Universidad de Valladolid
Campus de Palencia

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍAS AGRARIAS

Máster en Investigación en Ingeniería para la Conservación y el Uso Sostenible de los Sistemas Forestales

Restoration effect on vegetation dynamics in the peatland communities of the Ebro Reservoir surroundings (Burgos, Spain)

Alumna: Raquel Juan Ovejero
Tutores: Juan Andés Oria de Rueda Salgueiro y Carolina Martínez Ruiz

Septiembre 2014

“Me comería toda la tierra. Me bebería todo el mar.”

Confieso que he vivido, Pablo Neruda

AGRADECIMIENTOS

A mis tutores, Juan Andrés Oria de Rueda y Carolina Martínez Ruiz, por haberme ayudado y orientado. La identificación de especies del primero fue crucial y las correcciones y el apoyo de Carolina hacen que este trabajo tenga mucha más calidad que en un principio.

A Enrique Álvarez Gómez, principal autor de la restauración de la turbera Margarita, porque su ayuda y sus comentarios dieron un valioso foco de luz a este trabajo. Miguel Ángel Pinto Cebrián (Aula de Medioambiente-Caja Burgos) y Javier María García López (Junta de Castilla y León) también son responsables de que hoy podamos ver la turbera restaurada.

A Patxi Heras (Museo de Ciencias Naturales de Álava) por la identificación de los esfagnos. La briología es un gran mundo que me queda por descubrir.

I would like to express my gratefulness to Oili Tarvainen (Oulu Research Unit, Finnish Forest Research Institute) for all the discussions clarifying important concepts and providing new ways of understanding research. I will always keep in my mind that summer in the very north of the world as a great period of my life.

A mis amigos, porque espero que los buenos momentos sigan sucediéndose a lo largo de los años en alguna parte del mundo. La memoria de mi amiga Lorena no puede pasar desapercibida en este folio: es una pena inmensa que dejaras tantas velas por soplar.

Mi abuela Laude siempre dijo a la gente que yo estudiaba mucho, aunque no supiera muy bien qué era lo que estudiaba. La educación y el apoyo que me ha dado siempre mi familia fueron imprescindibles para ello. Gracias.

En Palma de Mallorca, a 28 de julio de 2014

Raquel

Índice

Abstract

Peatlands represent a spatially restricted habitat in Spain and they are home to a rich flora, including several rare plant species (*Myrica gale*, *Sphagnum* spp., *Eriophorum angustifolium*, *Drosera rotundifolia*). Peatlands in northern Spain have been specially affected by intensive human land use where they may be drained for peat extraction or simply disappeared under urban and industrial development. Accordingly, the fragmentation and loss of these habitats might have a significant impact on local and regional biodiversity. They are valuable ecosystems that usually do not have a good conservation state and there is a lack of knowledge on the restoration effect in such sites. We assess whether restoration has changed vegetation composition on degraded peatland communities in comparison with a pristine peatland, which provides a reference point. The study was carried out in central-northern Spain and we compared species composition and diversity of vascular plants and bryophytes on three peatlands: restored, unrestored and natural. Our results show that the restored peatland has the highest diversity values, and that *Sphagnum* mosses are growing in the area, so restoration techniques were successful. We predict that species composition and plant diversity in restored peatlands may stabilise at similar levels to pristine peatlands during the course of succession.

Key words: *peat extraction, degradation, bryophytes, diversity, succession*

Resumen

Las turberas representan un hábitat espacialmente restrictivo en España y albergan una flora muy valiosa con varias especies raras (*Myrica gale*, *Sphagnum* spp., *Eriophorum angustifolium*, *Drosera rotundifolia*). Las turberas del norte de España se han visto especialmente afectadas por un uso humano intensivo y han sido drenadas para posteriores extracciones de turba o simplemente han desaparecido tras el desarrollo urbano e industrial. De esta manera, la fragmentación y pérdida de estos hábitats podría tener un impacto significativo en la biodiversidad local y regional. Son valiosos ecosistemas que comúnmente no tienen un buen estado de conservación y hay pocos estudios sobre el efecto de su restauración. En este estudio se evalúa si la restauración ha cambiado la composición de la vegetación en comunidades degradadas de turberas en comparación con una turbera natural, la cual utilizamos como punto de referencia. El estudio se llevó a cabo en el centro norte peninsular y comparamos la composición de especies y la diversidad de plantas vasculares y briófitos en tres turberas: restaurada, no restaurada y natural. Nuestros resultados muestran que la turbera restaurada tiene los valores de diversidad más altos, y que los esfagnos están creciendo en el área, de manera que las técnicas de restauración fueron exitosas. Predecimos que la composición y diversidad de especies en turberas restauradas se podrían estabilizar en niveles similares a los que podemos encontrar en turberas prístinas a lo largo de la sucesión.

Palabras clave: *extracción de turba, degradación, briófitos, diversidad, sucesión*

Introduction

Peatlands represent a small but interesting proportion of endemic vegetation and terrestrial biodiversity around the whole Mediterranean basin and are of conservation concern. Southern-European peatlands differ from their homologues located in high latitudes. For instance, wetlands (general definition that includes peatlands) located further south in Europe and up north in Africa might therefore be expected to differ from boreal wetlands in their response to severe changes or perturbations (Cížková *et al.*, 2013). Currently, studies regarding the restoration effect on vegetation dynamics and succession in peatland communities are much more popular in high latitudes e.g. in Canada (Lavoie *et al.*, 2005; D'Astous *et al.*, 2013; Peacock *et al.*, 2013), Finland (Haapalehto *et al.*, 2010; Laine *et al.*, 2011), Sweden (Mälson and Rydin, 2007; Hedberg *et al.*, 2012) or the British Isles (Large, 2001; Sottocornola *et al.*, 2009) than in the Mediterranean region (e.g. Topić and Stančić, 2006; Bottollier-Curtet and Muller, 2009; Daoud-Bouattour *et al.*, 2011; Henkin *et al.*, 2012; Kaplan, 2012). Peatland ecosystems in Spain just cover ca. 10 km^2, which represents a 0.005% of the whole country surface (Raeymaekers, 2000; Joosten and Clarke, 2002). However, notable differences between peatlands of the Eurosiberian and Mediterranean regions within the Iberian Peninsula can be observed. Eurosiberian peatlands, formed under an Atlantic climate, have lower pH and smaller surfaces than Mediterranean peatlands. Moreover, peat decomposition is greater in Mediterranean peatlands, in such a way that they are less exploited because peat quality is not worthy enough for industrial purposes. Specifically, several peatlands in northern Spain have been drained and reclaimed for human purposes over the last 100 years, whereas their restoration management is being carried out nowadays and their results are rarely found in the literature.

Conceptual and on-ground aspects of restoration ecology must be linked in an on-going dialog that provides tools for finding and solving current problems (Hobbs and Harris, 2001). However, restoration projects do not always go along with research. As Gorham and Rochefort (2003) stated, it is crucial to incorporate an investigation of fundamental peatland science, and peatland researchers and managers should join forces. Anthropogenic actions may have been responsible of degradation, but could be as well the suitable agents for restoration. Identification and intervention processes are essential in ecological restoration: once specific problems are identified they can be overcome by artificial interventions, which are most successful if they use natural processes (Dobson *et al.*, 1997). As restoration management has its particular traits for each ecosystem, it is important to determine them in a first step. The main parameters for measuring the success of peatland restoration are the recovery of the characteristic floristic assemblages (including typical dominants and biodiversity) and hydrology manipulation, and over the long term, peat accumulation must be a key-process (Gorham and Rochefort, 2003). In addition, time is an important requirement to take into account for effective restoration because mires, especially ombrogenous bogs, can develop from a wide range of starting points and different situations (Money and Wheeler, 1999).

The aim of this study is to assess whether vegetation composition, cover and diversity (total and of different functional groups) of degraded peatland communities has been affected by the restoration treatment carried out in the study area relative to a natural peatland. We hypothesize that restoration increases species richness and results in a higher floristic composition similarity with respect to the natural peatland, in comparison with the unrestored peatland. Mire shrubs, sedges and Sphagna are expected to increase in coverage after restoration, as well as heterogeneity in plant communities. The results derived from this study are expected to be of great help to provide some technical recommendations for these habitats continuity.

Material and Methods

Site description and restoration treatment

The study was conducted into three peatland communities at the Ebro Reservoir surroundings in central-northern Spain (850 m a.s.l): a pristine or natural peatland (42º58'24.01''N, 3º56'46.67''W), the 'Margarita' restored peatland (42º58'6.28''N, 3º54'46.26''W) and the 'Elena' unrestored peatland (42º58'2.66''N, 3º54'30.04''W) (Figure 1).

