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# A TEST OF MOWING AND SOIL-REMOVAL RESTORATION TECHNIQUES IN WET HEATHS OF THE HIGH ARDENNE, BELGIUM

Anne-Laure Jacquemart[1], Dominique Champluvier[2], and Jacques De Sloover[1]
[1] *Unité d'Ecologie et de Biogéographie*
*Centre de recherche sur la biodiversité*
*Université catholique de Louvain*
*5 Place Croix-du-Sud*
*Belgium - 1348 Louvain-la-Neuve*
*E-mail: Jacquemart@ecol.ucl.ac.be*

[2] *National Botanical Garden of Belgium*
*Domaine de Bouchout*
*Belgium - 1680 Meise*

*Abstract:* Vegetation restoration was attempted in four plots of a degraded wet heath overgrown by *Molinia caerulea* in High Ardenne (Belgium). Two treatments, mowing for two years and removal of the top 3–28 cm of peat, were applied in spring 1989. The vegetation was recorded in 1989 and 1998 using the Braun-Blanquet method. After nine years, the mowing treatment had relatively little effect on vegetation composition. We observed a 0–25 % decrease of *Molinia* cover and an increase of some heath species like *Calluna vulgaris* (12–47 %) and *Erica tetralix* (0–12 %). However, top peat removal had a pronounced and beneficial effect. A decrease of a mean of 66 % in cover of *Molinia caerulea* was observed as well as an increase of the cover of *Erica tetralix* (0–12 %). Peat removal also promoted the re-establishment of some typical wet heath species like *Juncus squarrosus* and *Carex panicea*, as well as of some rare pioneer species like *Drosera rotundifolia* and *Lycopodiella inundata*. This treatment appears to be favorable for the regeneration of degraded wet heaths in High Ardenne.

*Key Words:* degraded wet heaths, top peat-removal, *Molinia caerulea*, wet heath restoration

## INTRODUCTION

Vegetation 'restoration' by its restricted definition implies a return to a former or original state (Pfadenhauer and Klötzli 1996, Higgs 1997). The degree of similarity between a former (or original) and a restored state is not explicit, but it is implicit that a restored object should have substantial similarity with a former condition (Brülisauer and Klötzli 1998). This paper investigated the use of peat removal and, to a lesser extent, mowing as techniques for restoring of wet heaths in the plateau des Tailles, in Upper Ardenne, Belgium.

Bogs and wet heaths occur predominantly in the cool temperate zones of Eurasia and America and were once much more widespread in Europe than they are today. Historically, losses in Europe were due to the conversion of heaths for agriculture and forestry (Göttlich and Kaule 1990, Aerts et al. 1995, Wheeler and Shaw 1995, Brooks and Stoneman 1997).

Until the beginning of past century, large areas in Upper Ardenne were covered by wet heaths. This semi-natural vegetation occupied thin peaty soils (less than 50 cm) and was maintained by traditional agriculture (Cardoen and Martens 1990, Dumont and Champluvier 1990), such as extensive sheep grazing, mowing, and rye (*Secale cereale* L.) cultivation (Hoyois 1981). Rye fire cultivation was practiced in Ardenne during the eighteenth and nineteenth centuries. This consisted of superficial draining and burning of the upper peat layers followed by cultivation of rye in the resultant ash-charcoal-peat mixture. Now, many wet heaths occur on the margins of mires, as traditional peat cutting has affected nearly all the bogs in the area (Hoyois 1981).

Using the European Braun-Blanquet classification, three peaty heath communities are recognized on the plateau des Tailles, in Upper Ardenne (De Sloover et al. 1980): (1) the *Oxycocco-Ericetum tetralicis* association belonging to the *Oxycocco-Sphagnetea*; (2) the sub-association of the *Calluno-Nardetea* with *Erica tetralix* of the *Vaccinio vitis-idaeae-Callunetum*; and (3) also in the *Calluno-Nardetea* association, the *Junco squarrosi-Nardetum*, a semi-bushy heath.

Once agricultural management ceases, these wet heaths rapidly convert into mono-dominant *Molinia caerulea* grassland (Chambers et al. 1999, Taylor et al. 2001). This change is generally ascribed to increased nutrient availability (particularly nitrogen) in these nutrient-poor ecosystems (Dumont and Champluvier 1990, Berendse et al. 1994, Bakker and Berendse 1999, Chambers et al. 1999). *Molinia caerulea* (L.) Moench is an erect, compactly tufted perennial grass, 15 to 250 cm high when flowering, forming either tussocks or extensive swards. This species is a common native species, widespread in Europe, usually abundant, and frequently dominating large areas, often to the exclusion of other flowering plants (Taylor et al. 2001). Species diversity decreases because many higher plant species, bryophytes, and lichens decrease in both species number and in cover (Chambers et al. 1999, Taylor et al. 2001).

Many insect species, rare reptiles, and bird species (e.g., *Tetrao tetrix* L.) also have disappeared from such sites in Belgium (Frankard et al. 1998). These Belgian communities eventually undergo succession to forest, after invasion by *Salix aurita* L., *S.* × *multinervis* Döll., *S. caprea* L., *Sorbus aucuparia* L., *Betula pubescens* Ehrh., and *Quercus robur* L. (Dumont and Champluvier 1990).

