Annex 3.

Botanical and Hydro-chemical Response of Alkaline and Calcareous Fen to Restoration.

Contribution based on paper submitted to technical proceedings of the LIFE project conference.

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Abstract

Rich-fens are minerotrophic peatlands which represent an important biodiversity resource as well as providing ecosystem services such as water purification and climate regulation. These functions are dependent on good ecological status, but cessation of traditional management and anthropogenic modification have led to widespread degradation, with monocultures of robust graminoids and reduced plant diversity as typical outcomes. Conservation efforts through management is required via, *inter alia*, grazing and mowing to ensure tall graminoids do not outcompete smaller target fen species (Hajkova, Hajek *et al*., 2009).

Derelict examples of two fen plant communities referable to alkaline fen and calcareous fen were evaluated to determine whether mowing affects floristic composition and structure, mobility of dissolved organic carbon (DOC), nutrient availability, electrical conductivity and acidity in the pore water. Treatment differences in these below ground environmental variables can then be correlated with changes in botanical composition, to better understand their interaction in relation to mowing and un-managed controls.

Concentrations of DOC increased significantly in the short term after mowing, possibly due to compression of the peat surface associated with mowing machinery. However, over time DOC concentrations decreased in the treatment plots and significant differences expired between these and the control plots. Calcareous groundwater mixing appears to have occurred also as a result of mowing, indicated by a significant increase in shallow pore-water electrical conductivity (EC) and an elevated water table. Mown plots of *Cladio-Molinietum* are significantly more species-rich and have a more open canopy compared with un-managed plots.

Introduction

Calcareous and alkaline fens are important rich-fen and in some cases peat-forming ecosystems that are dependent upon a supply of base-rich, oligotrophic groundwater (Joosten and Clarke, 2002). 'Rich'-fens are so named to take account of their minerotrophic character and are typically associated with pH values in excess of 5.5. The floristic composition of rich-fens typically includes sedges, distinctive dicotyledonous herbs and an ecological group of “brown mosses” in the families of *Amblystegiaceae* and *Calliergonaceae* (Bedford and Godwin, 2003; Hedenas, 2003). This latter important and often peat-forming vegetation component forms a key part of the conservation interest of rich-fens: mosses also influence biogeochemical processes (Cornelissen, Lang *et al*., 2007). Rich-fens are amongst the most species-rich, low production wetlands in the world (Ilomets, Truus *et al*., 2010). Many have international significance (Ramsar designated) and in Europe many are protected under the European Habitats Directive (JNCC, 2007). The field experiments reported here have been undertaken in collaboration with (and supported by) the Anglesey & Llŷn Fens *LIFE*+ project. Observations have focused on plant and hydro-chemical responses to restoration in two plant communities which form the core of two European protected habitats and which have been chosen for restoration intervention due to their rarity and degraded condition. The treatments considered are grazing combined with hand cutting in M13 *(Schoenus nigricans – Juncus subnodulosus)* (alkaline fen) and large-scale mechanised mowing and grazing in *Cladio-Molinietum* (calcareous fen). Both communities have become degraded in recent decades due to dereliction (cessation of traditional burning, mowing and grazing) and anthropogenic modification (including drainage and eutrophication). (Rydin, Sjors *et al*., 1999).

Cladio-Molinietum Plant Community (Calcareous Fen)

The *Cladio-Molinietum* is a tall herb community found in base-rich (pH 6.5-8.0) calcareous fens (Wheeler, 1980a; Saltmarsh, Mauchamp *et al*., 2006) and is included within the definition of the European Habitats Directive Annex I habitat ‘Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae’* (see Jones, Hanson and Farr, this volume). This community is dominated by *Cladium mariscus* with *Molinia caerulea*, *Potentilla erecta* and *Myrica gale,* and Anglesey supports a variant community that includes *Erica tetralix and Narthecium ossifragum.* In the project area it occurs on the flatter topogenous peats of valley-heads and basins and the summer water table is usually below the peat surface (Wheeler, 1980a).

In the UK, *Cladio-Molinietum* is rare and is found primarily in the Norfolk Broads and on the Anglesey and Llŷn Fens Special Areas of Conservation (SACs) in North Wales. The total UK extent of the calcareous fen Annex I habitat was estimated at no more than 500 ha in 2007, with *c*. 63 ha recorded for Wales (Jones *et al*., 2013). This rare habitat is to an extent naturally limited in extent and range due to the specific ecological and hydrological conditions which it requires (Bedford and Godwin, 2003). This habitat requires ongoing management to impede woody/graminoid invasions, and dereliction has also contributed to the decline of calcareous fen in Europe (Wheeler, 1980a; Buczek and Buczek, 1996; JNCC, 2007).

Dense, species-poor stands of *Cladium mariscus* can dominate large areas owing to land abandonment, leading to an impenetrable litter layer which prevents the recruitment of small fens species and blocks light from reaching the peat surface.