The Ebro Reservoir is the largest of the Ebro River basin and it was built in 1952. It has a surface of 62.50 km^2 and plays a major role in downstream streamflows. Its formation was due to the accumulation of siliceous sandrocks deposits (Romaní *et al.*, 2011; Zambrano-Bigiarini *et al.*, 2011), in a transition zone between continental-Mediterranean and Oceanic climates. The mean annual rainfall is of 800-1000 mm and most rain falls in late-autumn and winter months. The mean annual temperature is ca. 9 ºC, the monthly mean maximum temperature in the warmest month (August) is 15.9 ºC, and the monthly mean minimum temperature decreases below 0 ºC between December and February. Frosts and snow are frequent in the winter season (Álvarez-Gómez, 2002; Rodríguez-Velasco, 2012).

The peat has high decomposition values in the Von Post Scale, its depth varies between 0.2 and 2.0 m and it is ca. 4500 years old (Guerrero *et al.*, 1988). The landscape is mainly dominated by heathers, pastures and European beech forests (*Fagus sylvatica*). 7306.25 hectares of the Ebro Reservoir surroundings belong to Natura 2000, a network set by the "Habitats Directive" 92/43/EEC that preserves and protects biodiversity through the conservation of natural and semi-natural habitats and species of wild fauna and flora of European Community interest. Particularly, the peatlands communities under study are classified in the priority habitat type "*Sphagnum acid bogs*" (EU Habitat 7110) that includes 'acid bogs, ombrotrophic, poor in mineral nutrients, sustained mainly by rainwater, with a water level generally higher than the surrounding water table, with perennial vegetation dominated by colourful Sphagna hummocks allowing for the growth of the bog' (European Commission, 2007).

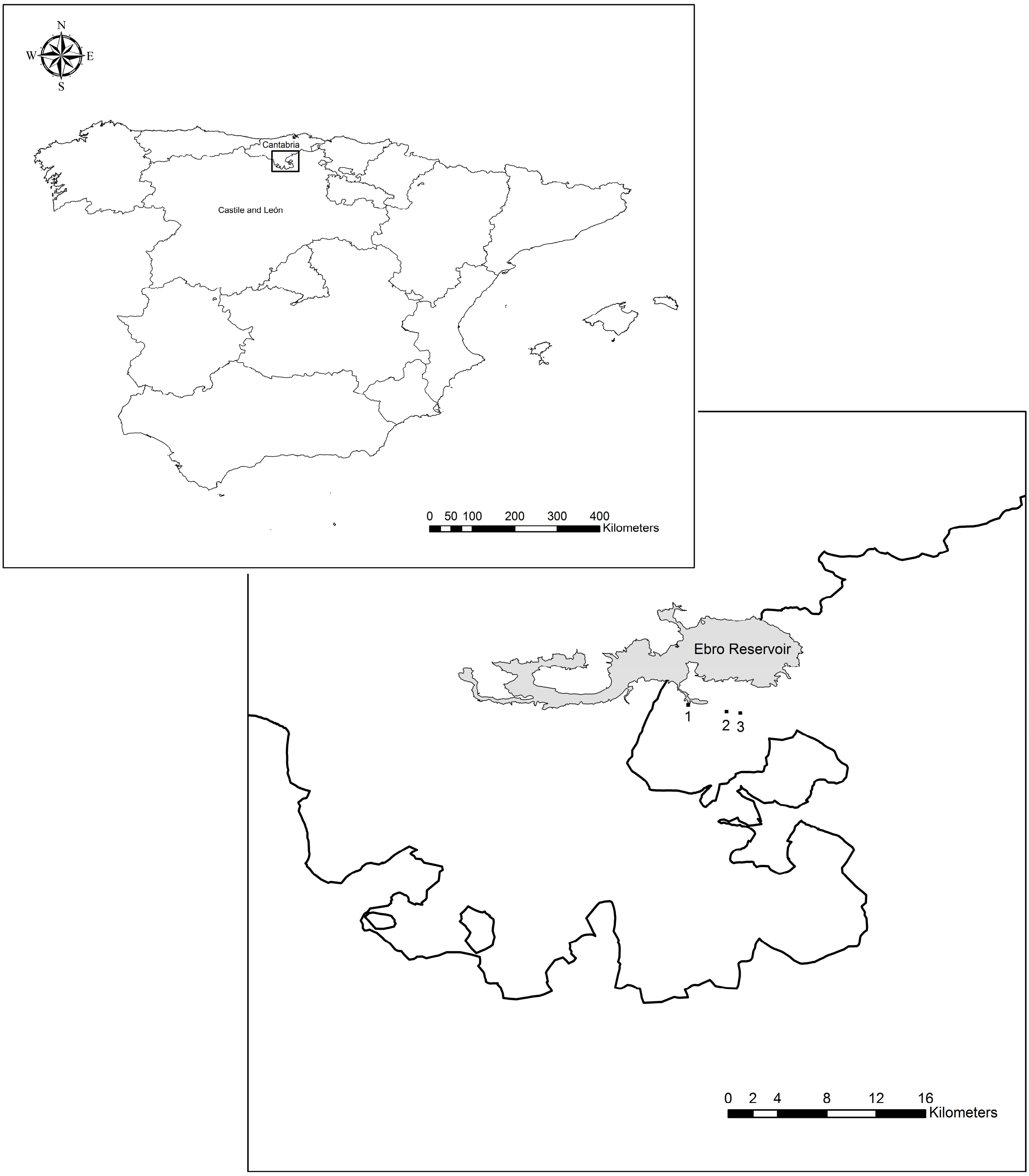

Figure 1. Location of the study area in central-northern Spain. 1: the natural peatland, 2: the restored peatland and 3: the unrestored peatland.

The pristine community, which conserves natural peatland vegetation and is not affected by any treatment or exploitation, is located 6 km away from the other two peatlands under study and has a surface of 0.5 ha. The 'Margarita' restored peatland has a surface of 21 ha. The restoration treatments took place in this peatland during summer and autumn 2002 on the mark of a collaboration project between the 'Castilla y León' Government and 'Caja Burgos'. The drainage ditch located in the northern limit of the site was blocked. A dam was placed close to the ditch and a 1.7 ha surface lagoon was excavated for recreational use. The dam was made by concrete and is 4x1.5x0.2 m. Other two secondary and smaller pools were created close to the main lagoon, resulting the total lagoon system surface on ca. 5 ha (Álvarez-Gómez, 2002). This technical measure helped to rewet the area and bring back natural peat formation. In addition, *Iris pseudacorus*, *Salix purpurea*, *Salix cantabrica, Carex panicea, Rubus ulmifolius, Prunus spinosa, Typha latifolia, Nuphar luteum, Nymphaea alba* and *Myrica gale* were planted around the lagoon system sides forming a vegetation belt, and young birch trees (*Betula alba*), which have their natural distribution in the Ebro Reservoir surroundings (Sanz *et al*., 2011), were planted in the western part of the site. Other species such as *Sorbus aucuparia*, *Populus tremula*, *Ilex aquifolium* and *Euonymus europaeus* were planted in the wide surroundings of the site due to their high ornamental value. The southern part of the restored site is limited by a fence to try to avoid the occasional horse grazing. (Allué-Camacho and García-López, 2003; Álvarez-Gómez, 2002). The 'Elena' unrestored peatland, with a surface of ca. 27 ha, is currently being exploited and any restoration treatment has been carried out. pH levels in the unrestored peatland and the restored peatland are ca. 4.0 (Guerrero *et al.*, 1988).

Experimental design and data collection

For the vegetation inventory, three plots of 2x100 m were established in each peatland (restored, unrestored and natural) in such a way that total spatial heterogeneity was represented within each plot. Within each plot, 20 quadrats of 0.5x0.5 m were located at a distance of 5 m from each other; a total of 180 quadrats were sampled. In the restored peatland, the first quadrat in each plot was located on the shore of the main lagoon. In the unrestored and natural peatlands, plots were established along the whole area. The cover (%) of all species present in each quadrat was estimated visually in mid-May 2014 during the spring season, and cover values per plot ranged from 0 to 100%. Species nomenclature follows Tutin *et al.* (1964-1986) for vascular plants and Hill *et al.* (2006) for bryophytes.

Data analyses

Diversity of three peatlands was assessed using the Shannon index (H') (Shannon and Weaver, 1949) with natural logarithms, and its two components, richness (S) and evenness (E) (Pielou, 1969). Beta diversity or spatial heterogeneity (H'_{β}) was calculated by means of the Margalef (1972) equation. Also richness and cover of different functional groups frequently present in this type of communities were calculated per plot (see Table 1). The first grouping considered bryophytes and vascular plants. The second grouping considered the main families: Cyperaceae, Juncaceae, Leguminosae, Sphagnaceae, Salicaceae and other families. The third grouping considered: trees and shrubs, *Sphagnum* spp., other mosses, rushes, sedges, ferns and herbs. The fourth and fifth grouping considered species habitat preference: forest, peatland, wetland and ruderal, and species water preference: humid, mesic, xeric and water generalists, respectively (D'Astous *et al.*, 2013).