As a consequence of these impacts, species-rich wet heaths are threatened ecosystems. Their restoration often requires a reduction of nutrient availability (Marrs 1985, 1993, Marrs and Gough 1989, Pywell et al. 1994, Aerts et al. 1995, De Graaf et al. 1998, Bakker and Berendse 1999). Restoration success depends strongly on species establishment (e.g., diaspore bank and diaspore dispersal) and species survival in relation to soil and water conditions (Putwain and Gillham 1990, Mitchell et al. 1997, 1999, 2000). Some restoration experiments have been carried out on degraded wet heaths and tried to decrease nutrient availability (Diemont et al. 1982, Diemont and Linthorst Homan 1989, Cardoen and Martens 1990, Marrs 1993, Pywell et al. 1994, Aerts et al. 1995, Moen 1995, Nolan et al. 1995, Dunne and Doyle 1998, Mitchell et al. 1999). One way to remove excess nutrients is to remove top soil (Werger et al. 1985, Marrs 1993, Sansen and Koedam 1996). The depth of the layer to be removed depends on the nutrient concentration at different soil depths. Scraping to a depth of c. 30 cm may be sufficient in most cases (Diemont 1990, Marrs 1993, Mitchell et al. 2000). This treatment is drastic, and it is often not known how this removal affects macronutrient availability or what proportion of the soil seed bank would remain (Marrs 1993, Dupieux 1998).

Another method for reducing nutrient availability is mowing (Marrs 1993), which has been successfully tested in Norway (Moen 1995). Increased mowing frequency and removing the cuttings would obviously remove more nutrients from the soil than one cut per year would, but this technique may weaken some of the characteristic species of fen meadows, particularly species that flower late in the year, such as *Molinia caerulea*. Grazing could also be used successfully (Nolan et al. 1995, Dunne and Doyle 1998, Dupieux 1998) if appropriate shepherding is available, which is not the case on the plateau des Tailles.

As the techniques for wet heath restoration are poorly documented (Dupieux 1998), the aim of this study was to investigate the effects of two treatments: (1) surface peat removal (up to the mineral layers) and (2) two years of mowing, on the floristic composition of degraded wet heaths. The vegetation was surveyed nine years after experimental treatments were applied. The objective of these treatments was to reduce *Molinia* cover and promote the re-establishment of typical wet heath species. Even with only two years of mowing, we expected to reduce *Molinia* tussocks and promote other species.

## METHODS

### Site Location

The study was conducted near Vielsalm at the plateau des Tailles in the Upper Ardenne, Belgium (50°14′ N, 5°47′ E, 550–620 m alt.). The site was located in the nature reserve 'Réserve Naturelle Domaniale de la Grande Fange de Bihain' of approx. 200 ha (Figure 1). The soil profile consists of a 5- to 30-cm layer of fine compact black peat containing rhizomes and roots, overlaying a 15–20 cm mineral horizon of light brown compact sand and silt. The mean annual rainfall is about 1260 mm, and the mean annual temperature is 6.9 °C. During past centuries, the site was used for peat digging and summer grazing, as well as rye cultivation. At the beginning of the past century, a significant part of this area (dry to wet) was drained and planted with *Picea abies* (L.) Karst. Today, the vegetation of a great part of the Reserve is dominated by *Molinia*-degraded wet heath and *Picea* plantations.

### Experiments

In May 1989, four plots (15 × 10 m) were chosen. They represented highly degraded wet heaths, dominated by *Molinia*. Plots were located on the margins of the reserve, and so they were easy to reach with machines (Figure 1).

In each plot, three quadrats (5 × 10 m) were delimited with wood stakes, and the following treatments were applied: (1) mowing (M1 to M4), (2) removal of surface peat (P1 to P4), and (3) unmanaged (U1 to U4). Peat removal was carried out on May 29 and 30, 1989 with an excavator. Only 1–2 cm of peat was left above the mineral soil. Mowing was done at the end

