Forestry Commission

Great sundew, *Drosera anglica*

Research Note

Restoring afforested peat bogs: results of current research

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The value of peat bogs as open habitats and stores of carbon may be lost if they are planted with trees. The number of bogs being restored is increasing but still modest in scale relative to the area of afforested peatland. Research is currently being carried out to determine the feasibility and methodology for restoring afforested bogs. Two experiments were set up to compare a range of methods for managing trees and drainage. In the blanket bog experiment, treatments that involved both felling trees and damming plough furrows were more successful than others in terms of raising the water table. Bog vegetation recovered rapidly in the felled treatments, particularly those with furrows dammed. In the lowland raised bog experiment, the water table rose dramatically in all treatments. Only during a prolonged dry summer was there a difference between treatments, the water table falling deeper in the whole-tree removal than in the fell-to-waste treatment, with conventional harvesting intermediate. Bog vegetation recovered best in the whole-tree removal treatments and least well in the fell-to-waste treatments. Felling is necessary for restoring afforested bogs, but removing lop and top is not. Damming plough furrows can help to restore blanket bog but damming main drains may suffice on lowland raised bogs. Damming furrows is ineffective if the peat is severely cracked. Tree seedlings often colonise bogs undergoing restoration – removing brash mats after harvesting and periodic maintenance should reduce this problem.

Introduction

In their natural state, peat bogs provide unique habitats for a range of plants and animals, including many habitat specialists (Figure 1). They also act as significant stores of soil carbon that need to be protected to avoid the release of the greenhouse gas carbon dioxide. Some land uses, including afforestation, reduce the value of peat bogs as special open habitats and may cause their soil carbon stores to slowly diminish (Hargreaves *et al.*, 2003). There is growing interest in protecting these assets and, where appropriate, seeking to restore them.

While the case for selectively restoring bogs to re-create habitats for specialist plants and animals is generally agreed, the net effect of the restoration of an afforested bog on the total greenhouse gas balance is unclear. Research is currently being carried out to determine whether changes in carbon dioxide, methane and nitrous oxide emissions from a bog undergoing restoration are beneficial for mitigating climate change.

There is little reliable information on whether it is feasible to restore bogs altered by afforestation and thus re-establish their values as habitats and as secure carbon stores (Anderson, 2001). Initial results from Finland suggest that bog and fen restoration trials caused the vegetation and CO_2–carbon balance to change towards that of pristine mires (Jauhiainen et al., 2002; Komulainen et al., 1999).

Although restoration has been on a small scale in the UK (Figure 2) there are at least 50 bog restoration projects and the scale of activity is growing (Figure 3). However, the process of recovery of bog vegetation is slow and most of these projects have had no formal monitoring. This has limited the development of practice beyond the notion that getting rid of the trees and blocking the drains should be sufficient.

Figure 1 Cranberry (*Vaccinium oxycoccos*), a bog habitat specialist.

Figure 2 Area of peat bog in Great Britain.

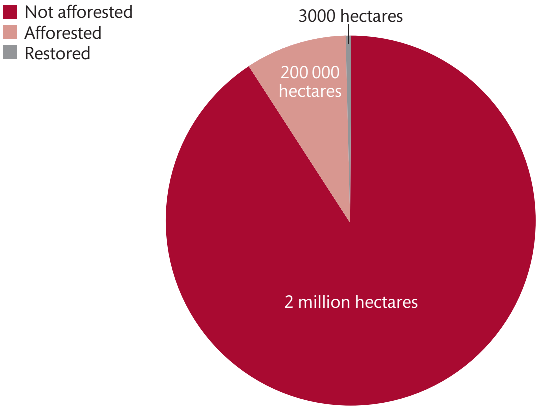
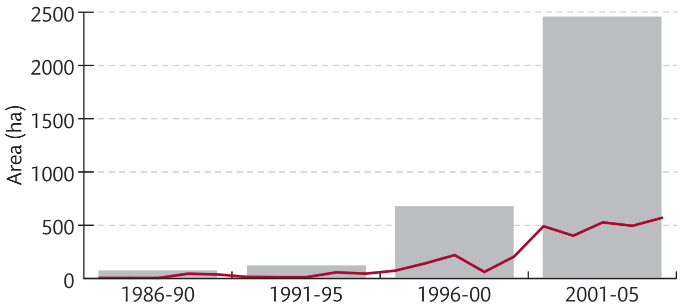


Figure 3 Area of afforested peat bog deforested and restored over the period 1986–2005.



