Efficacy of sod removal in regenerating fen vegetation for the conservation of the marsh fritillary butterfly *Euphydryas aurinia*, Montiaghs Moss Nature Reserve, County Antrim, Northern Ireland

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SUMMARY

The efficacy of 'sod removal' as a fenland restoration technique was tested using an experimental approach at Montiaghs Moss Nature Reserve, Northern Ireland, from 2006 to 2008. The site suffered from rank growth of purple moor-grass *Molinia caerulea* which was out-competing herbaceous species. Soil was removed up to a depth of 15 cm completely denuding vegetation in the experimental plot exposing bare peat. By July 2007, 15.2% of sod-removal areas were revegetated; by October 2008 cover had risen to 64.6%. Of this cover, purple moor-grass accounted for only 9-11% compared to 78-79% on control plots. Cover of other rank-forming grass species was also significantly reduced. Sod removal significantly increased the cover of species characteristic of fenlands including sedges *Carex* spp., rushes *Juncus* spp., marsh pennywort *Hydrocotyle vulgaris* and lesser spearwort *Ranunculus flammula*. It seems likely that sod removal, which lowered the surface of the peat, restored minerotrophic conditions and exposed the historical seed bank stimulating regeneration of some fenland specialists and pioneer species; this resulted in significantly higher species richness on sod removal plots than control plots two years after treatment. There was no demonstrable effect of sod removal on abundance of devil's-bit scabious *Succisa pratensis*, the larval food plant of the Annex II listed marsh fritillary butterfly *Euphydryas aurinia*. We recommend that consideration should be given to artificially seeding devil's-bit scabious soon after sod removal treatment to promote early recolonisation and to increase plant abundance on the site.

BACKGROUND

Fens are minerotrophic peatlands enriched by alkaline surface runoff water or upward seepage of the water table (Lamers *et al*. 2002, Joosten & Clarke 2002). Fen vegetation communities vary greatly but are generally dominated by sedges *Carex* spp. (Quinty & Rochefort 2003). In the UK, fens support many plant species of conservation concern including fen bedstraw *Galium uliginosum*, greater water-parsnip *Sium latifolium*, holy grass *Hierochloe odorata*, Irish lady's-tresses *Spiranthes romanzoffiana*, marsh helleborine *Epipactis palustris* and marsh pea *Lathyrus palustris*. They also support more widely spread but declining amphibian species such as common frog *Rana temporaria* and smooth newt *Triturus vulgaris*. In Northern Ireland, fens are particularly important for invertebrates including Irish damselfly *Coenagrion lunulatum* and the water beetle *Haliplus variegates*.

As a transitional habitat, fens are frequently mismanaged and often threatened by agricultural and urban development, habitat fragmentation and hydrological changes. In common with the rest of Europe (Muller *et al*. 1998, Jansen *et al*. 2000), the UK has lost over 95% of its species-rich fens since the 1940s (García 1992). In Northern Ireland, up

to 74% of fens designated as Areas of Special Scientific Interest (ASSIs) were deemed to be in '*unfavourable condition*' from 2002 to 2005 (McEvoy & Preston 2008).

Since 2005, fens in Northern Ireland have been subject to a Habitat Action Plan whilst some of the species they support have their own Species Action Plans; most notably the marsh fritillary butterfly *Euphydryas aurinia*. The marsh fritillary is listed on Annex II of the EC Habitats Directive and Appendix II of the Bern Convention. Fowles and Smith (2003) determined that the species can only exist at sites with extensive purple moor-grass *Molinia caerulea* cover (≥75%) interspersed by its larval food plant, devil's-bit scabious *Succisa pratensis* at coverages of 25% or more. Like many other rare butterfly species in Europe, the persistence of the marsh fritillary depends largely on successful habitat management (Schtickzelle *et al.* 2005).