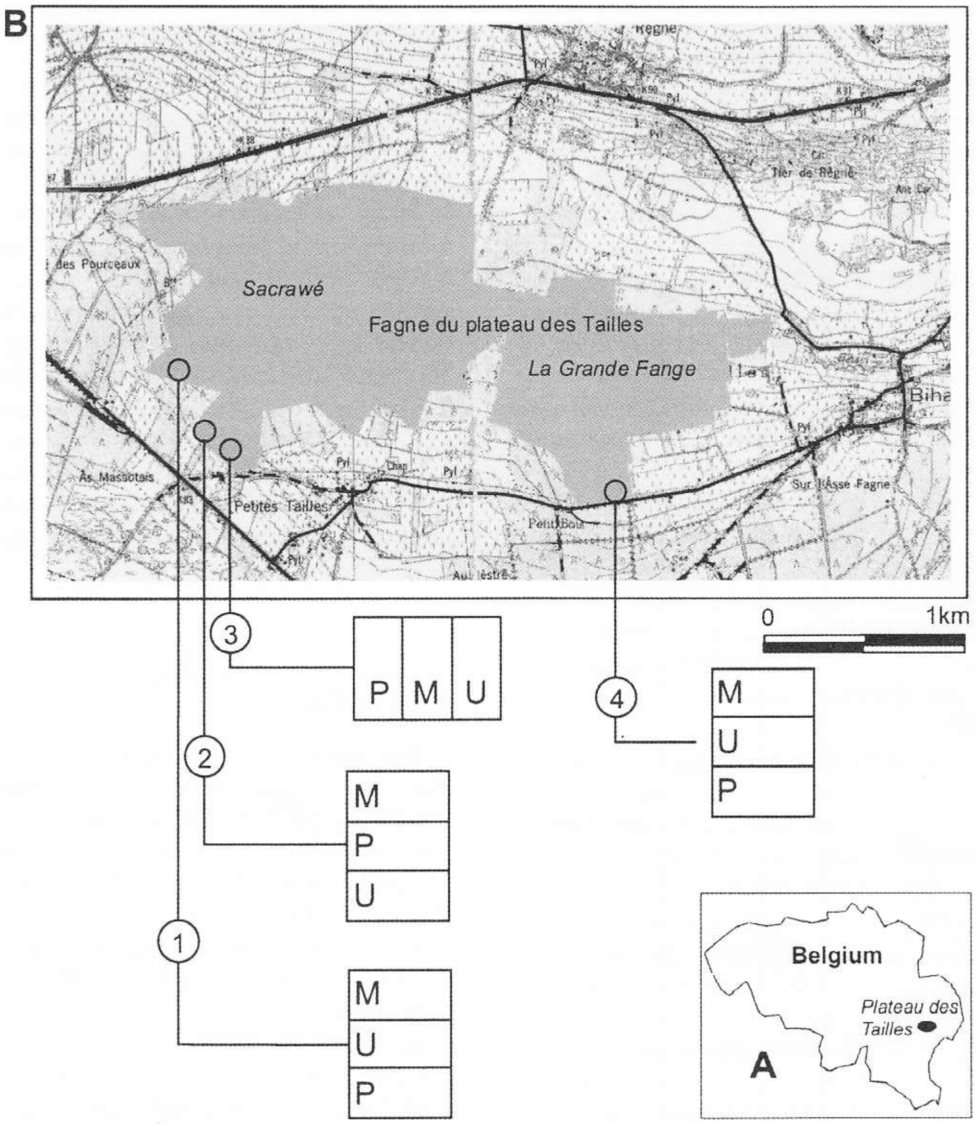


Figure 1. Location of the plateau des Tailles, Belgium (A) and of the experimental quadrats in la Grande Fange Reserve (B) wet heaths (U: unmanaged, P: top peat removed, M: mowed).

of the spring in 1989 and 1990 (see Dumont and Champluvier 1990 for details).

Vegetation Survey and Analyses

A total of 16 relevés: 4 (I1-I4, one per plot) in 1989 before restoration treatments and 12 (one per quadrat) in 1998, following the Braun-Blanquet method, were available for analysis. Nomenclature follows Lambinon et al. (1993) for Spermatophytes, Daniels and Eddy (1990) for Sphagna, vanden Berghen (1979) for liverworts, and Smith (1978) for other Bryophytes.

The species data were classified by Ward's method (agglomerative hierarchical fusion) using SIMIL (Steinhaus similarity index) and CLUSTER using the 'R Package', following van der Maarel ordinal transformation of the cover-abundance scores (Legendre and Vaudor 1991). Principal coordinates analysis (PCA) was also used (SIMIL and PCOORD, Legendre and Vaudor 1991). The program IndVal was used to determine the indicator species of the groups (Dufrêne and Legendre 1997). This IndVal index value is maximum (100 %) when all individuals of a species are found in a single group of sites ("specificity") and when the species occurs in all sites of that group ("fidelity"). The statistical significance of the species indicator values was evaluated using a randomization procedure (1000 bootstraps, $p = 0.05$). Spearman correlation tests were performed between species number and peat depth (SAS Institute 1993).

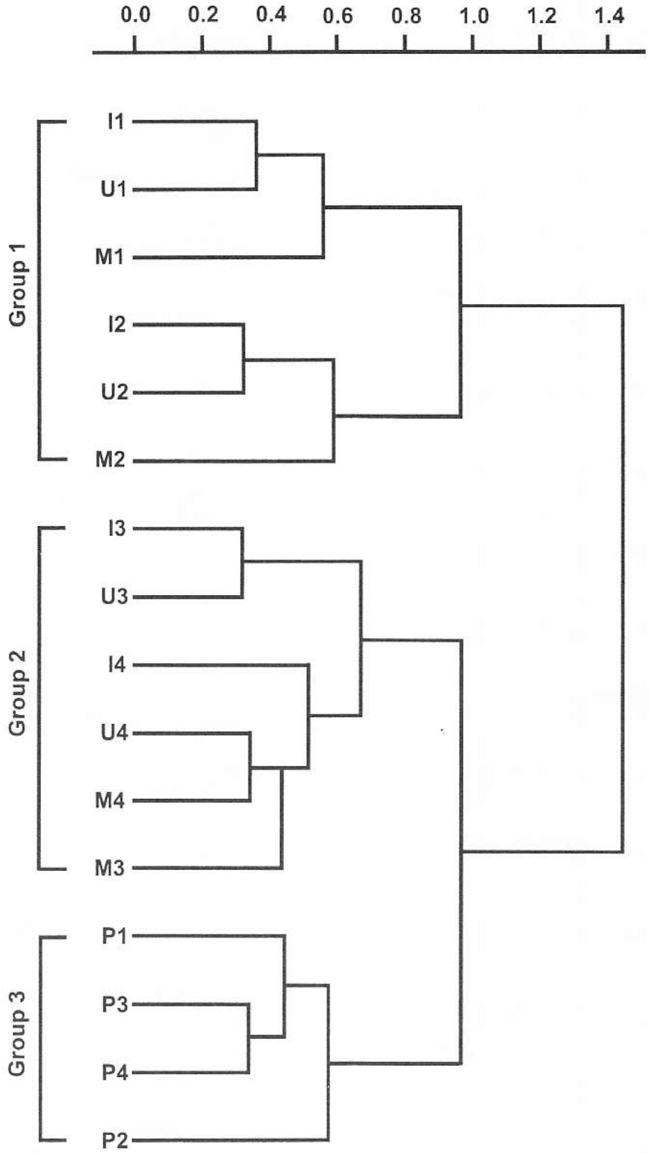


Figure 2. Pcoord classification of quadrat samples from La Grande Fange wet heaths. Symbols of samples refer to treatments (I: initial stage in 1989, U: unmanaged, P: top peat removed, M: mowed). Noda are indicated.

