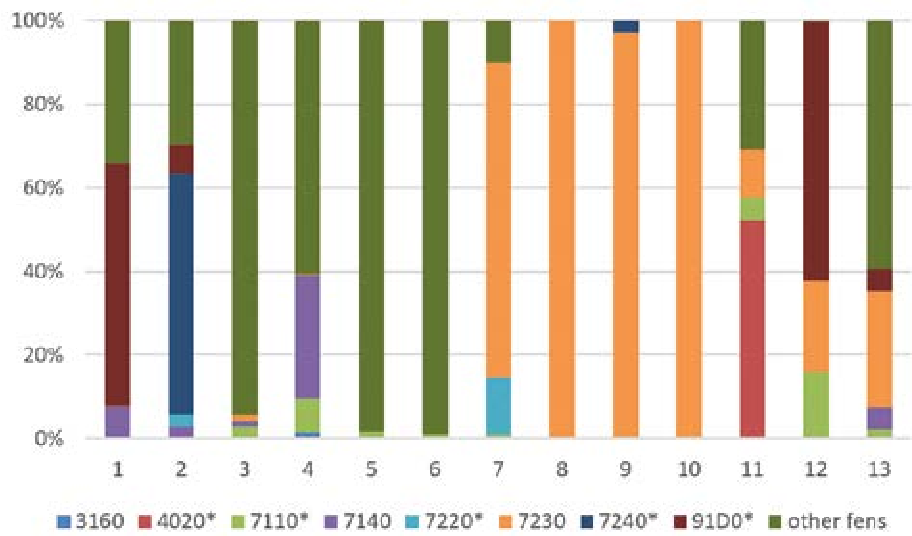



**Figure 5.**
Percentage of surface occupied by the different mire HCIs and other types of hydrophilic ecosystems (excluding free waters) in the different complex systems (see the numerical correspondence and its total expansion in Table 4).

| HCI | No herbivory | Low herbivory | Medium herbivory | High herbivory |
|---|---|---|---|---|
| 7110* Active raised bogs | 11.65 % | 51.46 % | 34.95 % | 1.94 % |
| 7140 Transition mires | 18.18 % | 72.73 % | 9.09 % | 0.00 % |
| 7220* Petrifying springs | 11.76 % | 29.41 % | 52.94 % | 5.88 % |
| 7230 Alkaline fens | 5.65 % | 34.68 % | 46.77 % | 12.90 % |
| 7240* Alpine pioneer formations | 14.29 % | 23.81 % | 57.14 % | 4.76 % |
| 91D0* Bog woodland | 0.00 % | 100.00 % | 0.00 % | 0.00 % |
| **Total** | **9.40 %** | **41.61 %** | **41.95 %** | **7.05 %** |