To evaluate the effect of community type on bare soil (Bs), diversity values (H', H'_{β}), total richness (S), and different functional groups cover and richness (see Table 1), one-way analyses of variance (ANOVA) were applied followed by Scheffé's tests to enable pairwise comparisons of means (p<0.05). In all cases, the inspection of residuals was carried out to check for normality and homoscedasticity using the Shapiro-Wilk's and Levene's tests, respectively (Guisande-González *et al.*, 2011). Nevertheless, when variables do not meet normality and variance assumptions (Guisande-González *et al.*, 2011) data were transformed using ln(x+1), i.e. for bare soil (Bs) and cover of rushes, *Sphagnum* and Juncaceae species (Cr, Csph, Cju). In the case of any transformation worked to make data normal and homoscedastic, data were compared by means of Kruskal-Wallis test, using the Wilcoxon Rank Sum test to enable pairwise comparisons of means (p<0.05), i.e. for richness and cover of forest, ruderal and xeric species (Sf, Srud, Sx, Cf, Crud, Cx).

In order to determine possible relationships among the 28 variables statistically significant in the previous analyses, a Pearson's correlation matrix was constructed considering: bare soil (Bs), Shannon diversity (H'), richness (S), spatial heterogeneity (H'_{β}), richness of bryophytes (Sb) and vascular plants (Sv), richness of trees+shrubs (St+s), rushes (Sr), *Sphagnum* spp. (Ssph), Juncaceae (Sju), Leguminosae (Sleg), forest species (Sfo), peatland species (Sp), humid species (Shum), mesic species (Sm), xeric species (Sx) and water generalists (Swg), cover of trees+shrubs (Ct+s), sedges (Cs), *Sphagnum* spp (Csph), Cyperaceae (Ccy), Leguminosae (Cleg), forest species (Cfo), peatland species (Cp), humid species (Chum), mesic species (Cm), xeric species (Cx) and water generalists (Cwg). A Principal Components Analysis (PCA) was used to summarize the relationships among community type and the significant variables as a whole. Data for the 28 variables used in PCA were standardized prior to analysis, to correct for different measuring units. A preliminary PCA was used to order plots according to their differences in floristic composition.

Results were expressed as mean ± standard error and all statistical computations were implemented in SAS (version 9.1.3; SAS Institute Inc., 2006), except for PCAs that were carried out using CANOCO 4.51 (Ter Braak and Šimilauer, 2002), with standard options and no downweighting of rare species.

Results

Floristic composition

A total of 45 species were recorded in the three sampled peatlands as a whole. In particular, 26 species were recorded in the reference community, 23 in the restored peatland and only 6 in the unrestored one, being, respectively, the 77, 52 and 33% of them exclusive of each community. Cyperaceae (5 species), Juncaceae and Sphagnaceae (4 species), and Leguminosae and Salicaceae (3 species) were the best represented taxonomical groups in species richness and cover. 15.6% of the whole species were bryophytes that represented the 10.2% of total plant cover.

The eigenvalues (λ) for the first four PCA axes were 0.573, 0.169, 0.120 and 0.080 respectively, explaining over 94 per cent of the variance in the data (PCA1 = 57.3%, PCA2 = 16.9%, PCA3 = 12% and PCA4 = 8%; Figure 2). PCA1 clearly separated plots on the restored community (positive end of PCA1) to those on the reference one (negative end of PCA1), occupying the unrestored community an intermediate position. PCA2 separated the unrestored plots (negative end of PCA2) from the rest (positive end of PCA2). This ordination shows great differences in floristic composition among three communities, as suggested by the high percentage of species exclusive of each community mentioned above. In the reference community, the most abundant species were *Erica tetralix*, *Myrica gale* and *Molinia caerulea*, but there were also many exclusive species (e.g. *Carex echinata*, *Carex paniculata*, *Carex rostrata, Euphorbia dulcis, Genista anglica*, *Menyanthes trifoliata*, *Narthecium ossifragum, Sphagnum flexuosum*, *Sphagnum subnitens*, *Viola palustris*). In the restored peatland, *Molinia caerulea* had a great abundance as well, and the most abundant exclusive species were: *Halimium lasianthum*, *Calluna vulgaris*, *Betula alba* and *Sphagnum auriculatum*. In the unrestored community *Molinia caerulea*, *Eriophorum angustifolium*, *Juncus squarrosus* and *Juncus articulatus* were the most represented species, being the two latter exclusive of this community.

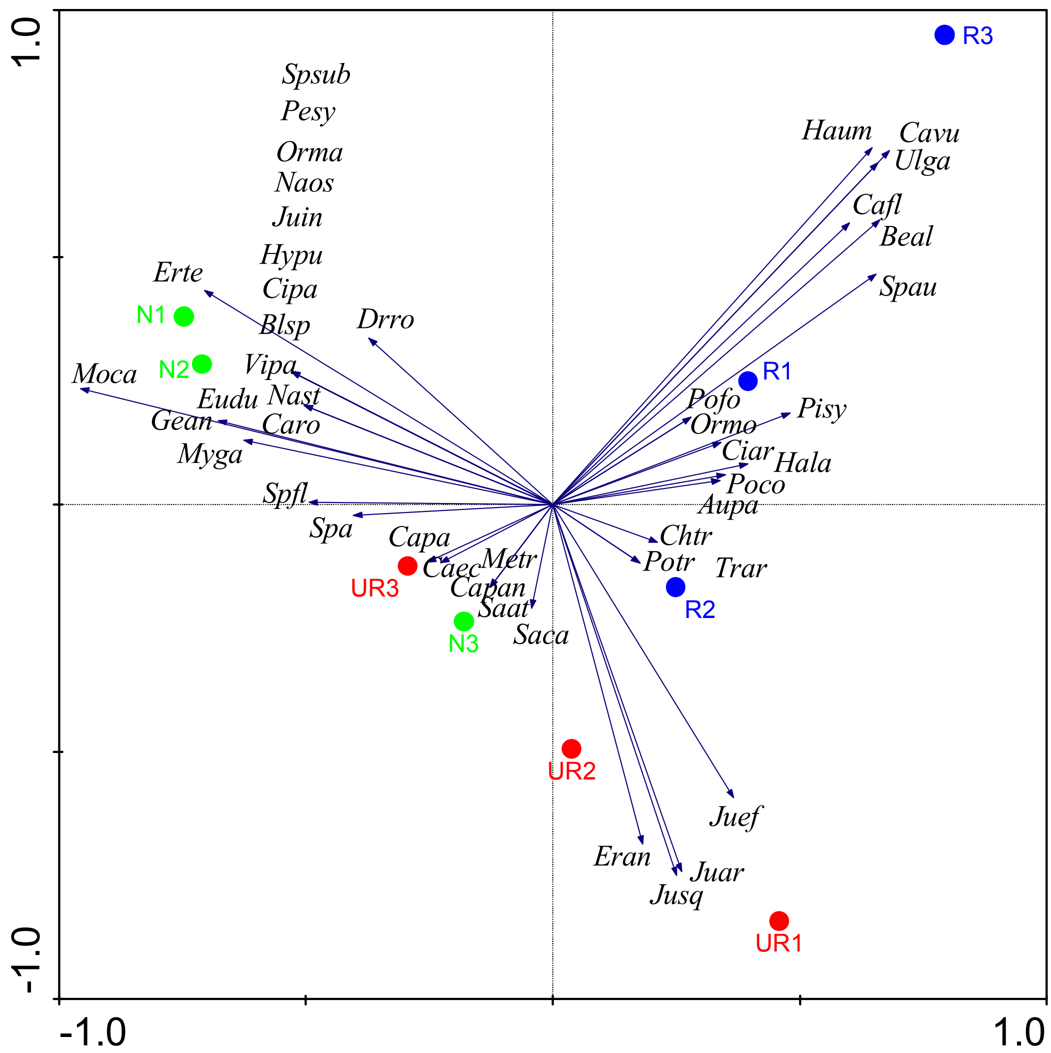

Figure 2. First two axes of PCA ordination of different plots, and species pool. R: restored peatland, UR: unrestored peatland, N: natural community. The number after the abbreviation of the community type indicates the number of replicate. See appendix for species identification.

Diversity and plant cover (total and of different functional groups)

Many of variables analyzed differed among communities (Table 1). No bare soil was found in the reference community and it was considerably higher in the unrestored peatland (53.5%) than in the restored one (6.6%). However, Shannon diversity, total richness and relative bryophytes richness (%) were higher in the restored peatland, not differing from the natural one. Neither *Sphagnum* species nor legumes were found in the unrestored peatland, and the relative richness and cover (%) of the former were higher in the reference community, whereas the relative richness and cover (%) of the latter were higher in the restored one. Juncaceae richness, and Juncaceae and Cyperaceae cover were higher in the unrestored community, although differences in Juncaceae cover were not statistically significant and differences in Cyperaceae cover were probably significant ($p < 0.1$).

