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Restoration of exploited peat areas in raised bogs: technical management and vegetation development

D. Maas
TU München–Weihenstephan, Institut für Landespflege und Botanik, Lehrgebiet Geobotanik, D-8050 Freising, FRG
P. Poschlod
Universität Hohenheim, Institut für Landeskultur und Pflanzenökologie, Postfach 700562, D-7000 Stuttgart 70, FRG

INTRODUCTION

Peat mining in raised bogs has an old tradition in southern Germany and methods of recultivation by afforestation or agricultural melioration after peat mining too. But we have no experience about the restoration of peat-mined areas, above all these huge industrially scratched areas, or how to initiate vegetation development to the former vegetation types, which is now the aim after peat mining.

Comparison of the habitat factors of exploited peat areas (by scartching or milling) to those of untouched raised bogs indicates that some of them have changed in such a way that they are detrimental to restoration:

(1) The peat water level has been altered irreversibly.
(2) The peat remaining after exploitation is compressed by bog subsidence as a result of the loss of water and mineralization.
(3) Bog subsidence results in diminishing infiltration rates of rain water, thus increasing the surface discharge of water.
(4) The microclimate on peat areas mined by scratching can be very extreme. In summer temperatures up to 80°C can occur on drier sites of the bare peat areas (Schmeidl 1965).
(5) Peat erosion occurs already on minor slopes (Phillips *et al.* 1981). Not only peat particles are translocated but also plant propagules and seedlings. Only a small number of plant species seem to be resistant to this influence before establishing an extended root system.

(6) The peat now forming the recolonizable surface is often not suited to the growth of ombrotrophic plants, e.g. when fen peat remains after exploitation (Eggelsmann 1987, Nick 1986).
(7) Minerotrophic water may influence the actual surface, either as artesic water or by import from outside the peat areas. This favours the establishment of minerotrophic plants typical for ruderal areas or pioneer vegetation.

To investigate these problems when restoring scratched fields on raised bog peat detailed investigations and careful planning of technical and biological management practices are necessary (Pfadenhauer 1989).

The following procedure is recommended:

(1) The study of natural succession on peat areas mined by scratching dependent on habitat conditions after peat mining, to acquire knowledge of which species are suitable to initiate succession by planting or sowing.
(2) Detailed investigation of peat layers down to the mineral ground by core sampling.
(3) Analysis of water quality (surface water as well as peat water).
(4) Investigation of the peat mining history.
(5) Reconstruction of the original vegetation, as far as possible.
(6) Surface levelling of the area.

Based on this analysis the following measures are planned:

(1) Consequential shaping of the surface in order to reduce peat erosion to a minimum, to hold precipitation water on the area and to regulate the discharge of surplus water.
(2) Initial planting or sowing of suitable species.

During the following years a monitoring programme for vegetation development and control of technical installations and their maintenance is imposed.

NATURAL SUCCESSION OF PEAT AREAS MINED BY SCRATCHING OR MILLING: EXAMPLE 'WENDLINGER FILZ'

The investigation of a raised bog in the foothills of the Alps, peat mined by scratching, shows that only a few species of the former peat-forming vegetation are successful (Poschlod 1988). This depends not only on habitat factors like the depth and composition of the remaining peat (Table 1), water level or pH of the water (Fig. 1), but also on population biological factors of the plants (Poschlod 1989). These are generative and vegetative reproduction (diaspore production, germination biology) and spreading (dispersal biology) of the species (Table 2).

In most cases all the successful species (*Calluna vulgaris, Eriophorum vaginatum, E. angustifolium, Rhynchospora alba, Carex rostrata, Phragmites australis, Juncus effusus*) form monodominant stands.

Table 1 and Fig. 1 show that there exist two species with a large ecological amplitude concerning depth and composition of the remaining peat and pH of the

Table 1 — Dependence of monodominant stands of the species successful on peat areas mined by scratching on the depth and composition of the remaining peat

Species	Depth of peat (m)				Composition of the peat		
	0–1	1–2	2–3	>3	rbp	tbp	fp
Calluna vulgaris	■	■	■	■	■	■	■
Rhynchospora alba		■	■	■	■	■	■
Eriophorum vaginatum			■	■	■	■	■
Eriophorum angustifolium			■	■		■	■
Carex rostrata	■	■	■			■	■
Phragmites australis	■	■					■
Juncus effusus	■						■

rbp=raised bog peat, tbp=transition bog peat, fp=fen peat.
From Poschlod (1988).

water. *Calluna vulgaris* grows on dry sites, *Rhynchospora alba* on wet sites. The other species, all occurring on wet sites, possess a closer ecological amplitude.