## RESULTS

### Vegetation Classification

Using vegetation classification generated by Ward's method (Figure 2, Legendre and Vaudor 1991) and PCA results (Figure 3), a three-nodum level was chosen after randomization to maximize IndVal values. PCA axes 1, 2, and 3 accounted for 30.8, 17.7, and 14.1 % of the floristic variation, respectively.

The main difference was between plots 1–2 and plots 3–4. The vegetation of plots 1 and 2 was distinct (Table 1) and occupied different parts of the PCA ordination (Figure 3). Within these two groups, the mown quadrats were grouped with the unmanaged ones. The second main difference separated the quadrats where peat was removed from the unmanaged and mown quadrats (Figures 2–3).

According to Indval values (expressed in percents), the following noda were recognized (they represent a sequence from unmanaged to quadrats with peat removal).

(1) *Narthecium ossifragum* nodum (I1, U1, M1), with a high constancy of *Narthecium ossifragum* and Ericaceae species, and a high number of mosses and liverworts (e.g., *Calliergon stramineum*, *Calypogeia fissa*, *Campylopus flexuosus*, *Cephalozia lammersiana*, *Cladonia portentosa*, *Hypnum cupressiforme*, *H. jutlandicum*, *Leucobryum glaucum*, *Lophozia bicrenata*, and *Polytrichum strictum*). Except for the presence of *Narthecium*, this group was quite similar to plot 2 (I2,

Table 1. Species composition following the different treatments (initial stage in 1989 (I), mowed (M), peat removed (P) or unmanaged (U)) (sd: seedlings). The species not indicated in the table are as follows. 1, I1: *Calliergon stramineum* (Brid.) Kindb. +, *Calypogeia fissa* (L.) Raddi +, *Campylopus flexuosus* (Hedw.) Brid. +, *Dicranum scoparium* Hedw. 1, *Hypnum jutlandicum* Holmen & Warncke +. 2, I2: *Galium saxatile* L. + 3, I3: *Epilobium angustifolium* L. 1 4, I4: *Campylopus pyriformis* (Schultz.) Brid. 1 5, U1: *Campylopus flexuosus* (Hedw.) Brid. +, *Cephalozia lammersiana* (Hüb.) Carring.+ 7, U3: *Galeopsis tetrahit* L. + 8, U4: *Senecio ovatus* (Gaertn, B. Mey. & Scherb.) Willd. + 9, M1: *Frangula alnus* Mill. +°, *Lophozia bicrenata* (Schmid. Ex Hoffm.) Dum. + 12, M4: *Dactylorhiza sphagnicola* (Höppner) Averyanov + 13, P2: *Carex pilulifera* L. +.