Table 1. Results of one-way ANOVA or Kruskal-Wallis test (*) assessing the effect of community type (natural, restored and unrestored) on different variables (mean±standar error). Bs: bare soil (%), H': Shannon diversity, S: richness, E: evenness, H'_{β}: spatial heterogeneity, Sb: richness of bryophytes (%), Cb: cover of bryophytes (%), Som: richness of other mosses (%), St+s: richness of trees+shrubs, Ss: richness of sedges, Sr: richness of rushes, Sf: richness of ferns, Ssph: richness of *Sphagnum* spp., Sh: richness of herbs, Scy: richness of Cyperaceae, Sju: richness of Juncaceae, Sleg: richness of Leguminosae, Ssal: richness of Salicaceae, Sof: richness of other families, Sfo: richness of forest species, Sp: richness of peatland species, Sw: richness of wetland species, Srud: richness of ruderal species, Shum: richness of humid species, Sm: richness of mesic speciezs, Sx: richness of xeric species, Swg: richness of water generalists, Com: cover of other mosses (%), Ct+s: cover of trees+shrubs, Cs: cover of sedges, Cr: cover of rushes, Cf: cover of ferns, Csph: cover of *Sphagnum* spp., Ch: cover of herbs, Ccy: cover of Cyperaceae, Cju: cover of Juncaceae, Cleg: cover of Leguminosae, Csal: cover of Salicaceae, Cof: cover of other families, Cfo: cover of forest species, Cp: cover of peatland species, Cw: cover of wetland species, Crud: cover of ruderal species, Chum: cover of humid species, Cm: cover of mesic species, Cx: cover of xeric species, Cwg: cover of water generalists.

	Community type							
Variable	**Natural**		**Restored**		**Unrestored**		**value**	***p***
Bs (%)	0.00±0.00	**a**	6.63±1.17	**b**	53.52±11.12	**c**	170.20	<0.001
H'	1.58±0.22	**ab**	2.11±0.11	**a**	1.16±0.16	**b**	7.91	0.021
S	14.00±1.53	**a**	15.67±0.88	**a**	5.33±0.33	**b**	28.66	0.001
E	0.61±0.09		0.83±0.04		0.76±0.08		2.33	0.179
H'_{β}	0.93±0.24		1.66±0.11		0.76±0.31		4.20	0.072
Sb (%)	16.57±0.66	**ab**	21.24±1.38	**a**	5.56±5.56	**b**	5.86	0.039
Cb (%)	12.63±4.95		15.94±5.14		2.04±2.04		2.87	0.134
Plant Functional Types (richness %)								
Som	0.00±0.00		12.43±3.03		5.56±5.56		2.90	0.131
St+s	32.38±8.24	**ab**	45.40±6.36	**a**	12.22±6.19	**b**	5.71	0.041
Ss	12.64±3.40		12.85±0.75		18.89±1.11		2.82	0.137
Sr	1.96±1.96	**a**	4.04±2.02	**a**	44.44±8.01	**b**	23.85	0.001
Sf (*)	1.96±1.96		0.00±0.00		0.00±0.00		1.00	0.317
Ssph	16.57±0.66	**a**	8.81±2.74	**b**	0.00±0.00	**c**	25.93	0.001
Sh	34.49±6.95		16.47±4.87		18.89±1.11		3.92	0.081
Families (richness %)								
Scy	12.64±3.40		12.85±0.75		18.89±1.11		2.82	0.137
Sju	1.96±1.96	**a**	4.04±2.02	**a**	44.44±8.01	**b**	23.85	0.001
Sleg	9.87±2.85	**ab**	10.89±2.56	**a**	0.00±0.00	**b**	7.41	0.024
Ssph	16.57±0.66	**a**	8.81±2.74	**b**	0.00±0.00	**c**	25.93	0.001
Ssal	7.91±4.45		4.17±4.17		0.00±0.00		1.26	0.348
Sof	51.06±7.59		59.24±6.04		36.67±8.82		2.28	0.183
Habitat preference (richness %)								
Sfo	25.29±6.80	**ab**	47.36±4.95	**a**	12.22±6.19	**b**	8.68	0.017
Sp	64.09±3.16	**a**	36.05±2.87	**b**	62.22±2.22	**a**	31.83	<0.001
Sw	10.62±6.89		10.47±1.68		25.56±7.29		2.18	0.194
Srud (*)	0.00±0.00		6.13±3.61		0.00±0.00		2.40	0.121
Water preference (richness %)								
Shum	60.71±5.96	**a**	40.09±3.52	**a**	87.78±6.19	**b**	19.91	0.002
Sm	34.77±7.90	**a**	19.40±3.95	**ab**	0.00±0.00	**b**	11.67	0.009
Sx (*)	0.00±0.00	**a**	15.23±3.11	**b**	0.00±0.00	**a**	4.355	0.037
Swg	4.52±2.32	**a**	25.28±2.31	**b**	12.22±6.19	**ab**	6.74	0.029

Table 1 (*continued*)

Variable	Community type						value	*p*
	Natural		Restored		Unrestored			
Plant Functional Types (cover %)								
Com	0.00±0.00		11.65±5.35		2.04±2.04		3.55	0.096
Ct+s	28.42±3.22	**ab**	54.40±9.73	**a**	5.43±2.91	**b**	15.85	0.004
Cs	5.70±4.49		4.50±1.45		22.53±6.35		4.88	0.055
Cr	1.00±1.00		0.27±0.15		15.44±11.41		1.67	0.265
Cf (*)	0.08±0.00		0.00±0.00		0.00±0.00		2.00	0.368
Csph	12.63±4.95	**a**	4.29±0.42	**a**	0.00±0.00	**b**	40.74	<0.001
Ch	52.17±9.59		24.89±5.49		54.56±12.47		2.93	0.129
Families (cover %)								
Ccy	5.70±4.49		4.50±1.45		22.53±6.35		4.88	0.055
Cju	1.00±1.00		0.27±0.15		15.44±11.41		1.67	0.265
Cleg	1.75±0.72	**a**	12.32±2.80	**b**	0.00±0.00	**a**	15.88	0.004
Csph	12.63±4.95	**a**	4.29±0.42	**b**	0.00±0.00	**a**	40.74	<0.001
Csal	2.72±2.59		1.42±1.42		0.00±0.00		0.63	0.562
Cof	73.25±12.22		75.34±2.46		59.77±17.56		0.36	0.71
Habitat preference (cover %)								
Cfo	13.83±2.35	**a**	54.42±9.73	**b**	5.43±2.91	**a**	18.95	0.003
Cp	84.43±3.85	**a**	39.21±8.98	**b**	81.98±7.41	**a**	12.90	0.007
Cw	1.73±1.61		3.82±1.52		12.59±10.10		0.93	0.445
Crud (*)	0.00±0.00		2.55±1.44		0.00±0.00		4.50	0.105
Water preference (cover %)								
Chum	84.43±2.47	**a**	39.47±9.07	**b**	94.57±2.91	**a**	26.66	0.001
Cm	14.68±2.49	**a**	9.75±1.57	**a**	0.00±0.00	**b**	19.36	0.002
Cx (*)	0.00±0.00	**a**	10.15±4.64	**b**	0.00±0.00	**a**	7.62	0.022
Cwg	0.88±0.59	**a**	40.63±12.28	**b**	5.43±2.91	**a**	8.90	0.016

Trees+shrubs richness and cover were higher in the restored peatland than in the unrestored one, not differing from the natural community. Contrary, rushes richness and rushes and sedges cover were higher in the unrestored peatland, although differences in rushes cover were not statistically significant and differences in sedges cover were probably significant ($p < 0.1$). Richness and cover of species typical of forest habitats were higher in the restored community, whereas richness and cover of species typical of peatland habitats were higher in the natural and unrestored ones. Finally, xeric species were only found in the restored community, whereas no mesic species were found in the unrestored one, not differing its richness and cover between natural and restored communities. Richness and cover of humid species were higher in the unrestored community, whereas water generalists' richness and cover were higher in the restored one.

Relationship between variables

The correlation analysis carried out to determine the relationship among the 28 variables analyzed (Table 2) showed that bare soil was negatively correlated with different richness (S, Sb, St+s, Ssph and Sm) and cover (Ct+s and Cm) values, and positively correlated with other richness (Sv, Sr, Sju and Shum) and cover (Cs and Ccy) values. However, bare soil was not correlated with diversity values (H', H'_{β}).