The feasibility and the costs of successful restoration are likely to be strongly influenced by the methods used. The felling is usually pre-commercial (i.e. occurs before the trees have a value as a crop) and incurs a net cost, which will be lowest if the trees are felled to waste and highest if all material, including lop and top, is removed from the bog. It has been suggested that the latter is necessary to avoid nutrient enrichment of the peat, which in turn would favour more nutrient-demanding and competitive plant species over the desired bog species. However, it may be that in the absence of field layer vegetation, any released nutrients get flushed off the site quickly in runoff water.

Blocking the drains may contribute to restoration but leaving them to fill in naturally would be much cheaper. Or perhaps blocking drains may be insufficient and the plough furrows should be blocked as well. Such choices have very significant cost implications.

Experiments were set up in 1996–98 to investigate the feasibility of deforesting and restoring bogs. These experiments compare methods for dealing with the trees and with the drainage system on blanket bogs in Caithness and on a lowland raised bog in the Forth Valley. The early findings up to year five are summarised in the following section.

Sites and methods

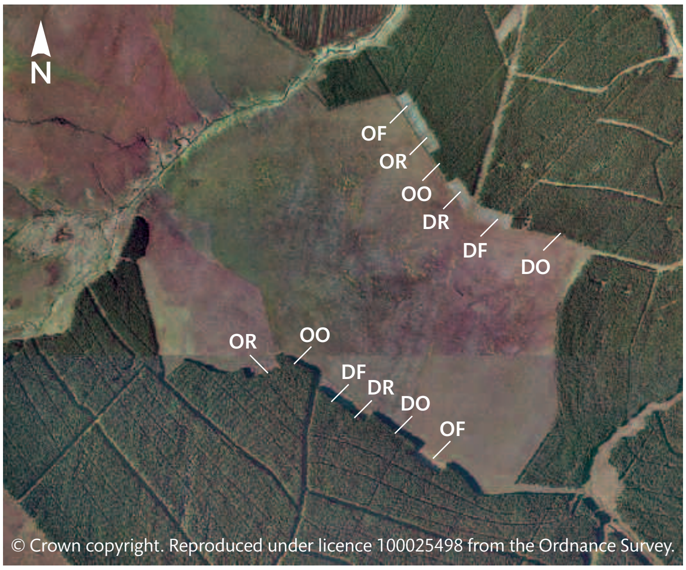
Blanket bog experiment

The blanket bog experiment had six replicates, four in 11-year-old mixed Sitka spruce (*Picea sitchensis*)/lodgepole pine (*Pinus contorta*) at Halsary Forest, Caithness and two in 15-year-old lodgepole pine at Braehour Forest, Caithness. In each replicate, six treatments were compared (Table 1), each applied to a plot of forest 100 x 40 m. The surrounding forest was left so the experiment plots adjoined forest on one long side and unplanted bog on the other (Figure 4).

Table 1 Blanket bog experimental treatment codes.

	Trees left growing	Trees felled to waste	Whole trees removed
Plough furrows open	OO (Control)	OF	OR
Plough furrows dammed every 20 m	DO	DF	DR

Figure 4 Aerial photograph showing the layout of two replicates of the blanket bog restoration experiment at Braehour Forest. The treatment plots are along the southwest and northeast facing forest edges adjoining the large open bog area in the centre.



Lowland raised bog experiment

The lowland raised bog experiment had four replicates in a 25-year-old lodgepole pine forest on Flanders Moss National Nature Reserve, Stirlingshire. Each replicate had 18 x 20 m plots of six restoration treatments (Table 2). The entire forest block, including the experiment plots, was felled so there was no opportunity for an unfelled control treatment (Figure 5). Post-treatment measurements were compared with pre-treatment measurements to detect changes.

Table 2 Lowland raised bog experimental treatment codes.