Fens are subject to natural ecological succession transitioning into ombrotrophic bogs due to the accumulation of peat, which raises the ground level preventing plants accessing basic-rich ground water (Svensson 1988, Hu & Davis 1995, Hughes & Dumayne-Peaty 2002). Consequently, fenland sites generally require management to maintain or to restore them to '*favourable conservation status*'.

This project aimed to test the efficacy of 'sod removal' as a fenland restoration technique. An experimental approach was used to determine whether denudation of vegetation and removal of the upper layers of peat improved plant communities by stimulating recruitment from the historical seed bank and promoting colonisation of less competitive, early successional species. Sod removal lowers the surface of the peat and restores minerotrophic conditions; it increases availability of base-rich soil nutrients thus stimulating fen regeneration. It was hypothesised that sod removal would decrease the dominance of species, such as purple moor-grass, increase the prevalence of sedges characteristic of fen communities and allow less invasive species, such as devil's-bit scabious, to spread and increase plant species richness. An increase in devil's-bit scabious would be particularly beneficial to the marsh fritillary, whilst undertaking sod removal on a small scale would also ensure persistence of adequate purple moor-grass cover. Monitoring and evaluation of the outcome of management is essential for improving restoration success (Nygaard 2004) and it was expected that sod removal would benefit fen biodiversity in general.

ACTION

Study site: Montiaghs Moss Nature Reserve (151 ha), County Antrim, Northern Ireland is a designated Area of Special Scientific Interest and Special Area of Conservation. It is a largely cutover lowland raised bog within the Lough Neagh Basin consisting of an intricate mosaic of peat ramparts, trenches, pools, drains, small hay fields, tall hedgerows and alder *Alnus glutinosa* and willow *Salix* spp. carr. The site is designated for its higher (vascular) plant and invertebrate assemblages including the marsh fritillary butterfly. The site is categorized as 'potential (rank) habitat' having been historically neglected and under-grazed. It is now dominated by purple moor-grass which forms a dense thatch that prevents recruitment of annual, biennial and perennial herbaceous species. McEvoy and Preston (2008) suggested that devil's-bit scabious is now rare at the site accounting for less than 1% total plant cover.

Experimental treatments: Four replicate 5 x 5 m areas of typical purple moor-grass dominated raised bog were subject to three experimental treatments during autumn 2006. The 'sod removal' treatment consisted of removing the top 15 cm of soil using a mechanical digger with arm and bucket to expose bare peat with complete denudation of vegetation. The 'disturbed' treatment (adjacent to the sod removal treatment) consisted of the spoil from the sod removal scrape being inverted and spread over intact ground vegetation to a depth of 15 cm. The 'control' treatment was a clearly demarcated area adjacent to the other two treatments but left untouched (Figs. 1 and 2).

Vegetation surveys: Vegetation was sampled within eight randomly placed 70 x 70 cm quadrats within each experimental treatment within each replicate area. Sampling was carried out at intervals of about 1- and 2-years post-treatment during July 2007 and October 2008 (n = 96 quadrats/years). The total area of vegetated cover and individual plant species cover was estimated for each quadrat, and a complete inventory of vascular species made. Species richness was taken as the maximum number of vascular species within each quadrat. To prevent edge effects, vegetation sampling was carried out at least 50 cm from the plot edge.

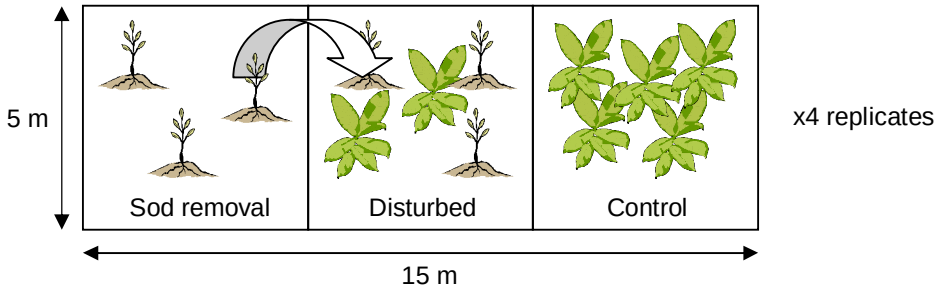

Figure 1. One experimental replicate showing the relative positions of the sod removal, disturbed and control plots.