Some mosses also occur, but only species typical of bare peat soils like *Dicranella cerviculata* and *Polytrichum gracile*.

Table 2 shows that the diaspores of the successful species are dispersed either by wind or by water (along the drainage ditches) — species which have only a low seed production, have a high germination rate or the seeds germinate immediately after sowing. Most of the species show an extensive vegetative spreading, except *Calluna vulgaris* and *Eriophorum vaginatum*. This fact is the main reason why these species form monodominant stands.

The following species of raised bogs present on unmined areas in the vicinity do not occur on scratched fields: *Pinus mugo, Andromeda polifolia, Vaccinium myrtillus, V. oxycoccus, V. uliginosum* and the main peat formers, *Sphagnum* spp. This is possibly due to their dispersal biology — seeds of *Andromeda polifolia* only fall from the capsule, berries of *Vaccinium* spp. are only dispersed by birds, which normally do not visit the bare peat soils. Other factors for the non-invasion of these areas can be high sensitivity of diaspores and seedlings to the extreme habitat conditions on these sites, which are susceptible to erosion or possess an extreme microclimate (see Introduction).

RESTORATION EXAMPLE: 'KENDLMÜHLFILZEN'

The area is situated in the fen and bog complex south of Lake Chiemsee. Elevation is approximately 520 m above sea level, annual precipitation is 1410 mm, mean annual temperature is 7.3°C. The scratched field to be restored covers approximately 30 ha.

The peat layers now forming the surface consist of transition bog peat in the western and raised bog peat in the eastern part. This has to be considered for the election of plant species used because of differing pH and ion content of the substrate and water.

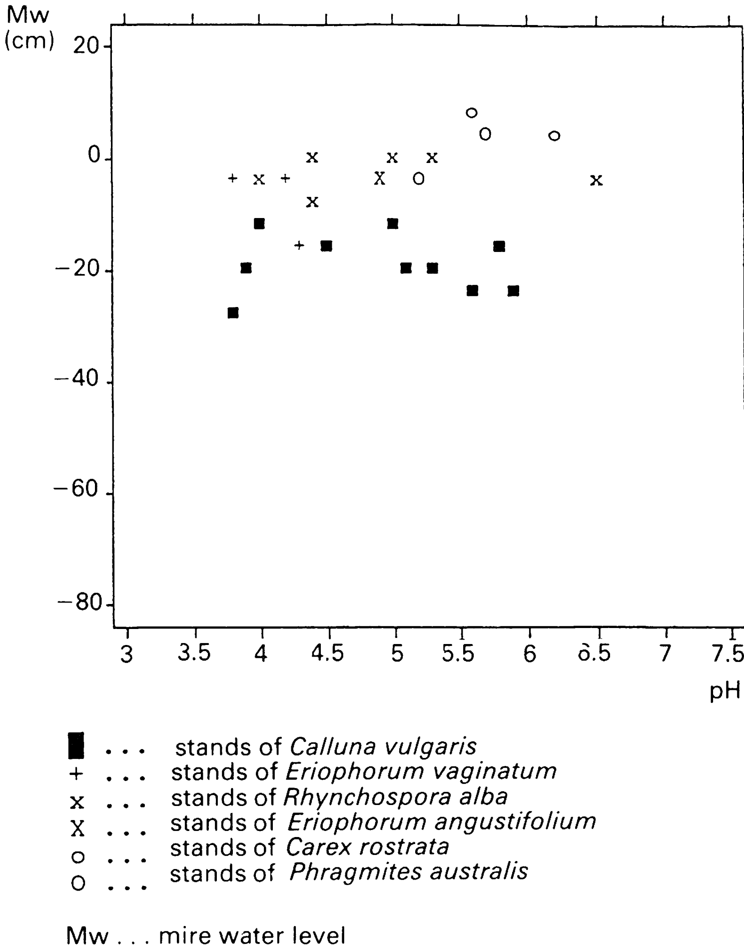

Fig. 1 — Dependence of monodominant stands (the species successful on peat areas mined by scratching) on water level and pH of the water. (From Poschlod 1988.)

Minerotrophic artesic water from a second bog water table is pressed up in the centre of the restoration area. The reason is a clay layer deposited by former flooding. This clay layer is not completely closed. As long as the upper peat layer with its own water table exerted a counter-pressure the upwelling of water was inhibited. Peat mining abolished this counter-pressure and led to the actual situation.