	Trees felled to waste	Trees harvested (lop + top left)	Whole trees removed
Plough furrows open	OF	OH	OR
Plough furrows dammed every 20 m	DF	DH	DR

Figure 5 Aerial photograph showing the layout of four replicates of the lowland raised bog restoration experiment at Flanders Moss, ten years after the forest was felled..

Results

Blanket bog experiment

The restoration treatments raised the water table compared with the control, improving the conditions for restoration (Figure 6) but water levels were still lower than those found in undisturbed blanket bog. The treatments that involved both felling the trees and damming the furrows (DF and DR) were more successful in raising the water table than the treatments involving either felling the trees or damming the furrows but not both (OF, OR and DO).

Ground vegetation changed following the restoration treatments (Figure 7). The most rapid changes were the decline of two forest floor mosses and the recovery of an important bog plant (Figure 8). Cover of waved silk-moss (*Plagiothecium undulatum*) decreased in all the treatments involving felling (OF,

Figure 6 Monthly measured water levels for the blanket bog restoration treatments (OF, OR, DO, DF and DR), the forested control (OO) and the adjacent undisturbed bog. The top of the chart represents the ground surface. Rainfall is shown at the bottom of the chart for comparison.

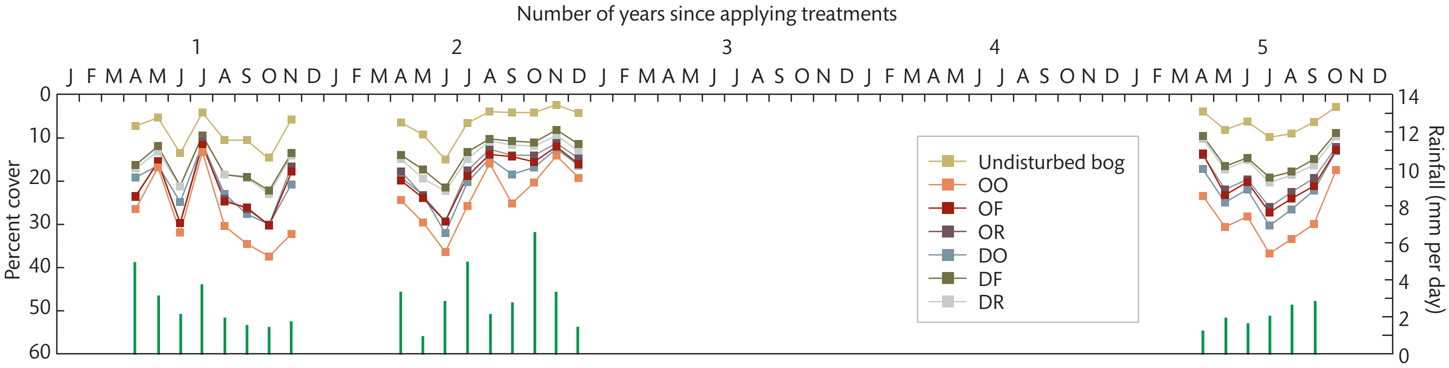


Figure 7 (a) Blanket bog restoration experiment (treatment OR) soon after felling and tree removal, and (b) four years later.