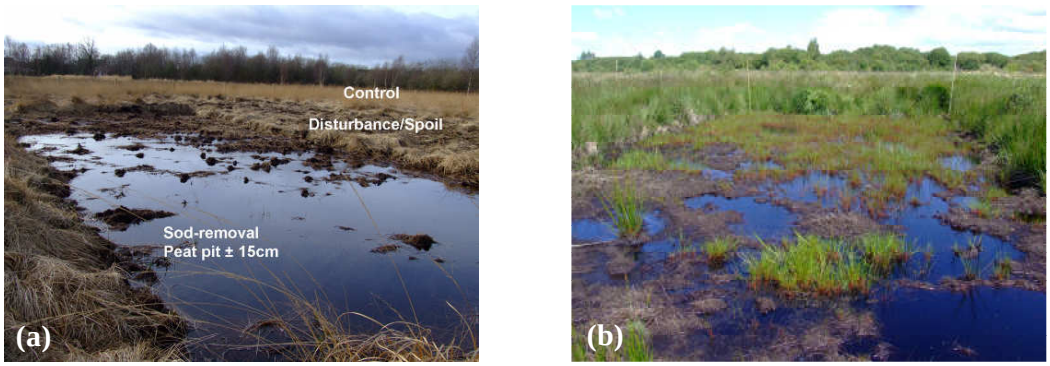

Figure 2. One experimental replicate **(a)** showing the relative positions of the sod removal, disturbed and control plots and **(b)** a sod removal plot in autumn 2007; one year after sod removal.

Statistical analysis: Only those species that occurred within ≥10% of quadrats were retained for analysis. Species occurrence was expressed as a percentage of the total area of vegetation. All percentages were arcsine square-root transformed prior to analysis. A full factorial two-way ANOVA was performed on the percentage occurrence of each species to determine differences between experimental treatments and years.

CONSEQUENCES

A total of 36 vascular plants species were recorded in the experimental restoration areas over the two study years (Appendix 1). Sod removal naturally had a highly significant negative effect on vegetation cover (Table 1). The peat soil was completely denuded of vegetation during autumn 2006 by the sod removal process and only 15.2% of sod-removal areas were revegetated by 2007; however, by October 2008 plant cover had risen to 64.6%.

Whilst the experimental treatment had no demonstrable effect on mean species richness *per se*, year and the interaction of year*treatment combined to have a significant effect (Table 1). During 2007, one year after experimental treatment, sod removal plots supported marginally fewer species than control or disturbed plots but this difference was not statistically significant (Fig. 3a). However, species richness significantly increased on sod removal plots between 2007 and 2008 resulting in a significantly greater number of species than on control or disturbed plots.

Experimental treatment (after two years) significantly affected the percentage cover of nine vascular plant taxa (Table 1). Of these, cover of sweet vernal grass *Anthoxanthum odoratum*, willowherbs *Epilobium* spp., meadowsweet *Filipendula ulmaria*, Yorkshire fog *Holcus lanatus* and purple moor-grass was significantly lower on sod removal plots than control and disturbed plots; notably, cover of purple moor-grass was substantially

Table 1. Percentage cover within experimental plots during 2007 and 2008 with two-factor ANOVA results. Significant factors are shown in bold. Species are listed in alphabetical order.