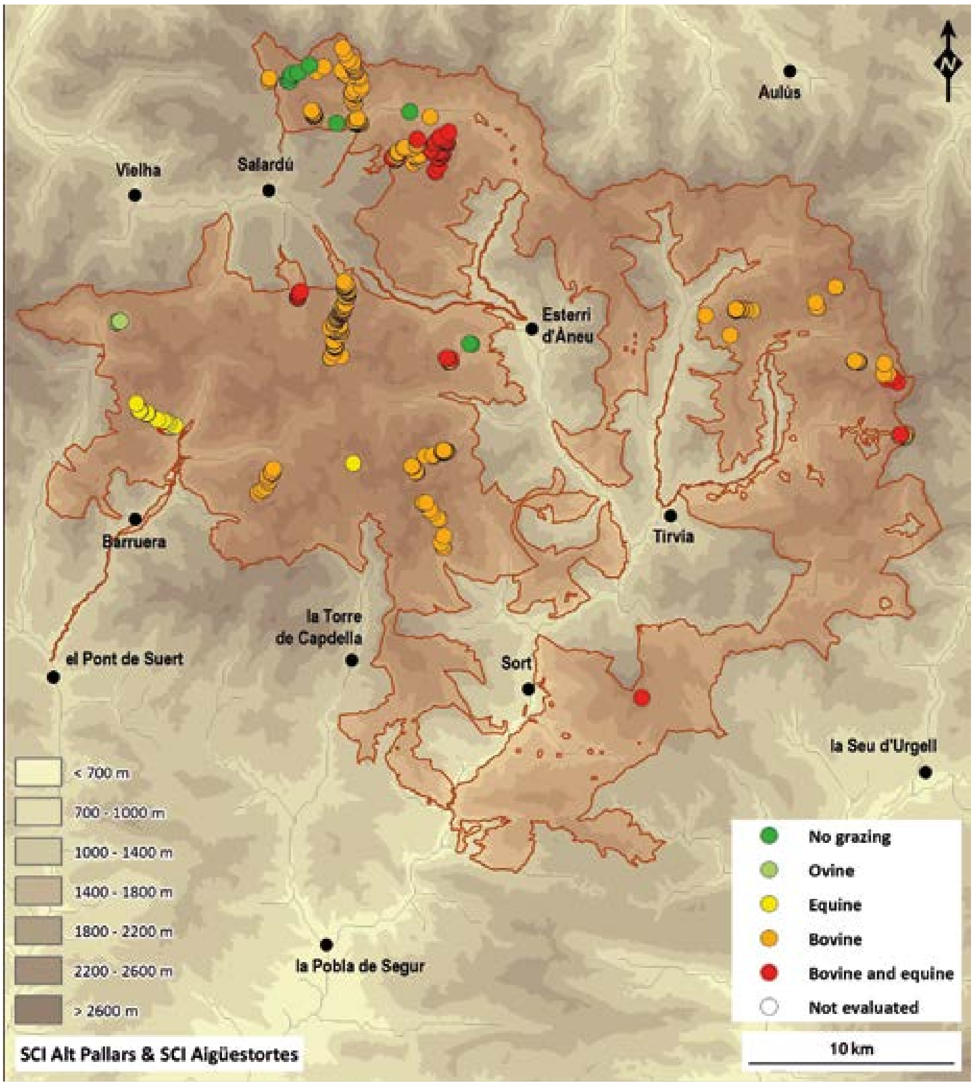
**Table 5.** Level of affectation of mire HCIs due to herbivory by large herbivores, as a percentage of points of each level of herbivory compared to the total points of each HCI and of the whole.

| HCI | No trampling | Low trampling | Medium trampling | High trampling |
|---|---|---|---|---|
| 7110* Active raised bogs | 16.67 % | 46.97 % | 30.30 % | 6.06 % |
| 7140 Transition mires | 18.18 % | 63.64 % | 18.18 % | 0.00 % |
| 7220* Petrifying springs | 11.76 % | 26.47 % | 50.00 % | 11.76 % |
| 7230 Alkaline fens | 4.69 % | 28.13 % | 46.88 % | 20.31 % |
| 7240* Alpine pioneer formations | 11.76 % | 41.18 % | 29.41 % | 17.65 % |
| 91D0* Bog woodland | 0.00 % | 100.00 % | 0.00 % | 0.00 % |
| **Total** | **9.58 %** | **36.40 %** | **39.85 %** | **14.18 %** |

▲ **Table 6**. Level of affectation of mire HCIs due to trampling by large herbivores, as a percentage of points of each level of trampling compared to the total points of each HCI and of the whole.

## Threats

In almost all the points assessed (97%) we considered that there were potential threats to conservation. In the vast majority of cases (93.6%) we detected the presence of herds of cows, horses or sheep (Table 7, Figure 6), that considered separately represented a threat in 87.5%, 25.8%, and 1.6% of the cases, respectively.