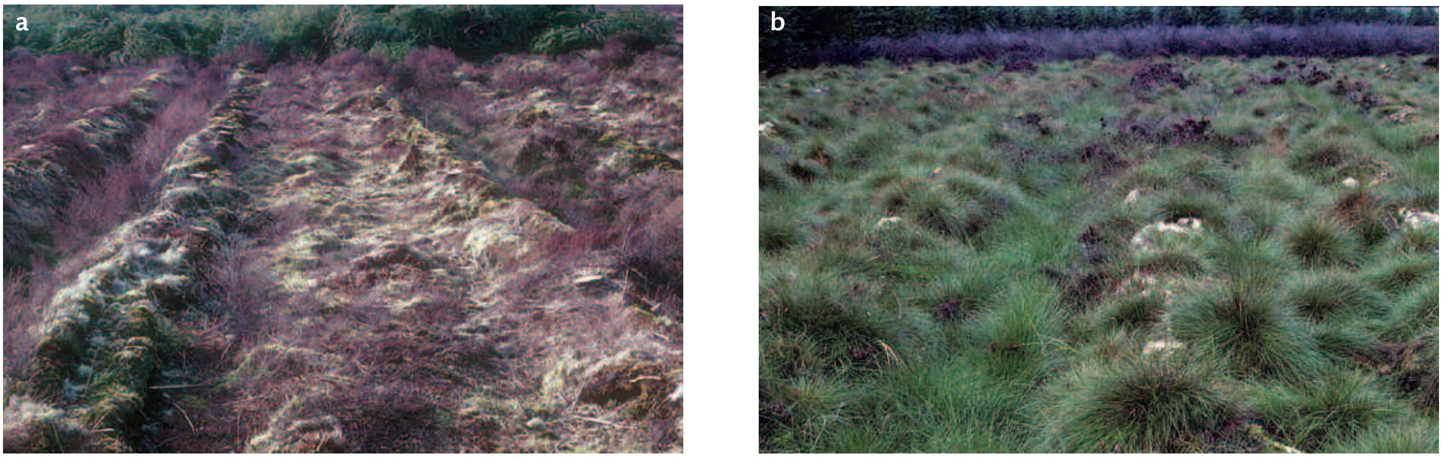
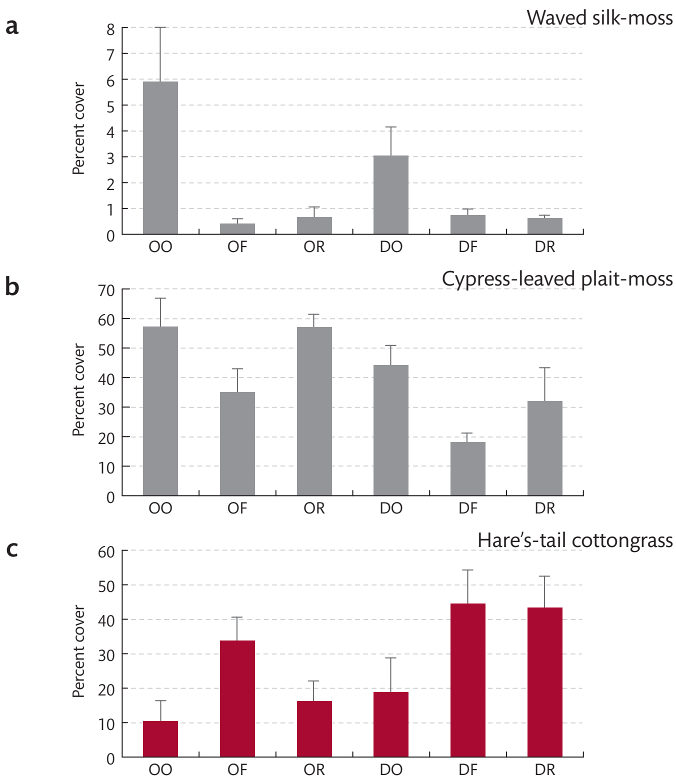


Figure 8 Percentage cover of plant species showing differential treatment responses in the blanket bog experiment.



Grey bars represent forest floor species. Red bars represent open bog species. Error bars represent one standard error.

OR, DF and DR) and that of cypress-leaved plait-moss (*Hypnum cupressiforme*) decreased in the fell-to-waste treatments (OF and DF). Hare's-tail cottongrass (*Eriophorum vaginatum*) responded to both felling and damming, with much greater cover in the felled treatments (OF, OR, DF and DR), particularly those with the furrows dammed (DF and DR) than in the control (OO). Many other bog species need to recover or recolonise to recreate vegetation like that of an undisturbed bog but the rapid recovery of hare's-tail cottongrass indicates that conditions are favourable.

There was some tree regeneration after treatment. Very few Sitka spruce seedlings became established and deer browsed many of those that did. Lodgepole pine seedlings established themselves on the restored areas, particularly on the inner edges of the plots, adjoining the remaining standing forest. There were no treatment differences. By year five the density was uneven and well below the stocking density of a planted conifer forest but some trees were starting to grow above browsing height and a few were starting to produce cones.