Cover	**Mean percentage**						**ANOVA**	
	Sod removal		**Disturbed**		**Control**			
	2007	**2008**	**2007**	**2008**	**2007**	**2008**		
Total vegetated cover	15.2	64.6	100.0	100.0	100.0	100.0	**Year**	**$F_{1,185}$=109.161, p<0.001**
							Treatment	**$F_{2,185}$=644.624, p<0.001**
							Year*Treatment	**$F_{2,185}$=108.581, p<0.001**
Total species richness	3.6	5.1	4.4	4.5	3.9	3.9	**Year**	**$F_{1,185}$= 4.837, p=0.029**
							Treatment	$F_{2,185}$= 1.815, p=0.166
							Year*Treatment	**$F_{2,185}$= 3.793, p=0.024**
Sweet vernal *Anthoxanthum odoratum*	0.0	0.0	0.7	0.7	1.2	1.4	Year	$F_{1,185}$= 0.005, p=0.946
							Treatment	**$F_{2,185}$= 6.825, p=0.001**
							Year*Treatment	$F_{2,185}$= 0.005, p=0.995
Sedges *Carex* spp.	21.1	13.3	1.6	0.9	1.0	0.8	Year	$F_{1,185}$= 3.171, p=0.077
							Treatment	**$F_{2,185}$= 32.174, p<0.001**
							Year*Treatment	**$F_{2,185}$= 3.993, p=0.020**
Willowherbs *Epilobium* spp.	0.2	0.0	1.1	0.6	0.1	0.2	Year	$F_{1,185}$= 0.636, p=0.426
							Treatment	**$F_{2,185}$= 7.299, p=0.001**
							Year*Treatment	$F_{2,185}$= 0.245, p=0.783
Meadowsweet *Filipendula ulmaria*	0.7	0.1	0.9	2.2	2.1	2.4	Year	$F_{1,185}$= 0.323, p=0.570
							Treatment	**$F_{2,185}$= 3.083, p=0.048**
							Year*Treatment	$F_{2,185}$= 0.589, p=0.556
Yorkshire fog *Holcus lanatus*	0.0	0.0	4.4	3.9	7.2	4.6	Year	$F_{1,185}$= 0.605, p=0.438
							Treatment	**$F_{2,185}$= 15.441, p<0.001**
							Year*Treatment	$F_{2,185}$= 0.479, p=0.620
Marsh pennywort *Hydrocotyle vulgaris*	1.1	6.8	0.0	0.0	0.2	0.0	**Year**	**$F_{1,185}$= 25.743, p<0.001**
							Treatment	**$F_{2,185}$= 51.123, p<0.001**
							Year*Treatment	**$F_{2,185}$= 28.810, p<0.001**
Rushes *Juncus* spp.	42.4	54.9	1.5	1.9	0.6	2.3	Year	$F_{1,185}$= 3.356, p=0.069
							Treatment	**$F_{2,185}$=164.516, p<0.001**
							Year*Treatment	$F_{2,185}$= 1.199, p=0.304
Purple moor-grass *Molinia caerulea*	9.3	10.6	80.2	79.3	78.5	77.7	Year	$F_{1,185}$= 0.405, p=0.526
							Treatment	**$F_{2,185}$=313.358, p<0.001**
							Year*Treatment	$F_{2,185}$= 1.424, p=0.243
Lesser spearwort *Ranunculus flammula*	5.4	3.7	0.3	0.2	0.1	0.1	Year	$F_{1,185}$= 0.114, p=0.736
							Treatment	**$F_{2,185}$= 12.701, p<0.001**
							Year*Treatment	$F_{2,185}$= 0.167, p=0.847