▲ **Figure 6.** Potential threats to the conservation of mire HCIs, derived from the presence of cattle, horses and sheep, at the 573 points recorded in the extensive study.

| HCI | Bovine | Equine | Ovine |
|---|---|---|---|
| 3160 Dystrophic lakes | 100.00 % | 0.00 % | 0.00 % |
| 7110* Active raised bogs | 90.00 % | 13.92 % | 1.25 % |
| 7140 Transition mires | 85.71 % | 22.58 % | 0.00 % |
| 7220* Petrifying springs | 78.00 % | 29.63 % | 0.00 % |
| 7230 Alkaline fens | 89.13 % | 26.51 % | 1.74 % |
| 7240* Alpine pioneer formations | 89.29 % | 0.00 % | 0.00 % |
| 91D0* Bog woodland | 90.91 % | 0.00 % | 9.09 % |
| **Total** | **88.27 %** | **20.24 %** | **1.39 %** |

▲ **Table 7**. Level of threat to mire HCIs due to livestock (bovine, equine, ovine), as a percentage of threatened points compared to the total points of each HCI and of the whole.

| HCI | Spontaneous afforestation | Tourist routes | Erosion |
|---|---|---|---|
| 3160 Dystrophic lakes | 0.00 % | 0.00 % | 0.00 % |
| 7110* Active raised bogs | 1.25 % | 5.15 % | 0.00 % |
| 7140 Transition mires | 0.00 % | 0.00 % | 0.00 % |
| 7220* Petrifying springs | 0.00 % | 7.41 % | 2.00 % |
| 7230 Alkaline fens | 3.04 % | 16.47 % | 1.30 % |
| 7240* Alpine pioneer formations | 0.00 % | 13.33 % | 10.71 % |
| 91D0* Bog woodland | 0.00 % | 0.00 % | 0.00 % |
| **Total** | **1.79 %** | **10.30 %** | **1.39 %** |

▲ **Table 8**. Level of threat to mire HCIs due to spontaneous afforestation, tourist traffic and erosion, as a percentage of threatened points compared to the total points of each HCI and of the whole.

| Disturbance | Bovine grazing | Equine grazing | Ovine grazing | Spontaneous afforestation | Erosion |
|---|---|---|---|---|---|
| Medium herbivory | 89.68 % | 26.98 % | 0.00 % | 0.79 % | 3.17 % |
| High herbivory | 100.00 % | 47.62 % | 0.00 % | 0.00 % | 9.52 % |
| Medium trampling | 86.67 % | 23.81 % | 0.00 % | 0.95 % | 0.00 % |
| High trampling | 91.89 % | 45.95 % | 0.00 % | 0.00 % | 0.00 % |

▲ **Table 9**. Incidence of the five types of threat in mire HCIs in cases where they are disturbed by grazing, as a percentage of points threatened with respect to each type of disturbance.

Apart from grazing, the other potential threats considered all at once were recorded in 13.5% of all points with HCIs (Table 8). Among these, the presence of hiking trails is the most significant threat. The presence of forest tracks and wildlife are considered threats in only one HCI point each. Water catchments did not affect any HCI, but did affect one acid mire.

In cases of high disturbance due to grazing (either by medium or high herbivory, or by medium or high trampling) the main threat corresponds to cattle (Table 9). Spontaneous afforestation was not reduced in the case of high levels of herbivory, while erosion is higher in cases of high herbivory, but not in those of high trampling.

## Species of interest

Throughout the field sampling we have documented the presence of 19 species of interest (Table 10), of which fourteen are vascular plants (very divided between groups, although there are two *Carex*) and five are bryophytes (four of the *Sphagnum* genus). Of the total, twelve are in some category of threat in the aforementioned references, and seven have been included in the evaluation because of their biogeographic or ecological interest.