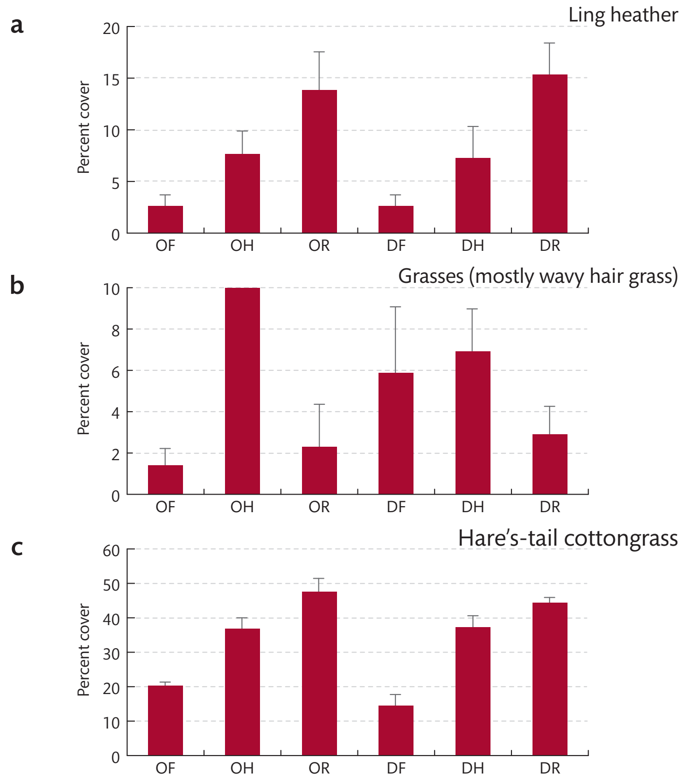
Lowland raised bog experiment

The restoration treatments brought about a dramatic rise in the water table. After restoration, winter water levels were nearer the surface and summer levels did not fall as low (Figure 9). There were no differences among the treatments except during a prolonged dry summer of year two – when the water table was deeper in the whole-tree removal treatments (OR and DR) than in the conventional harvesting treatments (OH and DH) and deeper in the latter than in the fell-to-waste treatments (OF and DF). It is thought that the felled-to-waste trees, and to a lesser extent the brash left after conventional harvesting, reduced evaporation from the ground surface thus limiting draw-down of the water table during prolonged dry summer conditions.

The improvement in soil wetness resulting from the restoration treatments was accompanied by a reduction in aeration of the peat. Before treatment, the average aeration depth, as indicated by the depth limit of very dark peat in cores, was 63 cm but this reduced to 16 cm two years after restoration (Figure 9).

The ground vegetation changed in response to the restoration treatments, with some of the main bog species making a comeback. Sphagnum moss (*Sphagnum* spp.), which grew in a few plough furrows in the forest, increased in all the treatments but was still largely confined to furrows. Ling heather (*Calluna vulgaris*) and Hare's-tail cottongrass (*Eriophorum vaginatum*), present but scarce in the forest, increased after restoration but varied by felling treatment (Figure 10). The increases were smallest in the fell-to-waste treatments (OF and DF), intermediate in the conventional harvesting treatments (OH and DH) and greatest in the whole-tree removal treatments (OR and DR). Grasses, which were virtually absent from the forest, appeared after restoration, particularly wavy hair grass (*Deschampsia flexuosa*). Although this grass is found on bogs, particularly near the edge, its increase probably indicates that the site has higher levels of nutrients than an undisturbed bog.

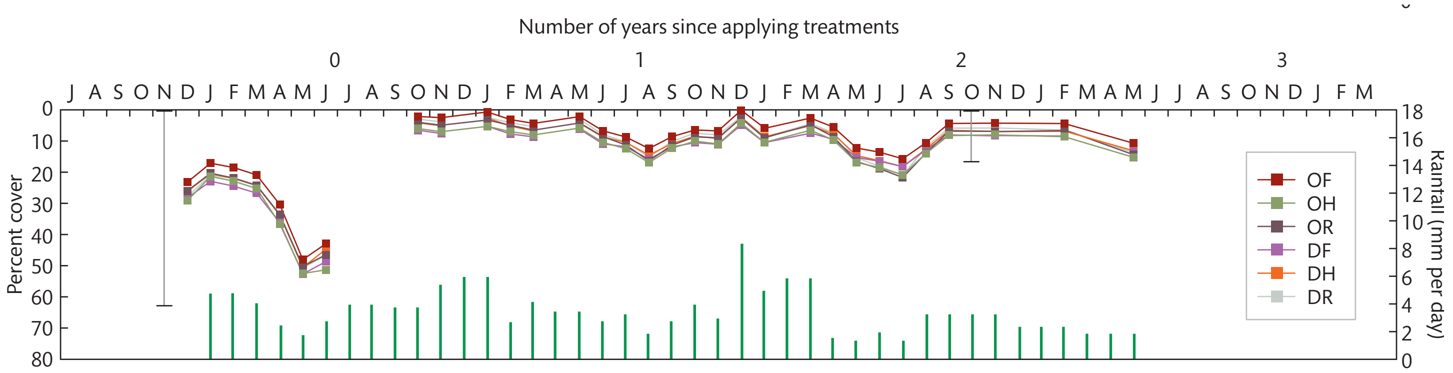
Figure 10 Percentage cover of plant species showing differential treatment responses in the lowland raised bog experiment.