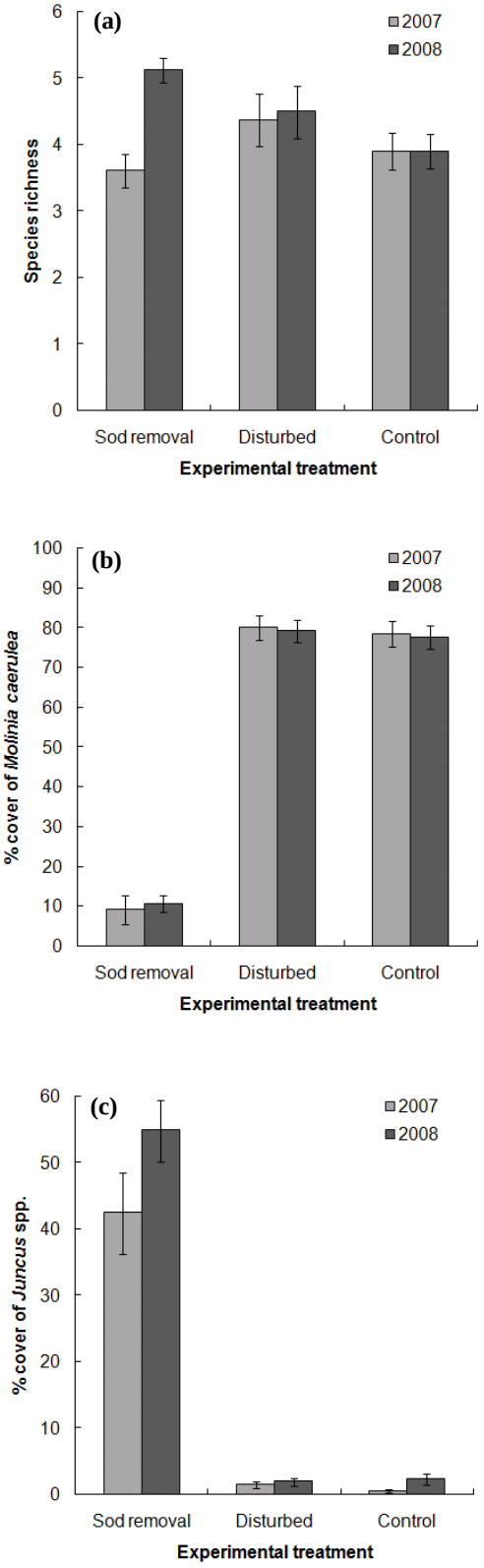

Figure 3. Mean **(a)** species richness and percentage cover of **(b)** *Molinia caerulea* and **(c)** *Juncus* spp. ± standard errors within experimental treatments across years.

reduced from 78-79% on control plots to 9-11% on sod removal plots (Fig. 3b).

Cover of sedges *Carex* spp., rushes *Juncus* spp., marsh pennywort *Hydrocotyle vulgaris* and lesser spearwort *Ranunculus flammula* was significantly higher on sod removal plots than control and disturbed plots. In particular, rushes colonized sod removal plots early on and dominated post-sod removal plant communities during 2007 and 2008 (Fig. 3c).

Twenty-three vascular plant species were either unaffected by the experimental treatments or were sufficiently rare to render any effect undetectable by the sampling methods used. Devil's-bit scabious occurred in only 3.1% of quadrats sampled and accounted for just 0.3% of total vegetated cover. The species did occur on sod removal plots and accounted for 0.2% of cover during both 2007 and 2008. It should be borne in mind that recolonization and establishment of this herbaceous perennial (and indeed other species) may take longer than faster establishing plants such as sedges and rushes.

Discussion: As with most fens, Montiaghs Moss Nature Reserve hosts a diverse plant community but due to neglect and under-grazing, requires restoration management to combat the dominance of the rank purple moor-grass sward and to reduce accumulated thatch. Sod removal eliminates recent seed bank deposits and any rhizomatous roots, dramatically reducing not only purple moor-grass cover but grass cover in general including at Montiaghs Moss, sweet vernal and Yorkshire fog. It restores minerotrophic conditions by lowering the surface of the peat providing areas of saturated bare ground ideal for fenland specialists such as sedges and rushes to recolonise. Sedges characteristic of fen communities were significantly more common on sod removal plots than disturbed or control plots. However, recolonisation was relatively slow with only about two thirds vegetation cover of experimental plots two years after treatment. Rushes dominated sod removal plots including jointed rush *Juncus articulatus*, toad rush *J.bufonius*, soft rush *J.effusus* and heath rush *J.squarrosus*. Like sedges, rushes were early colonizers. Whilst characteristic of fen communities, their vigour post-treatment may warrant further monitoring to assess if they out-compete recolonising herbaceous species.