Originally the fields were left with a slope of 2‰ when peat scratching was finished. In this case the slope is detrimental because of the peat erosion and has to be avoided by terracing the area into horizontal polders. Their width is adjusted to natural inclination to avoid steps too high between them. The polder are enclosed by peat walls and each one has a single water outlet at one edge to a central ditch

Table 2 — Population biological aspects of species successful on peat areas mined by scratching

Species	Diaspore	Dispersal of diaspores	Seed production	Germination rate (x= prompt germination)	Vegetative reproduction	Spreading
Calluna vulgaris	Fruit, seed	Wind	Very high	Very high, (x)	No	Generative
Eriophorum vaginatum	Seed	Wind	Low	High, x	Yes	Generative
Rhynchospora alba	Seed	Animal, water	Very low	High	Yes	Generative, vegetative
Eriophorum angustif.	Seed	Wind	High	Very high, x	Yes	Mainly vegetative
Carex rostrata	Seed	Water	High	Low, x	Yes	Mainly vegetative
Phragmites australis	Seed	Wind	Very high	Very low	Yes	Mainly vegetative
Juncus effusus	Fruit, seed	Wind, water	Very high	Very high	Yes	Generative

Seed production (per plant)	0–10 =very low 10–100 =low 100–1000=high >1000=very high	germination rate	0–5% =very low 5–25% =low 25–50% =high 50–100%=very high

From Poschlod (1989).

dammed up to a water level that results in slight flooding of the polders (optimal area 2–5 cm). The ditch is intended to discharge artesic or rain water.

Technical problems arise from the properties of the peat: all surface shaping was done with a modified snow-cat. Work is rendered more difficult by relict tree trunks, for example. Another problem is the plasticity of the peat: the weight of the snow-cat causes squeezing up of the material aside from the actual place of working. Thus a perfect plain inside the polders is impossible to achieve.

Initial planting and sowing is intended to accelerate the first steps of plant succession and induce the development of distinct plant communities of transient bogs. The plant species used are those found to be dominant in the different successional stages in abandoned peat exploitation sites (see section on natural succession, above). Additional species were used because of their vegetative or generative spreading abilities or high conservational value:

— *Eriophorum vaginatum* (see above).
— *E. angustifolium* and *Carex rostrata* are successful species in transient bogs and fen (see above).
— *Andromeda polifolia* and *Scheuchzeria palustris* are rare species of special conservational value.
— *Carex canescens* and *Trichophorum alpinum* are species with expressed vegetative spreading typical for areas with higher availability of mineral nutrients.
— *Eriophorum latifolium* is a fen species with vegatative spreading.
— *Sphagnum magellanicum, S. angustifolium* and *S. cuspidatum* were used to test

their survival abilities under the present conditions, which are not very suitable for their growth.

Additional species (see Table 2) were not sown or planted when:

— they are already present in the restoration area (*Juncus effusus, Phragmites australis, Typha latifolia*);
— they have a high generative spreading ability and are found in direct vicinity (*Calluna vulgaris*);
— they are unsuitable for restoration purposes due to their short life cycle of only two to three years and are sensitive to erosion due to their weak root system (*Rhynchospora alba*).

Sowing and planting was done by hand on permanent plots of 10×10 m. Usually the planted individuals consisted of one tiller (shoot+root+part of the rhizome). One person is able to plant approximately 100 m^2 per day.

A total of 31 plots were planted, and 22 plots were sown. Planting density was 4 individuals per square metre; 31 plots were left to natural succession and served as a control for the effectiveness of the planting and sowing measures.

For monitoring the vegetation development within the plots these were subdivided into four subplots of 5×5 m each and cover was estimated. Vegetation development on the whole scratched area was monitored in north–south direction sections of 10 m width by estimating cover.

The relevés were processed using correspondence analysis and species ranking (Wildi 1986).

RESULTS

All species present in August 1988 were already recorded in 1987; this means no new species occurred. Cover values are about 1% for most species. Exceptions are *Lemna minor* and *Typha latifolia*, with up to 25%. The species present can be assigned to different groups:

— Ubiquitious distribution over the whole regeneration area: *Molinia caerulea, Carex canescens* (dry bog heather species), *Juncus effusus* and *J. articulatus* (pioneer species of wet places). In nearly all sites, where one or several of these species established, their cover values and individual numbers are increasing.
— Indicators of minerotropic water, restricted to the central drainage ditch and parts of the polders which are flooded by minerotrophic water: *Lemna minor, Agrostis canina, Phragmites australis* and *Typha latifolia*. *Typha* especially is rapidly increasing its cover.
— Raised bog and transient bog species: *Eriophorum vaginatum, Carex rostrata* and *Eriophorum angustifolium*. They play only a minor role in the plant cover of the regenerating area. Nevertheless, their cover increase slowly after the species' establishment. But the potential to invade new sites is only small.
— Pioneer species of bare peat: *Rhynchospora alba, Drosera intermedia, D. rotundifolia*. They are characteristic for open and compacted peat surfaces which are often subject to heavy peat erosion. They possess a high generative invasion

ability which is expressed in the rapid increase of individual numbers (especially in the *Drosera* spp.) in areas where the species have been absent the year before (see above).