Red bars represent open bog species. Error bars represent one standard error.

Lodgepole pine and birch seedlings grew on the restored plots but the lodgepole pine had died or disappeared by the fifth year after restoration. Silver birch (*Betula pendula*) and downy birch (*Betula pubescens*) seedlings grew slowly except in the fell-to-waste treatments (OF and DF), where they grew above deer browsing height. It was clear from other areas of the site that silver birch seedlings in particular grew much more quickly on decomposing mats of timber and brash that had formed the main timber extraction routes than on ground with no harvesting residues.

Figure 9 Water levels for the lowland raised bog experiment before and after the restoration treatments were applied. The top of the chart represents the ground surface. Rainfall is shown at the bottom of the chart for comparison. The two grey vertical lines represent the peat aeration depth before and two years after treatment.



Implications for future practice

These experiments indicate that it is feasible to deforest and restore bog vegetation on afforested sites. However, the results also suggest that natural regeneration of trees on deforested bogs, if untreated, may in some cases lead to changes in the restored bog habitat and loss of open habitat. The following sections set out the implications for management practice in bog restoration projects.

Felling

Felling is essential for restoring blanket and raised bogs altered by afforestation. The practice of simply damming the drains so that the trees die has been used for bog restoration in Switzerland but does not appear suitable for British forests. Lodgepole pine, the species most commonly planted on deep peat soils in Great Britain, is able to tolerate soil waterlogging and seems also to confer this ability on mixed crops of lodgepole pine and Sitka spruce. In the blanket bog experiment, damming the furrows without felling the trees did improve the water regime slightly but the trees continued to grow.

The extra cost of removing lop and top from the site by whole-tree harvesting does not appear justified by improved ecological conditions for restoration. The experiments provide no evidence of bog plant species being favoured over more nutrient-demanding species where whole trees were removed from site. Soil wetness conditions were, if anything, made worse by removing whole trees from the site, which exacerbated peat drying during a summer drought. However, the disadvantage, in terms of exacerbated summer drought, may be outweighed by a combination of financial income (where markets for residues are available), more rapid re-establishment of bog vegetation and conditions that allow deer to browse tree seedlings freely.

Damming drains and plough furrows

It is too early to say whether successful blanket bog restoration can be achieved without damming furrows. It is clear that damming furrows creates better hydrological conditions for blanket bog restoration than only damming main drains and that this should encourage more rapid recovery of bog vegetation (but see Box 1). Where it is important to restore blanket bog as quickly as possible, damming plough furrows is recommended. Where it is acceptable for restoration to happen slowly, the cheaper option of only damming main drains may suffice but this has not yet been conclusively demonstrated.

Restoration of lowland raised bogs should be achievable by damming main drains only, providing the bog does not have any cut-away edges causing a lowered water table. If a bog

Box 1 – Peat cracking and furrow damming

It is important when damming plough furrows to first investigate if, and to what depth, the peat is cracked beneath the furrows (Figure 11a). Vertical shrinkage cracks tend to form along furrows after canopy closure as continued tree growth dries the peat. They are generally not visible on the surface but, if present, can be found by scraping away the mat of conifer needles, dead moss and tree roots in the base of the furrows. There may be cracks running along both sides of the furrow base or a single crack along the centre. If there are distinct cracks beneath the furrows, the extent and depth of cracking should be determined in a few places by digging. In its more advanced stages, cracking will also occur in-between furrows, forming a network of cracks that will keep the site drained (Figure 11b). With such advanced cracking, damming plough furrows would be ineffective. If cracks are present but confined to the furrows, dams need to be deeper than the cracks, otherwise water will escape via the cracks.