| | No Treatments | | | | | | | | Mowing | | | | Peat Removal | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1989 | | | | 1998 | | | | 1998 | | | | 1998 | | | |
| Column number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 11 | 14 | 13 | 15 | 16 |
| Treatment acronyms | I1 | I2 | I3 | I4 | U1 | U2 | U3 | U4 | M1 | M2 | M3 | M4 | P1 | P2 | P3 | P4 |
| Area of sample (m²) | 40 | 30 | 20 | 20 | 40 | 30 | 20 | 20 | 40 | 20 | 40 | 40 | 40 | 40 | 40 | 40 |
| Mean height: Herbs & grasses (cm) | 45 | 40 | 70 | 50 | 50 | 40 | 70 | 65 | 50 | 65 | 70 | 55 | 25 | 40 | 35 | 40 |
| Shrub cover (%) | — | — | — | — | — | 15 | — | — | — | — | — | — | — | — | — | — |
| Herbs, grasses & subshrub cover (%) | 100 | 100 | 100 | 100 | 100 | 85 | 100 | 98 | 100 | 100 | 95 | 98 | 55 | 92 | 70 | 85 |
| Moss cover (%) | 60 | 20 | 2 | 20 | 60 | <1 | 2 | 45 | 15 | 0 | 50 | 30 | 10 | 2 | 70 | 70 |
| Peat depth (cm) | 25 | 5 | 15 | 20 | 25 | 5 | 15 | 20 | 25 | 5 | 15 | 20 | 1 | 1 | 1 | 1 |
| Number of species | 26 | 11 | 14 | 18 | 26 | 10 | 17 | 25 | 16 | 5 | 16 | 25 | 23 | 19 | 27 | 18 |
| 1. Heathlands species (Nardo-Callunetea) | | | | | | | | | | | | | | | | |
| *Calluna vulgaris* (L.) Hull | 2 | + | · | 1 | 3 | 1 | +° | 1 | 4 | 3 | 3 | 2 | 1 | 4 | 1 | 1 |
| *Vaccinium vitis-idaea* L. | 2 | 1 | · | + | 1 | + | · | + | + | 2 | + | + | · | + | · | · |
| *Vaccinium myrtillus* L. | 3 | 2 | + | · | 3 | 1 | + | · | +° | · | · | · | +° | · | · | · |
| *Deschampsia flexuosa* (L.) Trin. | 1 | 2 | · | · | + | + | · | · | · | 1 | · | · | · | + | · | · |
| *Dryopteris carthusiana* (Vill.) H.P. Fuchs. | + | · | 1 | 1 | · | · | 1 | 1 | + | · | + | · | · | · | · | · |
| *Hypnus cupressiforme* Hedw. | 2 | + | · | · | 3 | · | · | · | · | · | · | · | · | · | · | · |
| *Pleurozium schreberi* (Brid.) Mitt. | · | · | · | · | + | + | · | · | · | · | · | · | · | · | · | · |
| *Cladonia impexa* Harm. | · | · | · | · | + | · | · | · | · | · | · | · | +° | + | · | · |
| *Vaccinium uliginosum* L. | 1 | · | · | · | 1 | · | · | · | · | 2 | · | · | · | · | +° | · |
| 2. Fen species (Scheuchzerio-Caricetea nigrae) | | | | | | | | | | | | | | | | |
| A. Rhynchosporion | | | | | | | | | | | | | | | | |
| *Lycopodiella inundata* (L.) Holub | · | · | · | · | · | · | · | · | · | · | · | · | · | · | 1 | · |
| *Juncus bulbosus* L. | · | · | · | 1 | · | · | · | · | · | · | · | · | 1 | · | 1 | 1 |
| B. Caricetalia nigrae | | | | | | | | | | | | | | | | |
| *Eriophorum polystachion* L. | 1 | +° | + | + | 1 | · | +° | + | 1 | · | 2 | 1 | 1 | ·° | + | + |
| *Sphagum recurvum* var. *mucronatum forma fallax* (Russow) Warnst. | 1 | + | 1 | 1 | 1 | · | 1 | 1 | + | · | 2 | 1 | + | + | 2 | 2 |
| *Sphagnum palustre* L. | · | · | + | · | 2 | · | + | 3 | · | · | 2 | 3 | 2 | 1 | 3 | 2 |
| *Carex echinata* Murray | · | · | 1 | + | · | · | + | + | · | · | 1 | 1 | 1 | · | + | + |
| *Carex nigra* (L.) Reichard | · | · | 1 | · | · | · | 1 | + | · | · | · | 1 | · | +° | + | · |
| *Agrostis canina* L. | · | · | · | 1 | · | · | +° | + | · | · | 1 | 1 | · | + | 1 | 2 |
| *Viola palustris* L. | · | · | + | 2 | · | · | + | + | · | · | 1 | + | · | + | + | · |
| *Carex panicea* L. | · | · | · | · | · | · | · | · | · | · | · | 2 | 3 | 2 | 2 | 3 |
| *Carex demissa* Vahl ex Hartman | · | · | · | + | · | · | · | · | · | · | · | · | + | + | 1 | 3 |
| *Sphagnum auriculatum* Schimp. | · | · | · | · | · | · | · | + | · | · | · | 1 | · | 1 | 1 | 3 |

Table 1. Continued.

| | No Treatments | | | | | | | | Mowing | | | | Peat Removal | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1989 | | | | 1998 | | | | 1998 | | | | 1998 | | | |
| *Leucobryum glaucum* (Hedw.) Angstr. | 2 | . | . | . | 2 | . | . | . | 1 | . | . | . | + | . | . | . |
| *Narthecium ossifragum* (L.) Huds. | 1 | . | . | . | 2 | . | . | . | 3 | . | . | . | . | . | . | . |
| 3. Ombrogenous bogs species (Oxycocco-Sphagnetea) | | | | | | | | | | | | | | | | |
| *Sphagnum papillosum* Lindb. | 2 | . | . | 2 | . | . | . | . | 2 | . | . | . | + | . | 3 | . |
| *Vaccinium oxycoccos* L. | 1 | . | . | . | + | . | . | . | + | . | . | . | + | . | . | . |
| *Eriophorum vaginatum* L. | + | . | . | . | . | . | . | . | . | . | . | . | + | . | . | . |
| *Polytrichum strictum* Brid. | 3 | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . |
| *Sphagnum magellanicum* Brid. | . | . | . | . | . | . | . | . | . | . | . | . | 2 | . | . | . |
| *Drosera rotundifolia* L. | . | . | . | . | . | . | . | . | . | . | . | . | . | . | 1 | . |
| 4. Moorlands species (Erico-Sphagnetalia papillosi) | | | | | | | | | | | | | | | | |
| *Juncus squarrosus* L. | . | . | . | . | . | . | . | . | . | . | . | + | 2 | 2 | 3 | 3 |
| *Sphagnum capillifolium* var. *capillifolium* (Ehrh.) Hedw. | 2 | . | . | . | 1 | . | . | 1 | 2 | . | + | + | + | + | + | 1 |
| *Potentilla erecta* (L.) Räuschel | . | . | . | 1 | . | . | . | + | . | . | + | 1 | . | + | + | + |
| *Scirpus cespitosus* L. | 1 | 2 | . | . | + | 2 | . | . | . | . | . | +° | . | 2 | . | . |
| *Erica tetralix* L. | + | . | . | 1 | . | + | . | 1 | . | . | . | 2 | . | 2 | . | . |
| *Aulacomnium palustre* (Hedw.) Schwaegr. | . | . | . | . | . | . | . | + | . | . | . | + | . | . | . | . |
| 5. Wet meadows species (Molinietalia) | | | | | | | | | | | | | | | | |
| *Molinia caerulea* (L.) Moench. | 4 | 4 | 5 | 5 | 3 | 4 | 5 | 5 | 3 | 4 | 4 | 4 | 1 | 2 | 2 | 2 |
| *Juncus effusus* L. | . | . | 1 | . | . | . | 1 | + | . | . | 2 | 2 | 1 | . | 1 | 2 |
| *Cirsium palustre* (L.) Scop. | . | . | + | + | . | . | . | 2 | . | . | . | 1 | . | . | + | + |
| *Angelica sylvestris* L. | . | . | +° | . | . | . | +° | +° | . | . | . | + | . | . | . | +° |
| 6. Other species | | | | | | | | | | | | | | | | |
| *Sorbus aucuparia* L. | + | . | . | . | + | . | . | + | . | . | . | . | . | . | . | . |
| *Picea abies* (L.) Karst. | . | . | . | . | + | . | . | . | . | . | . | . | + | . | +° | . |
| 9*Pinus sylvestris* L. | . | . | . | . | + | . | . | . | . | . | . | + | . | + | +° | . |
| *Salix* × *multinervis* Döll | . | 1 | . | . | . | 1 | . | 1 | . | . | . | + | . | . | . | 2 |
| *Salix aurita* L. | . | . | . | . | . | . | . | . | . | . | 1 | . | . | . | + | . |
| *Agrostis tenuis* × *canina* Sibth. | . | . | + | . | . | . | . | 1 | . | . | . | . | . | . | . | . |
| *Dicranella heteromalla* (Hedw.) Schimp. | + | . | . | . | + | . | + | + | + | . | . | . | + | . | + | . |
| *Polytrichum commune* Hedw. | . | . | . | 1 | + | . | + | + | + | . | + | + | . | . | + | . |
| *Dicranum bonjeani* De Not. | . | . | . | . | 3 | + | . | . | . | . | . | . | +° | . | . | . |
| *Calypogeia muelleriana* (Schiffn.) K. | . | . | . | + | + | . | . | . | . | . | . | . | . | . | . | . |
| *Sphagnum fimbriatum* Wis. | . | . | . | . | . | . | + | . | . | . | + | . | . | . | . | . |