Table 2. Pearson correlation matrix between bare soil, richness, diversity and functional groups richness and cover. See Table 1 for abbreviations. In bold type are significant correlations at $p<0.05$

	Bs(%)	H'	S	H'b	Sb	Sv	St+s	Sr	Ssph	Sju	Sleg	Sfo	Sp	Shum	Sm	Sx	Swg	Ct+s	Cs	Csph	Ccy	Cleg	Cfo	Cp	Chum	Cm	Cx	Cwg
Bs(%)	1																											
H'	-0.52	1																										
S	**-0.88**	**0.72**	1																									
H'b	-0.23	**0.93**	0.52	1																								
Sb	**-0.86**	0.56	**0.82**	0.25	1																							
Sv	**0.86**	-0.56	**-0.82**	-0.25	**-1.00**	1																						
St+s	**-0.74**	0.66	0.62	0.51	**0.68**	**-0.68**	1																					
Sr	**0.98**	-0.56	**-0.86**	-0.29	**-0.84**	**0.84**	**-0.83**	1																				
Ssph	**-0.81**	0.30	**0.69**	0.07	0.55	-0.55	0.55	**-0.83**	1																			
Sju	**0.81**	-0.22	-0.57	0.02	**-0.72**	**0.72**	**-0.71**	**0.82**	-0.49	1																		
Sleg	-0.43	**0.71**	0.56	0.66	0.62	-0.62	**0.78**	-0.53	0.25	-0.36	1																	
Sfo	-0.65	0.65	0.60	0.53	**0.69**	**-0.69**	**0.95**	**-0.75**	0.38	**-0.68**	**0.88**	1																
Sp	0.27	-0.65	-0.49	**-0.71**	-0.44	0.44	-0.57	0.34	0.01	0.22	**-0.84**	**-0.75**	1															
Shum	**0.81**	**-0.69**	**-0.78**	-0.53	**-0.78**	**0.78**	**-0.91**	**0.87**	-0.55	**0.71**	**-0.79**	**-0.95**	**0.74**	1														
Sm	**-0.79**	0.31	0.59	0.10	0.50	-0.50	0.56	**-0.80**	**0.86**	-0.49	0.17	0.45	-0.10	-0.63	1													
Sx	-0.34	0.66	0.51	0.65	0.56	-0.56	**0.71**	-0.44	0.14	-0.31	**0.98**	**0.84**	**-0.91**	**-0.76**	0.08	1												
Swg	-0.17	0.43	0.29	0.44	0.40	-0.40	0.45	-0.21	-0.32	-0.47	0.63	0.61	**-0.68**	-0.50	-0.32	**0.68**	1											
Ct+s	**-0.69**	**0.70**	**0.73**	0.55	**0.78**	**-0.78**	**0.88**	**-0.78**	0.54	-0.57	**0.94**	**0.93**	**-0.73**	**-0.92**	0.47	**0.88**	0.49	1										
Cs	**0.90**	-0.33	**-0.81**	-0.05	**-0.90**	**0.90**	-0.57	**0.85**	-0.66	**0.76**	-0.42	-0.59	0.38	**0.76**	-0.65	-0.41	-0.23	-0.66	1									
Csph	-0.61	0.43	0.46	0.23	0.32	-0.32	0.47	-0.61	**0.69**	-0.36	0.01	0.19	0.29	-0.27	0.59	-0.14	-0.26	0.22	-0.23	1								
Ccy	**0.90**	-0.33	**-0.81**	-0.05	**-0.90**	**0.90**	-0.57	**0.85**	-0.66	**0.76**	-0.42	-0.59	0.38	**0.76**	-0.65	-0.41	-0.23	-0.66	**1.00**	-0.23	1							
Cleg	-0.43	**0.71**	0.56	0.66	0.62	-0.62	**0.78**	-0.53	0.25	-0.36	**1.00**	**0.88**	**-0.84**	**-0.79**	0.17	**0.98**	0.63	**0.94**	-0.42	0.01	-0.42	1						
Cfo	-0.49	**0.67**	0.64	0.60	**0.69**	**-0.69**	**0.75**	-0.58	0.28	-0.45	**0.98**	**0.86**	**-0.83**	**-0.80**	0.15	**0.97**	**0.68**	**0.93**	-0.53	-0.02	-0.53	**0.98**	1					
Cp	0.21	**-0.69**	-0.50	**-0.71**	-0.48	0.48	-0.51	0.29	-0.09	0.05	**-0.92**	-0.65	**0.85**	0.59	0.04	**-0.94**	-0.56	**-0.78**	0.28	0.18	0.28	**-0.92**	**-0.91**	1				
Chum	0.51	**-0.70**	**-0.67**	-0.63	**-0.71**	**0.71**	**-0.75**	0.59	-0.27	0.45	**-0.98**	**-0.86**	**0.85**	**0.82**	-0.16	**-0.97**	**-0.69**	**-0.93**	0.55	0.01	0.55	**-0.98**	**-1.00**	**0.92**	1			
Cm	**-0.84**	0.42	**0.85**	0.19	0.65	-0.65	0.46	**-0.83**	**0.92**	-0.50	0.30	0.35	-0.08	-0.55	**0.70**	0.20	-0.13	0.55	**-0.72**	0.62	**-0.72**	0.30	0.37	-0.21	-0.38	1		
Cx	-0.31	**0.67**	0.52	**0.69**	0.41	-0.41	0.41	-0.30	-0.13	-0.25	0.48	0.52	**-0.81**	-0.60	0.09	0.58	0.65	0.42	-0.39	-0.13	-0.39	0.48	0.52	-0.51	-0.55	0.02	1	
Cwg	-0.26	0.53	0.40	0.51	0.54	-0.54	0.65	-0.37	0.08	-0.32	**0.96**	**0.79**	**-0.78**	-0.65	-0.05	**0.95**	**0.70**	**0.85**	-0.33	-0.18	-0.33	**0.96**	**0.95**	**-0.91**	**-0.94**	0.15	0.38	1

The Shannon diversity (H’) showed a significant positive correlation with total richness (S), spatial heterogeneity (H'_{β}), richness and cover of legumes (Sleg, Cleg), and cover of trees+shrubs (Ct+s), forest (Cfo) and xeric (Cx) species (Table 2). However, H’ was negatively correlated with richness and cover of humid species (Shum, Chum), and with cover of peatland species (Cp). In general, the richness and cover of each functional group were strongly positively correlated.

The PCA performed for the joint comparison of all the variables produced an ordination of plots with the first two axes accounting for 91% of the total variance (Figure 3). The first component explained 70% of variance and was strongly positively correlated with H’, S, Sb, St+s, Sleg, Sfo, Sx, Ct+s, Cleg, Cfo and Cwg; on the contrary, it was strongly negatively correlated with Bs, Sv, Sr, Sp, Shum, Cs, Ccy, Cp and Chum (Table 3). The second component explained an additional 21% and showed only positive correlation with Ssph, Sm and Csph (Table 3).

Table 3. Pearson correlation coefficients of plot scores along axes 1 and 2 and the 28 variables used in the principal components analysis (PCA). In bold type are significant correlations at *p*<0.05

	Axis 1	Axis 2
Bs (%)	**-0.74**	-0.65
H'	**0.72**	-0.08
S	**0.79**	0.35
H'b	0.56	-0.32
Sb	**0.83**	0.30
Sv	**-0.83**	-0.30
St+s	**0.88**	0.19
Sr	**-0.81**	-0.58
Ssph	0.51	**0.68**
Sju	-0.64	-0.51
Sleg	**0.92**	-0.37
Sfo	**0.94**	-0.01
Sp	**-0.77**	0.44
Shum	**-0.95**	-0.19
Sm	0.46	**0.76**
Sx	**0.88**	-0.46
Swg	0.57	-0.44
Ct+s	**0.98**	-0.03
Cs	**-0.72**	-0.50
Csph	0.22	**0.67**
Ccy	**-0.72**	-0.50
Cleg	**0.92**	-0.37
Cfo	**0.94**	-0.33
Cp	**-0.76**	0.58
Chum	**-0.94**	0.32
Cm	0.56	0.58
Cx	0.53	-0.17
Cwg	**0.82**	-0.52
Eigenvalues	0.70	0.21
Explained variance	70%	21%

In the ordination diagram, the first axis was related to a diversity gradient, increasing diversity, total richness and richness and cover of several functional groups to the positive end, and produced a separation between plots from the unrestored peatland on the left end to those from the restored one on the right end, and occupying the natural community an intermediate position (Figure 3). Plots from the unrestored peatland (UR) were located on the left associated with greater bare soil and lower richness. However, plots from the restored peatland (R) appeared on the right with low bare soil and greater species number. The second axis was related to the dominance of *Sphagnum* species and other species characteristics of mesic environments, increasing richness and cover of *Sphagnum* species as well as richness of mesic species to the positive end, and produced a separation between plots from the reference community and those on the restored and unrestored peatlands.