Dams in drains or plough furrows can be made of peat, plastic piling or various board materials. Peat is usually readily available but may have become porous if subjected to drying. To avoid porous peat, take it from well below the surface. It is also necessary to remove porous peat from the drain or furrow base and sides and to compress the plug of peat into the hole to form a watertight dam.

Figure 11 (a) Shrinkage cracks in peat beneath a plough furrow exposed by removing the mat of conifer needles, dead moss and tree roots from the base of the furrow. (b) More advanced peat cracking with cracks between furrows as well as beneath them, making furrow damming ineffective.

does have cut-away edges, a legacy of pre-forestry peat cutting activity, it may be damaged beyond restoration. However, Forest Research is planning experimental trials of a contour membrane rewetting technique that may allow restoration of bogs with cut-away edges.

Tree regeneration

Trees become a problem on bogs when sufficiently numerous and dense to eventually form closed canopy woodland, thus shading out the bog vegetation and drying the peat. Tree regeneration after restoration will determine the character of the restored bog. Individual or sparsely scattered trees are not necessarily a problem as they can provide additional microhabitats. They may need to be cleared if they start causing further regeneration by spreading their own seed onto the bog.

If the bog has been rewet sufficiently for the water table to stay near the surface for most of the year, the regenerating trees should not grow well and, unless they are very dense, should not form closed canopy woodland. Of the tree species likely to be present, only lodgepole pine is capable of growing well on a peat bog with the water table close to the surface.

Silver birch can colonise old brash mats and grow well enough to form closed canopy woodland. On sites receiving silver birch seed, removing brash mats after harvesting should reduce this problem.

In the more likely event that rewetting of the bog has been partly successful, the water table may be close enough to the surface to support bog vegetation but not close enough to prevent trees growing on it. Tree regeneration may then become a problem (see Box 2).

Box 2 – Tackling tree regeneration

Where conifer regeneration originates from seed from the cleared forest, it should be possible to remove it as a one-off operation. This can be done by hand-pulling the seedlings when they are still very small or by cutting them with clearing saws or chainsaws. They need to be cut below the lowest live branch to kill them. Providing they are cleared before they set seed, there should be little further regeneration.

In the case of conifer or birch regeneration arising from seeds blown onto the deforested bog from adjacent trees, there may be an ongoing problem of trees colonising the bog – particularly any decomposing brash mats. It has been suggested that this will cease when a complete cover of bog vegetation has formed but as yet there is no evidence for this. Clearing trees that are acting as a seed source near the bog should help but in some cases these will belong to other landowners.

Deer browsing can suppress very high densities of birch regeneration, but relying on this effect is unwise. There is a danger that, if deer numbers drop for a while – perhaps for as little as one or two years – the birch seedlings will grow above browsing height and then may quickly form a closed-canopy birchwood.

Growing markets for wood fuel, especially wood chips, look likely to improve the prospects for economic removal of unwanted trees from bogs undergoing restoration.

Figure 12 Silver birch (shown) and downy birch seedlings tend to regrow when cut and may require herbicide treatment for successful control.

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References

ANDERSON, R. (2001). *Deforesting and restoring peat bogs – a review*. Forestry Commission Technical Paper 32. Forestry Commission, Edinburgh.

HARGREAVES, K.J., MILNE, R. and CANNELL, M.R.G. (2003). Carbon balance of afforested peatland in Scotland. *Forestry* **76**, 299–317.

JAUHIAINEN, S., LAIHO, R. and VASANDER, H. (2002). Ecohydrological and vegetational changes in a restored bog and fen. *Annales Botanici Fennici* **39**, 185–199.

KOMULAINEN, V.-M., TUITTILA, E.-S., VASANDER, H. and LAINE, J. (1999). Restoration of drained peatlands in southern Finland: initial effects on vegetation change and CO_2 balance. *Journal of Applied Ecology* **36**, 634–648.

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