| Species of interest | 3160 | 7140 | 7230 | 7110* | 7220* | 7240* | 91D0* | Total |
|---|---|---|---|---|---|---|---|---|
| *Cardamine pratensis* subsp. *crassifolia* (ce) | | | 3 | | | | | 3 |
| *Carex curta* (ce) | | 7 | | | | | | 7 |
| *Carex lasiocarpa* (df, rb) | | 8 | | | | | | 8 |
| *Carex limosa* (df, rb) | | 1 | | | | | | 1 |
| *Cochlearia pyrenaica* (df) | | | | | 5 | | | 5 |
| *Drosera longifolia* (df, rb) | | 3 | 1 | 2 | | | | 6 |
| *Equisetum variegatum* (ce) | | | 14 | 4 | | 1 | | 19 |
| *Erica tetralix* (df) | | | 6 | 5 | | | | 11 |
| *Eriophorum vaginatum* (ce) | | | | 3 | | | | 3 |
| *Juncus balticus* subsp. *pyrenaeus* (df) | | | 6 | | | | | 6 |
| *Menyanthes trifoliata* (df) | | 2 | | | | | | 2 |
| *Salix hastata* (df, rb) | | | 1 | | | | | 1 |
| *Saxifraga aquatica* (ce) | | | 1 | | 7 | 3 | | 11 |
| *Scorpidium scorpioides* (df) | | 1 | 1 | | | | | 2 |
| *Sphagnum fuscum* (df) | | | | 1 | | | | 1 |
| *Sphagnum magellanicum* (df) | | | | 1 | | | | 1 |
| *Sphagnum squarrosum* (ce) | | | | | | | 1 | 1 |
| *Sphagnum warnstorfii* (ce) | | | 1 | 1 | | | | 2 |
| *Utricularia minor* (df) | 4 | 2 | | | | | | 6 |
| **Total presence** | **4** | **24** | **34** | **17** | **12** | **4** | **1** | **96** |
| **Total species** | **1** | **7** | **9** | **7** | **2** | **2** | **1** | **19** |

▲ **Table 10**. Presence of species of interest in the different HCIs (number of times they appear in each HCI, over the total points of this HCI, see table 1). The abbreviations that follow the name of each species in parentheses indicate that it is contained in threat categories of the "Decree on flora conservation" (Catalonia, 2018, 2015) (df), of the "Red Book" (Sáez *et al.*, 2010) (rb), or they are of high biogeographic or ecological interest, according to expert criteria (ce).

# DISCUSSION

## The archipelago of mires

The high alpine mountain hosts numerous representations of wet systems, but these are always small and scattered elements, a fact that is particularly pronounced in the Pyrenees (Ninot *et al*., 2017). Thus, the distribution and dimensions of the mires in the cartography obtained, allows them to be understood as an archipelago of small scattered islands, which conditions the processes related to biodiversity maintenance (Hájek *et al*., 2011). The fact that both the size of each mire system and the global area occupied by the mires are so small, determines that they are habitats particularly fragile to disturbances. The same also points to a low adaptive capacity of the vegetation in case of climatic changes, given the difficulty of finding favourable habitats by dispersing seeds. As a consequence, other groups of organisms associated with mires may also have conservation problems in relation to their colonising capacity. For example, flying animals are expected to reach more favourable new habitats more easily than those with short-distance dispersal, such as molluscs (Steinitz *et al.*, 2006).

From the mapping of mires we can point out that a significant part of the species could not maintain stable populations over time in each mire separately. Rather, they must function under active metapopulation dynamics (Heegaard, 2000) using the island system to maintain viable populations. It also follows that those species present in only a few mires are particularly fragile, and in quite a few cases, we can consider them relics from colder times (Jiménez-Alfaro *et al*., 2016).

In the absence of specific studies, it is advisable to keep the entire archipelago of mires in good condition, and not to focus efforts on a few specific mires. In order to properly manage these habitats, detailed specific mapping of them is needed.

## Grazing

The presence of livestock does not necessarily represent a conservation problem in grassland vegetation. In fact, many types of mires are dominated by graminoid plants that recover well after being grazed (Diaz *et al*., 2007). In addition, the typical community structure (diversity and abundance of vascular plant and bryophyte species)

▲ **Figure 7**. Large livestock (cattle and horses) tend to concentrate in wetlands, as in Marimanha, where they can profoundly alter these fragile ecosystems.

often depends on herbivore activity (Ausden *et al*., 2005). However, when grazing pressure is high or very high (Figure 7), excessive herbivory and trampling cause damage to ecosystems, which in some cases can be difficult to reverse (Morris & Reich, 2013). In Pyrenean mires we detected an excess of herbivory or trampling at approximately half of the study points. Thus, the intensive consumption of some plant species may lead them to disappear locally (Olff & Ritchie, 1998), although this fact is documented enough with our data. In addition, in many cases, frequent trampling by livestock caused the presence of compacted and disorganized soils. These alterations cause changes in the processes linked to runoff and water retention capacity, so important in wetlands (Couwenberg & Joosten, 1999).