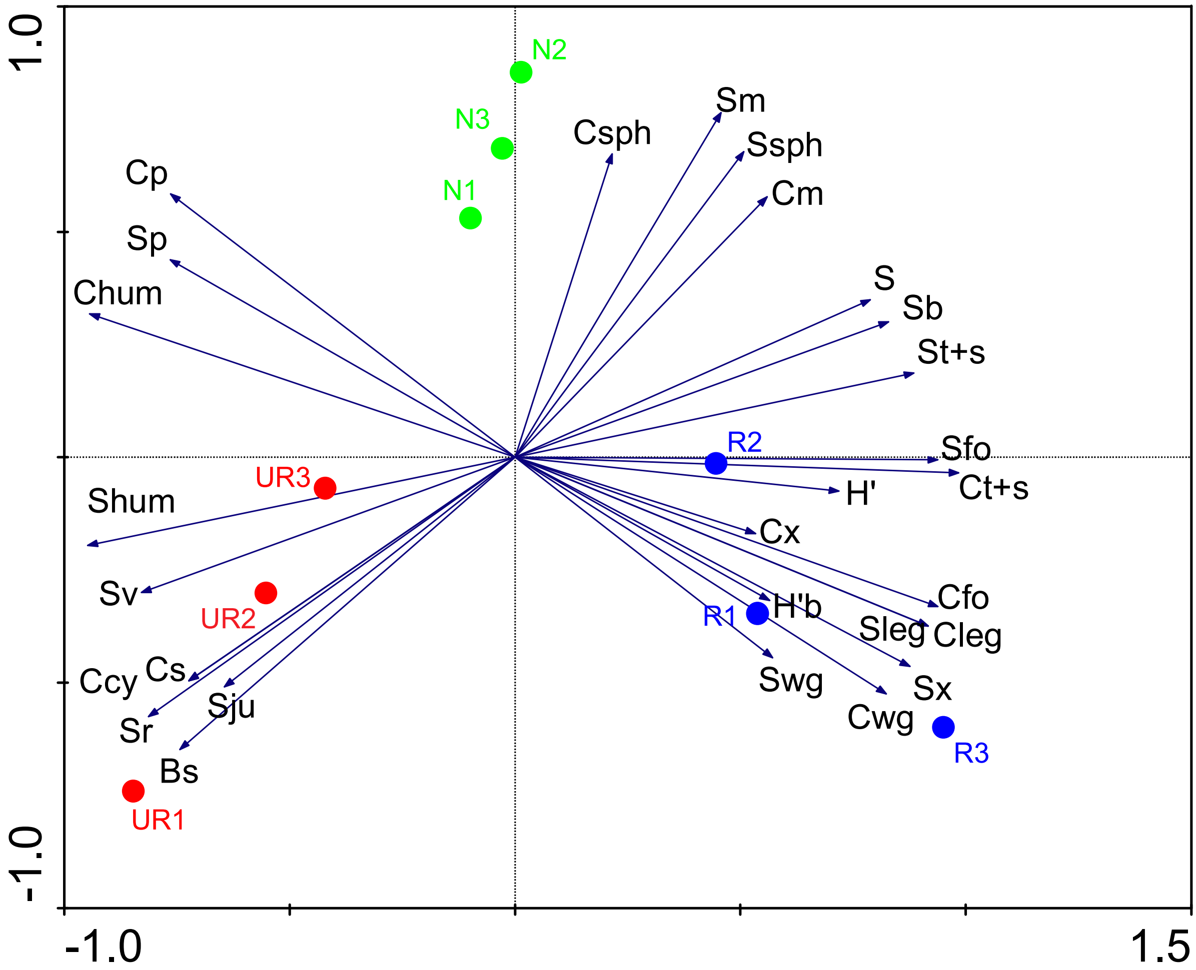

Figure 3. First two axes of PCA ordination of different plots, summarizing the relationship among communities and the 28 selected variables as a whole. See Fig. 1 and Table 1 for abbreviations identification.

Discussion

Our results show that restoration works, carried out in 2002 in the study area, influenced positively vegetation composition, richness and cover during the first 12 years after restoration, thus our hypothesis is accepted. Damming has been successful and water table levels were restored close to the soil surface, so bryophytes cover has started to increase on the shores pools. However, peat mining reduces the ecological integrity of peatland communities, as our data show for the unrestored peatland, where total richness is very low in comparison with the natural and the restored communities and bare soil is predominantly present in the whole surface of the area.

Species composition and diversity

There is a notable influence of the restoration works in Shannon Diversity and total richness. Diversity is affected by total richness and eveness (Westman, 1990), and our results illustrate that 12 years after peatland restoration, both variables are higher in the restored peatland than in the unrestored and natural areas, although there are not significant differences between the pristine and the restored peatland. At the same time, the beta-diversity has its greatest value in the restored peatland, but no differences between communities for this variable were found. As Feldmeyer-Christe *et al.* (2011) stated for peatlands located in southern Germany, these indices can act as clear indicators of early succession. Restoration is therefore successful and increases diversity values. Bedford *et al.* (1999) highlighted the importance of species-specific responses in order to determine the effects of nutrients enrichment on diversity. Nutrient availability usually increases richness in temperate wetlands, but in our restored peatland this variable increased after restoration in spite of the nutrient limitation of peat. Several rare species can only be found in acidic ecosystems like these peatlands, and it is crucial to preserve them with restoration treatments.

The restored peatland is the most hetereogeneous community, but there are stil clear differences in vegetation composition between this peatland and the pristine one. *Sphagnum* mosses form several hummocks in the natural peatland and have greater richness and cover than in the restored community, but there are not statistical significant differences between the restored and natural community for these variables. As it was expected, *Sphagnum* mosses are extremely sensitive to water availability and they can act as key indicators on mining effect on vegetation (Rydin and McDonald, 1985; Price, 1997). Particularly, *Sphagnum auriculatum*, a typical species that grows in peatlands where restoration took place not long time ago (Clymo and Hayward, 1982), has a great abundance around the main pool of the restored peatland, as well as other pioneer mosses that commonly appear in restored peatland communities and can act as nurse-plants in active restoration, like

Aulacomnium palustre (Graf and Rochefort, 2008) and *Polytrichum* spp. (Groeneveld et al., 2007), which were surveyed further from the shores but in places with high water table levels. The restored peatland has a mosaic-like vegetation structure with mainly Salicaceae, Cyperaceae species and bryophytes around the pools, and more mesic and xeric species (Cistaceae and Leguminosae) along the water gradient. Mesic and xeric species typical from Mediterranean environments appear in the restored and natural communities in places where water table level is not very close to the soil surface and peat depth is low, justifying that the peatland communities in the Ebro Reservoir surroundings belong to one of the most northern points of the Mediterranean region within the Iberian Peninsula, although they have a clear influence of the Eurosiberian region (Alejandre-Sáenz *et al.*, 2009).

Juncaceae and Cyperaceae families have higher covers in the unrestored community than in the other two communities, showing that these families are more tolerant to bare peat soils than Sphagnaceae (Large, 1991). In addition, *Eriophorum angustifolium* is a common species for our restored and unrestored communities and it has any representation in the pristine peatland. A similar result was found in Canadian cutover peatlands (Poulin *et al.*, 2011), where pool margins were colonised by *Eriophorum*, and they suggested that this invasion might be a transient phase in the early stages of restoration.

The natural peatland communitiy, with 0.5 ha, has a very high Shannon Diversity, although it is lower than in the restored peatland, but the latter occupies a very much larger area (21 ha). Many species that were found in the pristine community are exclusive of the Ebro Reservoir surroundings and do not appear in other areas within the same latitudes (Allué-Camacho and García-López, 2003). *Molinia caerulea* dominates most of the surface of the pristine area and this could bring to the exclusion of other flowering plants (Taylor *et al.*, 2001), so special emphasis in this aspect should be considered. On the other hand, *Myrica gale* is forming several aggregations and playing an important role in nitrogen fixation for the whole community (Skene *et al.*, 2000).

Vegetation dynamics

The issue of the time that is needed for a restoration process to be effective has been extensively discussed by Money and Wheeler (1999). They suggested that a bog can start to develop from a variety of stages until it reaches a climax habitat, so a starting point have to be established before restoration works will take place. Our peatlands are in three very different stages and time scale should be taken into account in order to know how they will develop.

It could be said that our restored peatland follows the definition of Heathwaite (1993), who stated that a peatland is an ecosystem in an active state where peat is being generated and accumulated, peat depth is higher than 30-50 cm and vegetation grows over it.