Correspondence analysis was applied to answer the question whether planting and sowing have any effect on vegetation development numerically traceable. It yielded four groups separated from a central cluster. The groups represent those permanent plots where *Eriophorum angustifolium, E. vaginatum* and *Carex rostrata* have been planted, and those where *Lemna* and *Typha* are dominant, irrespective of other species which were planted or sown in these plots (e.g. *Sphagnum cuspidatum*). The central point cluster includes those quadrats without planting or sowing or where sowing was not successful (e.g. *Scheuchzeria palustris, Andromeda polifolia*).

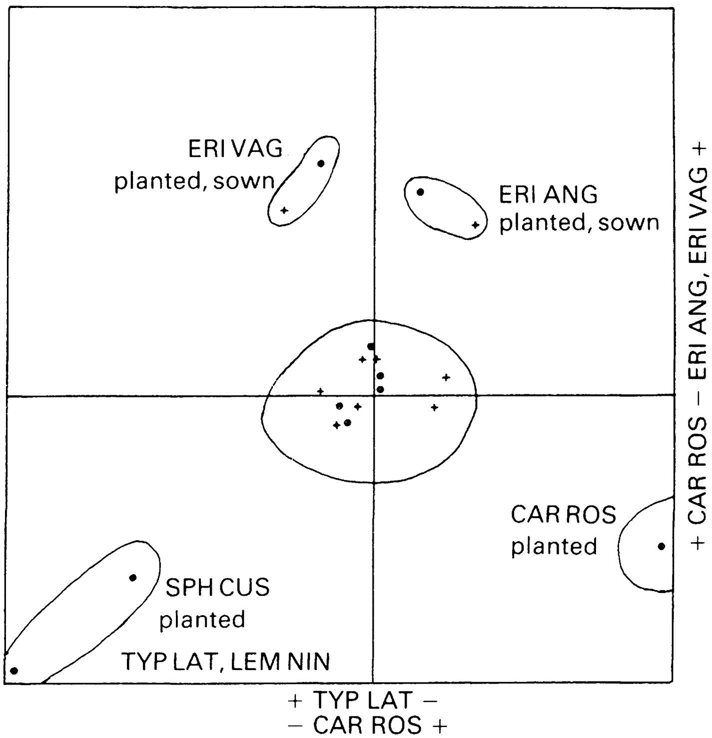

Fig. 2 — Ordination diagram of the permanent quadrats 'Kendlmühlfilzen' + =single data point, ●=multiple data points indistinguishable by printing device.

Species ranking revealed a clear coincidence between the first two ordination axes and the species planted. These five species explain nearly 99% of the variation and allow the interpretation of the ordination axes as increasing and diminishing cover values for these species: the horizontal (first) axis coincides from left to right with a decrease in *Lemna minor* and *Typha latifolia*, and an increase of *Carex rostrata*. The vertical (second) axis from bottom to top can be explained as a decrease in *Carex rostrata* and an increase in both *Eriophorum* species.

DISCUSSION

Future development of the vegetation will probably lead to the dominance of *Molinia* in the driest, and *Typha* and *Phragmites* in the wettest parts. Of the species planted, *Carex rostrata, Eriophorum vaginatum* and *E. angustifolium* will survive and probably extend their present area by vegetative spreading. The establishment of *Sphagnum* can only be expected when the water table is regulated to suitable depths and the water quality approaches that of undisturbed raised bogs. Fen species are not suitable for regeneration of scratched fields, even if fen peat is the substrate. The introduction of very rare species of high conservational value is also not successful in the present stage of succession.

A final remark concerns the costs. The shaping of the surface of 1 ha costs approximately \$15 000. Planting of 100 m^2 costs another \$160. Planting of 1 ha would cost \$160 000, provided that plant material would be available commercially, which is not the case in practice. So our view is that restoration of industrial peat mines will remain a framented enterprise due to technical, financial and biological shortcomings.

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