The affectation by livestock was not the same at all the habitats. Overall, the effects of trampling are greater when the water table is close to the surface or when mosses dominate, as detected in other regions (Morris & Reich, 2013). For example, we can see how the expansion of sphagnum (7110* Active raised bogs) are especially vulnerable to the trampling of equine livestock, although them prefer to graze in other habitats. Therefore, the most affected habitats must be carefully studied in order to plan efficient corrective management measures. Alkaline fens (7230), Alpine pioneer formations (7240*) and Petrifying springs (7220*), which present excessive grazing levels, should be a conservation priority in relation to livestock.

## Potential threats

Among all threat categories considered, herds of cows and horses are the most significant by far. In fact, we considered bovine herds a threat to conservation in more than 75% of cases in all habitats except one. From the perspective of habitat conservation, the negative effects of livestock should be considered when making management decisions. In any case, our study cannot be conclusive when determining which livestock burden is harmful. In addition, it should also be considered that an adequate livestock load can contribute to the proper conservation of mires (Olff & Ritchie, 1998; Stammel *et al*., 2006). In fact, in some cases we find that visiting cattle may be related to the attenuation of the threat of spontaneous afforestation, which in certain habitats may be a major cause of loss of heritage value of mires (Colomer *et al*., 2019).

Also, tourism is a cause of concern for managers of natural areas. In particular, the Aigüestortes i Estany de Sant Maurici National Park and the Alt Pallars Natural Park are visited by a very large number of tourists. In this study we have found that hiking trails are a potential threat in a significant part of the mires. However, we found that they caused significant degradation only on a few occasions (as in the Molières and Sotllo systems, subject to corrective measures in the LIFE+ LimnoPirineus project). In most cases we interpret the trails as narrow linear elements that cause irrelevant degradation in wet systems. We must also consider the threat due to the installation of sports infrastructure, such as ski resorts, which can affect mires located in nearby areas. If we leave aside the alterations due to hydroelectric dams, not considered in this work, there are no more relevant potential threats in the context of the Central Pyrenees, although some areas intensely visited by livestock suffer erosion.

In addition, spontaneous afforestation proved to be an insignificant conservation factor. However, when we have approached detailed studies based on GIS techniques (Galobart *et al*., 2019) We have detected that in the subalpine area there may be a threat in some mires. The evaluation of spontaneous afforestation is more precise when the whole mire is considered and not only the area immediately surrounding a georeferenced point (as we have done in this work). It seems, therefore, that in order to detect the dynamics of spontaneous afforestation, this process must be studied on a relatively large spatial and temporal scale, including each mire system over at least 30-50 years.

# CONCLUDING REMARKS

The set of wetlands studied includes a good variety of mire habitats, including eight HCIs, hosting 19 plant species that are found in different threat categories or that are of high biogeographic and ecological interest. Both rare HCIs and specialist species are often very dispersed over the complex mosaic of Pyrenean ecosystems within the study area, which is a challenge to conservative management.

The mires of these two protected natural areas are, as a whole, in an acceptable and, in many cases, good state of conservation. However, approximately half of them suffer excessively from visiting livestock. Among all the disturbances analysed, we believe that the level of high trampling, especially as a result of visiting cattle, is the one that most affects the correct conservation state of the mires. Consequently, it is recommended that the managers of the natural spaces aim to reduce the impacts of overgrazing in those points most affected. Potential threats that could damage the conservation status of mires also have to do with grazing livestock. Apart from livestock, the rest of the threats evaluated have a low or irrelevant effect, which should lead to focusing conservation efforts on livestock management. The management of spontaneous afforestation must be considered separately, once its effects have been measured through specific studies, based on a particular methodology different from that used here.

Therefore, managers must look further into the causes of the degradation of mires and promote applied work that seeks to mitigate the damage caused by livestock. Some experiences with livestock exclusion fences may help to base the management of mires with minimal damage to livestock activity, which, as we have stated, also has beneficial effects on biodiversity.

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~ Petrifying springs of Montseny de Pallars ~