Devil's-bit scabious was sufficiently rare to prevent statistical evaluation of the efficacy of

sod removal for improving the species' status. McEvoy & Preston (2008) demonstrated that devil's-bit scabious seed density is low and non-persistent in the seed bank (Jensen 2004). It is, therefore, unlikely to regenerate directly from the seed bank after sod removal, but reduced competition from more dominant species, most notably purple moor-grass, should provide suitable conditions for colonization via seed rain from adjacent parental stock provided that seed can reach the area. Sod removal is a labour intensive and expensive restoration technique and (given budget restraints) can only be achieved over relatively small areas. It seems likely that if sod removal plots were distributed throughout the Montiaghs Moss Nature Reserve the increased heterogeneity of purple moor-grass cover and increased suitability of conditions for devil's-bit scabious recruitment should benefit the marsh fritillary butterfly. Increases in other nectar-rich flowering species, such as lesser spearwort, may also be beneficial providing a useful food resource for adult butterflies. If sod removal is incorporated into future site management strategies, consideration should be given to artificially seeding devil's-bit scabious soon after treatment to promote early recolonisation and increase plant abundance on sod removal plots. Trials of domestic livestock grazing might also be employed to assess their efficacy at suppressing colonization and growth of reinvading purple moor-grass and other invasive grass species.

The removal of dominant competitive grasses, persistence of bare peat, exposure of the historical seed bank and establishment of pioneer species resulted in sod removal plots having greater species richness than disturbed or control plots. However, the effect was only evident two years after treatment suggesting that more time is required to achieve something resembling full restoration of fen communities. Greater species diversity and lagged regeneration times should produce a heterogeneous sward with a complex structure (Greig-Smith 1979). This should benefit biodiversity in general but should directly benefit the marsh fritillary butterfly because greater habitat openness allows greater penetration of solar radiation into the sward increasing devil's-bit scabious leaf and plant size. Open swards also provide better opportunities for caterpillars to bask in the sun which increases autumn and overwinter survival rates (Schtickzelle *et al*. 2005).

Restoring minerotrophic conditions, reducing purple moor-grass dominance and increasing species richness are essential to restore fen plant communities to favourable condition. Sod removal appears to be an efficacious means by which to achieve this provided small areas are targeted in a 'patchy' fashion to ensure heterogeneity of habitat structure and species composition.

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Appendix 1. Vascular plant species recorded in the experimental plots during surveys in 2007 and 2008 at Montiaghs Moss Nature Reserve (species are listed in alphabetical order).

Scientific name	Common name
Agrostis stolonifera	Creeping bent
Angelica sylvestris	Wild angelica
Anthoxanthum odoratum	Sweet vernal
Carex spp.	sedges
Epilobium spp.	willowherbs
Equisetum arvense	Common horsetail
Eriophorum angustifolium	Cottongrass
Festuca spp.	fescues
Filipendula ulmaria	Meadowsweet
Glyceria fluitans	Floating sweet grass
Holcus lanatus	Yorkshire fog
Hydrocotyle vulgaris	Marsh pennywort
Juncus articulatus	Jointed rush
Juncus bufonius	Toad rush
Juncus effusus	Soft rush
Juncus squarrosus	Heath rush
Lotus pedunculatus	Greater bird's-foot trefoil
Molinia caerulea	Purple moor-grass
Pedicularis sylvatica	Lousewort
Plantago lanceolata	Ribwort plantain
Poa pratensis	Smooth meadow-grass
Potentilla erecta	Tormentil
Potentilla palustris	Marsh cinquefoil
Ranunculus flammula	Lesser spearwort
Ranunculus repens	Creeping buttercup
Rubus fruticosus	Bramble
Rumex acetosa	Common sorrel
Salix spp.	willows
Stellaria uliginosa	Bog stitchwort
Succisa pratensis	Devil's-bit scabious
Vicia cracca	Tufted vetch
Viola palustris	Marsh violet