Moreover, diversity and spatial heterogeneity in it are very high in comparison with the unrestored peatland. Some vascular plants that were sowed in 2002 just disappeared (*Typha latifolia*, *Iris pseudacorus*, *Nuphar luteum*, *Nymphaea alba*) but others that are tolerant to very acidic soils are growing successfully (*Betula alba* and *Salix cantabrica*). Despite of this, the community needs a speed-up restoration help in order to reach a more natural state (Laine *et al.*, 2011). The restored peatland is still in a recovery process and its floristc composition differs clearly in comparison with the natural peatland. Specific vascular plant species that can be found in natural peatland communities in the Ebro Reservoir surroundings are still absent in the restored area (such as *Carex echinata*, *Carex rostrata*, *Menyanthes trifoliata, Narthecium ossifragum*, *Rhynchospora alba* and *Viola palustris*). Nowadays the peatland is in a transient phase where bryophytes with wide ecological niches and tolerant vascular plants of ombrogenic environments are successfully growing. 50 years are considered to be the time scale that allows a peatland to "self-heal", but special care must be taken in possible new restoration measures, and monitoring can be a great opportunity to know and control all the changes that will take place in the area (Money and Wheeler, 1999; Peacock *et al.*, 2013)

The unrestored peatland vegetation currently occupies an intermediate position between the natural and restored communities, and this could be used as an interesting point to consider future restoration treatments. It is important to highlight that *Eriophorum angustifolium*, a first colonist species that usually disappears as restoration is succeeding (Feldmeyer-Christe *et al.*, 2011), is widely growing in the area, so we are facing a profitable situation that can be managed with anthropogenic actions like the one carried out in Swizterland (Poschlod *et al.*, 2007), where sowing *Eriophorum angustifolium* allowed the community to enter in a phase with peat-forming species growth. Reducing the bare soil percentage should be one of the first key-points to take into account and vascular plants establishment is crucial as a first step.

The pristine peatland could be considered as the most stable of the three communities, because any anthropogenic action has been carried out there and it follows the natural course of succession. Nowadays *Molinia caerulea* is the most abundant species in the area and we predict that it will remain in the community but in less proportions, allowing other humid species to grow (Gaertner *et al.*, 2010). Nevertheless, a study of peat features in areas of the Ebro Reservoir that have not been drained may help to understand its current stage and link it with the successional stages we are coping with in the restored and unrestored sites.

Conclusions

Typical species from bogs or acidic peatlands are found in the three communities. The restored area have a high spatial heterogeneity and active accumulation and decomposition of peat, and we predict that it will turn into a *Sphagnum*-dominated peatland in the future. The unrestored peatland is in a very early transient phase were humid species are growing in patches and bare soil dominates the whole area, but suitable restoration measures could enforce its plant diversity. The natural peatland will probably lose *Molinia caerulea* individuals in favor of some other species, like *Myrica gale*, *Viola palustris*, *Drosera rotundifolia* or *Sphagnum* spp., so the beta-diversity will surely increase. The restored peatland may have a vegetation composition more similar to the natural peatland, but for that many changes have to occur in a long-time scale.

Regarding the restoration measures, floristic assamblages have been partially recovered, as well as the hydrological conditions. Apart from biodiversity, restoration can enhance other ecosystem services, such as recreational use of peatlands and bird watching. We suggest that active planning and long-term monitoring are suitable measures to achieve an efficient restoration process.

References

Alejandre-Sáenz JA, García-López JM, Mateo-Sanz G. 2009. Atlas de la flora vascular silvestre de Burgos. Monografías de Botánica Ibérica 2. Jolube Consultor y Editor Ambiental. Huesca. [In Spanish]

Allué-Camacho C and García-López JM. 2003. Las turberas en Castilla y León: unos ecosistemas singulares a conservar. Medio Ambiente 19, 31-40. [In Spanish]

Álvarez-Gómez E. 2002. Proyecto de restauración de la turbera “Margarita 1”, situada en la localidad de Herbosa (Burgos). Final Work of Forestry Engineering. Escola Tècnica Superior d’Enginyeria Agrària. Universitat de Lleida. [In Spanish]

Bedford BL, Walbridge MR, Aldous A. 1999. Patterns in nutrient availability and plant diversity of temperate north American wetlands. Ecology 80 (7), 2151-2169.

Bottollier-Curtet M and Muller SD. 2009. Past context and dynamics of the development of a Mediterranean peatland (Mont Aigoual, France). C R Biol 332, 69-82.

Cížková H, Květ J, Comín F.A., Laiho R, Pokorný J, Pithart D. 2013. Actual state of European wetlands and their possible future in the context of global climate change. Aquat Sci 75, 3-26.

Clymo RS and Hayward PM.1982. The ecology of *Sphagnum*. In: Bryophyte Ecology. (Smith AJE, ed.). Chapman & Hall, London.

Daoud-Bouattour A, Muller SD, Jamaa HF, Saad-Limam SB, Rhazi L, Soulié-Märsche I, Rouissi M, Touati B, Jilani IB, Gammar AM, Ghrabi-Gammar Z. 2011. Conservation of Mediterranean wetlands: interest of historical approach. C R Biol 334, 742-756.

D'Astous A, Poulin M, Aubin I, Rochefort L. 2013. Using functional diversity as an indicator of restoration success of a cut-over bog. Ecol Eng 61B, 519-526.

Dobson AP, Bradshaw AD, Baker AJM. 1997. Hopes for the future: restoration ecology and conservation biology. Science 277 (5325), 515-522.

European Commission. 2007. Interpretation Manual of European Union Habitats. Technical report, Brussels. 144 pp.

Feldmeyer-Christe E, Küchler M, Wildi O. 2011. Patterns of early succession on bare peat in a Swiss mire after bog burst. J Veg Sci 22 (5), 943-954.

Gaertner M, Konold W, Richardson DM. 2010. Successional changes on a former tank range in eastern Germany: Does increase of the native grass species *Molinia caerulea* cause decline of less competitive *Drosera* species? J Nat Conserv 18, 63-74.

Gorham E and Rochefort L. 2003. Peatland restoration: a brief assessment with special reference to *Sphagnum* bogs. Wetl Ecol Manag 11, 109-119.

Graf MD and Rochefort L. 2008. Moss regeneration for fen restoration: field and greenhouse experiments. Restor Ecol 18 (1), 121-30.

Groeneveld EVG, Massé A, Rochefort L. 2007. *Polytrichum strictum* as a nurse-plant in peatland restoration. Restor Ecol 15 (4), 709-719.

Guerrero E, Monso MA, Polo A. 1988. Condiciones de formación y características del histosol de Herbosa (Burgos). Ecología 2, 69-78. [In Spanish]

Guisande-González C, Vaamonde-Liste A, Barreiro-Felpeto A. 2011. Tratamiento de datos con R, STATISTICA y SPSS. Ediciones Días de Santos. [In Spanish]

Haapalehto T, Vasander H, Jauhiainen S, Tahvanainen T, Kotiaho JS. 2010. The effects of peatland restoration on water-table depth, elemental concentrations, and vegetation: 10 years of changes. Restor Ecol 19 (5), 587-598.

Heathwaite AL. 1993. Disappearing peat – Regenerating peat? The impact of climate change on British peatlands. Geogr J 159, 203–208.

Hedberg P, Kotowski W, Saetre P, Mälson K, Rydin H, Sundberg S. 2012. Vegetation recovery after multiple-site experimental fen restorations. Biol Conserv 147, 60-67.

Henkin Z, Walczak M, Kaplan D. 2012. Dynamics of vegetation development on drained peat soils of the Hula Valley, Israel. Mires and Peat 9.

Hill MO, Bell N, Bruggemann-Nannenga MA, Brugués M, Cano MJ, Enroth J, Flatberg KI, Frahm JP, Gallego MT, Garilleti R, Guerra J, Hedeñas L, Holyoak DT, Hyvönen J, Ignatov MS, Lara F, Mazimpaka V, Muñoz J, Söderström L. 2006. An annotated checklist of the mosses of Europe and Macaronesia. J Bryol 28, 198–267.

Hobbs RJ and Harris JA. 2001. Restoration ecology: Repairing the Earth's ecosystems in the New Millennium. Restor Ecol 9 (2), 239-246.

Joosten H and Clarke D. 2002. Wise Use of Mires and Peatlands. Background and Principles including a framework for Decision-making. International Mire Conservation Gropu and International Peat Society. Jyväskylä, Finland.

Kaplan D. 2012. Instability in newly-established wetlands? Trajectories of floristic change in the re-flooded Hula peatland, northern Israel. Mires and Peat 9.

Laine AM, Leppälä M, Tarvainen O, Päätalo ML, Seppänen R, Tolvanen A. 2011. Restoration of managed pine fens: effect on hydrology and vegetation. Appl Veg Sci 14, 340-349.

Large ARG. 1991. The Slievenakilla bog-burst: investigations into peat loss and recovery on an upland blanket bog. The Irish Naturalist's Journal 24, 354–359.

Large ARG. 2001. Reversing spontaneous succession to protect high-value vegetation: assessment of two Scottish mires using rapid survey techniques. Appl Veg Sci 4, 103-110.

Lavoie C, Saint-Louis A, Lachance D. 2005. Vegetation dynamics on an abandoned vacuum-mined peatland: 5 years of monitoring. Wetl Ecol Manag 13, 621-633.

Mälson K and Rydin H. 2007. The regeneration capabilities of bryophytes for rich fen restoration. Biol Conserv 135, 435-442.

Margalef R. 1972. Homage to Evelyn Hutchinson, or why is there an upper limit to diversity. Trans Conn Acad Arts Sci 44, 211–235.