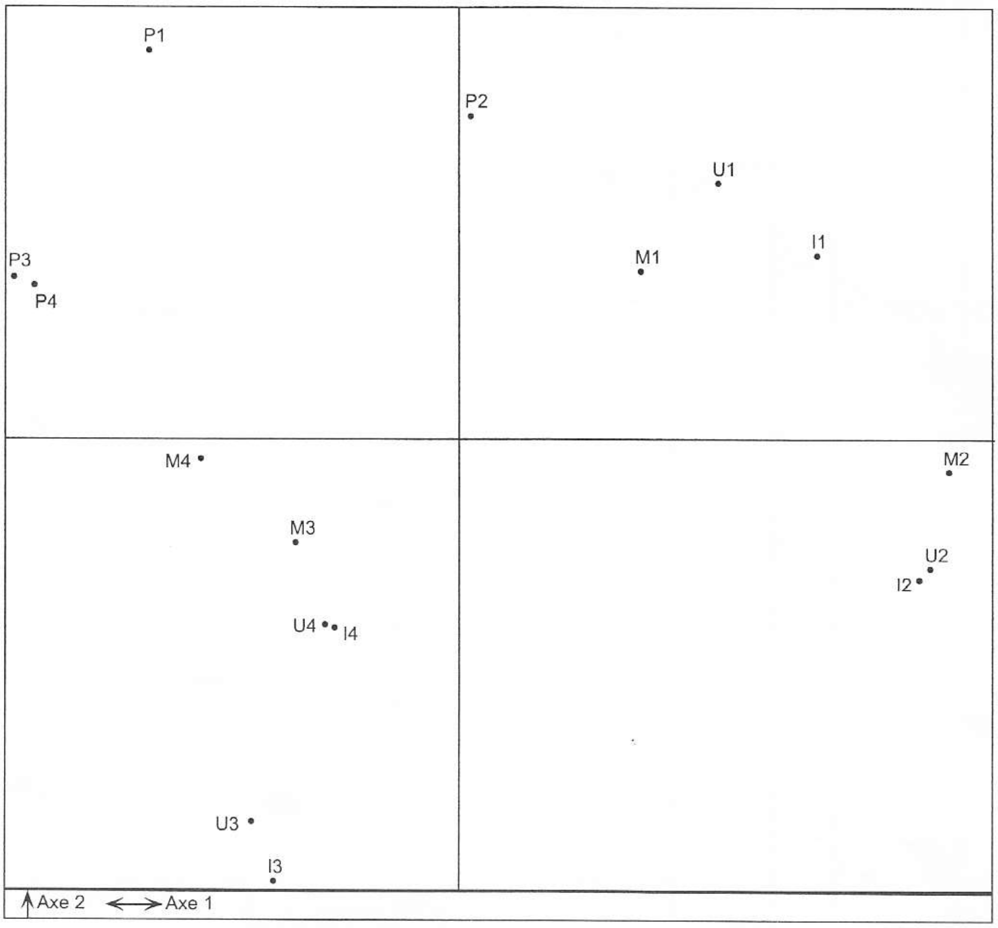


Figure 3. 2-D ordination of quadrat samples along principal components axes 1 and 2 (30.8 and 17.7 % respectively of the total floristic variance). Symbols of samples refer to treatments (I: initial stage in 1989, U: unmanaged, P: top peat removed, M: mowed).

U2, M2) which presented the fewer number of species (5 to 12) of all quadrats. The indicator species using Indval were *Deschampsia flexuosa* (77.2 %), *Vaccinium vitis-idaea* (76.9 %), *Vaccinium myrtillus* (68.9 %), *Scirpus cespitosus* (53.8 %), *Narthecium ossifragum* (50.0 %), and *Vaccinium uliginosum* (47.4 %).

(2) A second group was also dominated by *Molinia caerulea* (I3, U3, I4, U4, M3, M4) but presented more species, with *Viola palustris* (84.2 %), *Dryopteris carthusiana* (64.8 %), *Angelica sylvestris* (51.3 %), and *Polytrichum commune* (50.9 %) as indicator species. The mean height of herbs and grasses was more important than in the plots 1 and 2 (Table 1).

(3) The four peat-removal quadrats (P1-P4) were well-separated from the others: *Juncus squarrosus* (94.7 %), *J. bulbosus* (61.4 %), *Carex demissa* (91.3 %), *C. panicea* (87.8 %), *Sphagnum capillifolium var. capillifolium* (65.9 %), and *S. auriculatum* (58.7 %) were characteristic (Indval values > 50 %). *Molinia caerulea* cover was reduced (abundance of 4 or 5 in 1989 in I1–4, 1 or 2 in 1998 in P1–4), and some pioneer species were found only here (e.g., *Drosera rotundifolia*, *Lycopodiella inundata*, *Sphagnum magellanicum*, and *S. subsecundum* (Table 1)).

## Variation in Vegetation Composition

Species richness of the vegetation samples ranged from 5 to 27 species per quadrat. The total number of species reached 69 in 1998 compared to 44 in 1989. There were 42 species in the unmanaged plots in 1998, 42 species in the peat-removal quadrats, and 40 species in the mowed quadrats. The number of species was not correlated with treatment or year but was correlated with peat depth (before treatment), with more species in plots on deeper peat ($r = 0.728$, $n = 18$).

Between 1989 and 1998, the vegetation evolved without any direct anthropogenic intervention. *Juncus bulbosus*, *Polytrichum strictum*, and *Sphagnum papillosum* disappeared. *Scirpus cespitosus*, *Vaccinium vitis-idaea*, *V. oxycoccos*, *Deschampsia flexuosa, and S. capillifolium* var. *capillifolium* decreased, whereas *Calluna vulgaris* and *Cirsium palustre* increased. It is noticeable that low densities of several tree species appeared or developed in all plots (seedlings of *Picea abies*, *Pinus sylvestris*, *Salix aurita*, *S.* × *multinervis*, and *Sorbus aucuparia*). For example, a single *Salix* × *multinervis* bush developed on several square meters in U2 quadrat.

### Effects of Mowing

Differences between the mowed treatment and the unmanaged quadrats were quite minor (Figures 2–3). The effect of mowing was not drastic; however, a slight decrease of *Molinia caerulea* was observed in quadrats 3 and 4 (abundance of 5 in 1989 and 4 in 1998) but not in quadrats 1 and 2. *Vaccinium myrtillus* and *Epilobium angustifolium* disappeared (Table 1). On the other hand, *Narthecium ossifragum*, *Calluna vulgaris*, *Eriophorum polystachion*, *Carex echinata*, *Vaccinium vitis-idaea*, *Erica tetralix*, and *Sphagnum palustre* increased. Two new species were detected: *Dactylorhiza sphagnicola* and *Juncus squarrosus*.

### Effects of Peat Removal

Nine years after treatments, bare patches were found in peat-removal plots, although the total cover of vegetation reached between 55 and 99 %. The bare patches (all less than 5 $m^2$) were located in the wettest places, which were under water for several months per year. Nevertheless, there was a decrease in *Molinia caerulea* cover, as well as *Cirsium palustre* and *Leucobryum glaucum*, and a loss of *Vaccinium vitis-idaea*, *V. myrtillus*, *Dryopteris carthusiana*, and *Epilobium angustifolium* (Table 1).

However, pioneer species such as *Sphagnum auriculatum*, *S. palustre*, *S. recurvum*, and *Agrostis canina* increased. *Carex demissa* and *Juncus effusus* increased or appeared in the stripped areas. *Carex panicea*, *C. pilulifera*, *Juncus squarrosus*, *J. bulbosus*, *Lycopodiella inundata*, *Drosera rotundifolia*, *Sphagnum capillifolium var. capillifolium*, *S. magellanicum* and *S. subsecundum* also appeared. Typical heath taxa, such as *Calluna* or *Scirpus* increased (Table 1).

The Sphagna species invaded the quadrats mainly on the borders or around the tussocks of pioneer species like *Juncus* or *Carex* spp. Some species spread vegetatively from the borders: *Molinia caerulea*, *Calluna vulgaris* (and by seeds), *Vaccinium oxycoccos*, *Salix aurita*, and *Juncus squarrosus*.