Money RP and Wheeler BD. 1999. Some critical questions concerning the restorability of damaged raised bogs. Appl Veg Sci 2, 107-116.

Peacock M, Evans CD, Fenner N, Freeman C. 2013. Natural revegetation of bog pools after peatland restoration involving ditch blocking – The Influence of pool depth and implications for carbon cycling. Ecol Eng 57, 297-301.

Pielou EC. 1969. An introduction to mathematical ecology. Wiley, New York.

Poschlod P, Meindl C, Sliva J, Herkommer U, Jäger M, Schuckert U, Seemann A, Ullmann A, Wallner T. 2007. Natural revegetation and restoration of drained and cut-over raised bogs in southern Germany – A comparative analysis of four long-term monitoring studies. Glob Env Res 11, 205-216.

Poulin M, Natacha F, Rochefort L. 2011. Restoration of pool margin communities in cutover peatlands. Aquat Bot 94, 107–111.

Price JS. 1997. Soil moisture, water tension, and water table relationships in a managed cutover bog. J Hydrol 202: 21-32.

Raeymaekers G. 2000. Conserving mires in the European Union. Actions co-financed by LIFE-Nature. Ecosystems Ltd. Luxembourg.

Rodríguez-Velasco JJ. 2012. Variabilidad temporal de la precipitación y la temperatura en las comarcas de la región de Cantabria. Doctoral thesis. Universidad de Cantabria, Santander. [In Spanish]

Romaní AM, Sabater S, Muñoz I. 2011. The physical framework and historic human influences in the Ebro River. In: The Ebro River Basin. The Handbook of Environmental Chemistry 13. (Barceló D and Petrovic M, eds.). Berlin-Heidelberg, Springer-Verlag.

Rydin H and McDonald JS. 1985. Tolerance of *Sphagnum* to water level. J Bryol 13: 571-578.

Sanz R, Pulido F, Camarero J. 2011. Boreal trees in the Mediterranean: recruitment of downy birch (*Betula alba*) at its southern range limit. Ann For Sci 68, 793-802.

SAS Institute Inc.. 2002. SAS/STAT Version 9.1.3. SAS Institute Inc., Cary, NC.

Shannon CE and Weaver W. 1949. The mathematical theory of communication. University of Illinois Press, Urbana.

Skene KR, Sprent JI, Raven JA, Herdman L. 2000. *Myrica gale* L. J Ecol 88, 1079-1094.

Sottocornola M, Laine A, Kiely G, Byrne KA, Tuittila ES. 2009. Vegetation and environmental variation in an Atlantic blanket bog in south-western Ireland. Plant Ecol 203, 69-81.

Taylor K, Rowland AP, Jones HE. 2001. *Molinia caerulea* (L.) Moench. J Ecol 89, 126-144.

Ter Braak CJ and Šmilauer P. 2002. CANOCO Reference Manual and CANODRAW for Windows User's Guide version. Microcomputer Power 4.5. Ithaca, New York.

Topić J and Stančić Z. 2006. Extinction of fen and bog plants and their habitats in Croatia. Biodivers Conserv 15, 3371-3381.

Tutin TG, Heywood VH, Burges NA, Moore DM, Valentine DH, Walters SM, Webb A. 1964–1986. Flora Europaea, Voll. I -V. Cambridge University Press, UK.

Westman EW. 1990. Managing for biodiversity: unresolved science and policy questions. Bioscience 40, 26–33.

Zambrano-Bigiarini M, Majone B, Bellin A, Bovolo CI, Blenkinsop S, Fowler HJ. 2011. Hydrological impacts on climate change on the Ebro River basin. In: The Ebro River Basin. The Handbook of Environmental Chemistry 13. (Barceló D and Petrovic M, eds.). Berlin-Heidelberg, Springer-Verlag.

Appendix. Family and category of different functional groups characteristic of this type of communities for the whole species found in the study; in green, blue and red colours species exclusive of natural, restored and unrestored peatlands, respectively.

Code	Species name	Family	Plant Functional Types	Habitat preference	Water preference
Aupa	*Aulacomnium palustre* (Hedw.) Schwägr.	Aulacomniaceae	Other mosses	Peatland	Humid
Beal	*Betula alba* sensu Coste, non L.	Betulaceae	Trees and shrubs	Forest	Mesic
Blsp	*Blechnum spicant* (L.) Roth	Blechnaceae	Fern	Wetland	Humid
Cavu	*Calluna vulgaris* (L.) Hull	Ericaceae	Trees and shrubs	Forest	Water generalist
Capa	*Caltha palustris* L.	Ranunculaceae	Herbs	Peatland	Humid
Caec	*Carex echinata* Murray	Cyperaceae	Sedges	Peatland	Humid
Cafl	*Carex flacca* Schreber	Cyperaceae	Sedges	Wetland	Mesic
Capan	*Carex paniculata* L.	Cyperaceae	Sedges	Peatland	Humid
Caro	*Carex rostrata* Stokes in With.	Cyperaceae	Sedges	Peatland	Humid
Chtr	*Chamaespartium tridentatum* (L.) P. Gibbs	Leguminosae	Trees and shrubs	Forest	Xeric
Ciar	*Cirsium arvense* (L.) Scop.	Compositae	Herbs	Ruderal	Water generalist
Cipa	*Cirsium palustre* (L.) Scop.	Compositae	Herbs	Wetland	Mesic
Drro	*Drosera rotundifolia* L.	Droseraceae	Herbs	Peatland	Humid
Erte	*Erica tetralix* L.	Ericaceae	Trees and shrubs	Forest	Mesic
Eran	*Eriophorum angustifolium* Honckeny	Cyperaceae	Sedges	Peatland	Humid
Eudu	*Euphorbia dulcis* L.	Euphorbiaceae	Herbs	Forest	Mesic
Gean	*Genista anglica* L.	Leguminosae	Trees and shrubs	Peatland	Mesic
Hala	*Halimium lasianthum* (Lam.) Spach	Cistaceae	Trees and shrubs	Forest	Xeric
Haum	*Halimium umbellatum* (L.) Spach	Cistaceae	Trees and shrubs	Forest	Xeric
Hypu	*Hypericum pulchrum* L.	Guttiferae	Herbs	Wetland	Mesic
Juar	*Juncus articulatus* L.	Juncaceae	Rushes	Wetland	Humid
Juef	*Juncus effusus* L.	Juncaceae	Rushes	Wetland	Humid
Juin	*Juncus inflexus* L.	Juncaceae	Rushes	Wetland	Humid
Jusq	*Juncus squarrosus* L.	Juncaceae	Rushes	Peatland	Humid
Metr	*Menyanthes trifoliata* L.	Menyanthaceae	Herbs	Peatland	Humid
Moca	*Molinia caerulea* (L.) Moench	Gramineae	Herbs	Peatland	Humid
Myga	*Myrica gale* L.	Myricaceae	Trees and shrubs	Peatland	Humid
Nast	*Nardus stricta* L.	Gramineae	Herbs	Forest	Mesic
Naos	*Narthecium ossifragum* (L.) Hudson	Liliaceae	Herbs	Peatland	Humid
Orma	*Orchis mascula* (L.) L.	Orchidaceae	Herbs	Forest	Water generalist
Ormo	*Orchis morio* L.	Orchidaceae	Herbs	Forest	Water generalist
Pesy	*Pedicularis sylvatica* L.	Scrophulariaceae	Herbs	Peatland	Humid
Pisy	*Pinus sylvestris* L.	Pinaceae	Trees and shrubs	Forest	Water generalist
Poco	*Polytrichum commune* Hedw.	Polytrichaceae	Other mosses	Peatland	Humid
Pofo	*Polytrichum formosum* Hedw.	Polytrichaceae	Other mosses	Peatland	Humid
Potr	*Populus tremula* L.	Salicaceae	Trees and shrubs	Forest	Mesic
Saat	*Salix atrocinerea* Brot.	Salicaceae	Trees and shrubs	Forest	Mesic
Saca	*Salix cantabrica* Rech. fil.	Salicaceae	Trees and shrubs	Forest	Mesic
Spau	*Sphagnum auriculatum* Schimp.	Sphagnaceae	*Sphagnum* mosses	Peatland	Humid
Spfl	*Sphagnum flexuosum* Dozy & Molk.	Sphagnaceae	*Sphagnum* mosses	Peatland	Humid
Spa	*Sphagnum papillosum* Lindb.	Sphagnaceae	*Sphagnum* mosses	Peatland	Humid
Spsub	*Sphagnum subnitens* Russow & Warnst.	Sphagnaceae	*Sphagnum* mosses	Peatland	Humid
Trar	*Trifolium arvense* L.	Leguminosae	Herbs	Ruderal	Water generalist
Ulga	*Ulex gallii* Planchon	Leguminosae	Trees and shrubs	Forest	Water generalist
Vipa	*Viola palustris* L.	Violaceae	Herbs	Peatland	Humid