## DISCUSSION

### Species Establishment

One summer after the peat removal, seedlings of *Eriophorum polystachion* (in each quadrat), *Molinia caerulea*, *Juncus bulbosus* (very abundant), *Cirsium palustre*, *Carex nigra*, as well as rare seedlings of *Vaccinium myrtillus* and *Potentilla erecta*, were observed (Dumont and Champluvier 1990). Seedlings of *Calluna vulgaris* were observed mainly in quadrats P2 and P4 in autumn 1989. However, some seeds of *Molinia caerulea* were spread during mowing of the adjacent quadrats. After nine years, this problem appeared to have been overcome, as *Molinia* cover remained poor. After these years, several species indicate satisfactory re-establishment of wet heath vegetation: *Sphagnum papillosum* (P1, P3), *S. magellanicum* (P1), *S. capillifolium var. capillifolium* (all quadrats), *Erica tetralix* (P2), and *Scirpus cespitosus* (P2). As in our study, the re-establishment of the same taxa was recorded in French mires 1–2 years following peat removal (*Carex* spp., *Drosera* spp., *Erica* spp., *Juncus* spp., *Molinia caerulea*, *Narthecium ossifragum*, *Potentilla erecta*), 2–3 years following removal (*Scirpus cespitosus*), or longer (*Sphagnum* spp.) (Dupieux 1998). Peat removal could be the more rapid treatment for restoration of wet heaths.

The presence in our quadrats of *Juncus effusus* (plots 3 and 4) and *Sphagnum fimbriatum* (U3 and M3) may indicate some eutrophication or mineralization problems (Wheeler and Shaw 1995). Other environmental changes, such as wetter conditions, may explain some floristic changes. For example, many Sphagna are invading the quadrats where peat was removed. Of course, the peat removal quadrats presented a lower soil surface, closer to the ground-water table, so they stayed wet during several months each year. Greenhouse experiments have shown that water level in the peat column greatly influences the recolonization success of *Sphagna* diaspores (Campeau and Rochefort 1996), with most species reacting positively to wetter conditions. Increasing the humidity conditions for diaspore germination is by far the most promising approach to rapidly re-establishing a significant moss cover (Salonen 1994, Campeau and Rochefort 1996). *Sphagnum recurvum* var. *mucronatum* forma *fallax* (= *S. fallax*) has been frequently observed as a colonist of wet peat cuttings in mires (Smart et al. 1989, Grosvernier et al. 1997) and seems to be very effective in restoration processes, particularly because of its fast growth rate and carpet-forming capacity (Grosvernier et al. 1997). Commensalism with spermatophytic tussock-formers like *Eriophorum*, *Carex*, or *Juncus* can provide a favorable microclimate (Grosvernier at al. 1997) and can explain the relatively rapid establishment of the seven different species of Sphagna in our plots.

### Effects on *Molinia caerulea*

The observed decrease of *Molinia* and re-establishment of typical wet heath species in our areas where peat was removed are evident. In our study, *Molinia* cover decreased from a value of 4–5 in the abundance-dominance scale to 1–2 after peat removal. These results corresponded to a mean of 75 % cover reduced to 9 % (Braun-Blanquet scales), a decrease of a mean of 66 % in cover. Peat removal was beneficial in our experiments by possibly decreasing nutrient availability. Usually, nutrients are lost from the soil system by natural processes, such as leaching and erosion, and by fixation into organic matter and insoluble minerals. It may be possible to accelerate losses with regular cultivation or with grazing and the removal of stock at night (no poaching and dungs). However, nutrient removal could take many years with these methods. Nutrient pools can be removed directly by soil stripping (Marrs 1985, Sansen and Koedam 1996). It has already been shown that many nutrients, especially N, P, and K, are concentrated in the top 40 mm of the soil (Marrs 1993, Pywell et al. 1994) and were usually lower following soil removal treatment in heathlands (Mitchell et al. 1999, 2000). Soil stripping, even in drier situations, has been used to restore heather successfully in Britain (Smith et al. 1991, Mitchell et al. 1999, 2000) and in the Netherlands (Diemont et al. 1982, Werger at al. 1985). Fertility could be reduced quickly by simply removing the surface 20 cm (Marrs 1985) or 30 cm (Diemont 1990) of top soil.

Contrary to the effect of peat removal in our experiment, the decrease in *Molinia* cover was variable after two years of mowing. The cover of quadrats 3 and 4 decreased from 5 to 4 in abundance-dominance, resulting in a mean decrease of 15 % in cover. In plot 1, the decrease reached 25 % in cover (from 4 to 3), and in plot 2, no decrease at all was observed (abundance of 4 in all cases). In other studies, results were also highly variable. Moen (1995) reported that the effects of mowing differed between different plant populations. *Molinia caerulea* was often drastically reduced following annual mowing around 1 August (in central Norway) for only about three years (Moen 1995). A decrease of the biomass of *Molinia* from 137 g/m$^2$ (both above and below ground parts) to 14 g/m$^2$ was observed after 40 years of annual scything (Moen 1995). The length of the treatment seems to be site-specific. The regular mowing was beneficial for *Dactylorhiza* spp., *Carex* spp., and *Juncus* spp. but detrimental to Sphagna (Moen 1995). The benefits of mowing in heaths are thought to be control of growth and rejuvenation of *Calluna* and a reduction in growth of *Molinia* (Wheeler and Shaw 1995, Dupieux 1998, Chambers et al. 1999, Taylor et al. 2001). Nevertheless, a mowed heath will always be richer in grasses than in ericaceous dwarf shrubs (Diemont et al. 1982).

## Conclusion

Our objectives, restoration of the typical heath dwarf shrubs and decrease of *Molinia caerulea* dominance were reached through application of top peat removal. The cover of some typical heath species like *Juncus squarrosus* and *Carex demissa* was increased and some species, like *Carex panicea*, appeared some years after peat removal. Rare pioneer wet heath species like *Lycopodiella inundata* and *Drosera rotundifolia* also appeared and the cover of several *Sphagnum* species increased. *Molinia caerulea* cover decreased by a mean of 66 %. Top peat removal appears to be a favorable treatment for the regeneration of degraded wet heaths in Upper Ardenne.


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