Cladium mariscus has a vigorous clonal growth regime, with significant vegetative growth. Some individuals will produce seed under favourable conditions, although reproductive success rates are less than 15% without intervention and seeds are often attacked by fungi (Namura-Ochalska, 2005). It is possible then, that cutting above ground shoots will not deter the re-growth of below-ground roots.

M13 Schoenus nigricans – Juncus subnodulosus mire community (Alkaline Fen)

This plant community often occurs in association with varying facies of *Cladium-Molinietum* as well as other species-rich mires, where plant community boundaries are fluid and vegetation is heterogeneous, owing to the complex hydro ecological gradients (Rodwell, 1992; JNCC, 2007).

The M13 plant community is composed of a complex and rich assemblage of rich-fen species and the current UK extent for all alkaline fens including M9 *Carex rostrata – Calliergon cuspidatum/giganteum* mire and M10 *Carex dioica – Pinguicula vulgaris* mire is estimated at 1632 hectares, of which 52-88% are being managed and conserved (JNCC 2007). The extent in Wales is estimated at 120 ha (Jones *et al*., 2013). Losses in the British Isles are due primarily to agricultural intensification and eutrophication (Criodain and Doyle, 1997), with drainage and groundwater abstraction important factors in Eastern England.

M13 is a tussock forming community which is dominated with *Schoenus nigricans*, *Juncus subnodulosus* and *Molinia caerulea* which together create heterogeneous topographical conditions to include tussocks, runnels and hollows. Physical characteristics should also encompass an open canopy, which permits low growing species and patches of bare ground which together contribute to overall species richness (Wheeler, 1980b).

Rationale to this study

It is hypothesised that restoration by machine mowing and biomass removal in the calcareous fen, and hand-cutting and biomass removal in the alkaline fen, coupled with follow-on grazing in both contexts, will increase plant diversity by opening up the canopy to allow fen specialist vascular plants and bryophytes to establish. Baseline and post-restoration measurements of pore-water chemistry have included DOC which is a major component of biogeochemical activities in the soil and an important source of nitrogen, phosphorus and carbon to plants (Nieminen, 2004) in this nutrient poor habitat (Bedford and Godwin, 2003). We hypothesise that harvesting above-ground biomass should impede nutrient cycling to the soil nutrient pool, which is expected to maintain low nutrient conditions and deter invasion by nutrient demanding species (Aerts, 1996). It is also expected that in the medium term DOC export to headwaters will be reduced, which will have a positive impact on drinking water quality and greenhouse gas emissions. At the ecosystem scale we hypothesise that after restoration, the fen systems will support efficient ecological functioning by removing higher concentrations of DOC and becoming more resilient to climate change as the system increases in biological diversity.

Methods

Vegetation heterogeneity and plant community distribution within the study areas is recorded on National Vegetation Classification survey maps (Mapinfo Version 10.5.2) produced by Natural Resources Wales and its predecessor the Countryside Council for Wales (see Birch *et al.,* this volume). These show the extent of the fen communities and were used to ensure placement of the treatment and control plots in comparable vegetation communities. Three paired plots (see Figure 1 for experimental design) were located in each of the two plant communities, namely the *Cladio-Molinietum* (n = 9) and M13 *Schoenus nigricans - Juncus subnodulosus* mire (n = 8). The 17 paired plots were located within the Anglesey Fens SAC which is under-pinned by 7 Sites of Special Scientific Interest (SSSI) and which forms part of the Anglesey and Llŷn Fens Ramsar site. All of the sites studied here are situated on the island of Anglesey, North Wales, U.K, namely Cors Erddreiniog (247418.2.E.,382844.N), Cors Goch (250123.4E.,381382.7E.N) and Cors Bodeilio (279774.4.E.,377258.9.N). Plots were positioned adjacent to one another, ensuring that hydrological and topographical conditions were reasonably comparable, and were randomly assigned as treatment or control, see Figure 1. Paired 10 m^2 plots were permanently located by placing steel marker pegs in the peat at each corner of the plot, to allow for re-location with a metal detector after cutting. A hand held global positioning unit of sub-50 cm accuracy (Trimble GeoXT 2008 series) was used to mark the corners, and allow permanent location of dip wells and quadrats.

Bamboo canes were also used for ease of re-location of quadrats and plots, but were removed or pushed into the peat during mowing. A 2.5 m (5 m total) buffer was established between paired plots, and a 5 m buffer beyond the plots so cutting was undertaken beyond the plot perimeter in the treatment, to allow for edge effects.
An online random number generator (Random.org) was employed to generate numbers between 1-10 which created co-ordinates for quadrat location within each 10 m^2 plot, and numbers 1-5 to assign each quadrat with a numeric name (Figure 1).
Baseline plant surveys were undertaken between 26 June 2011 and 28 October 2011, and

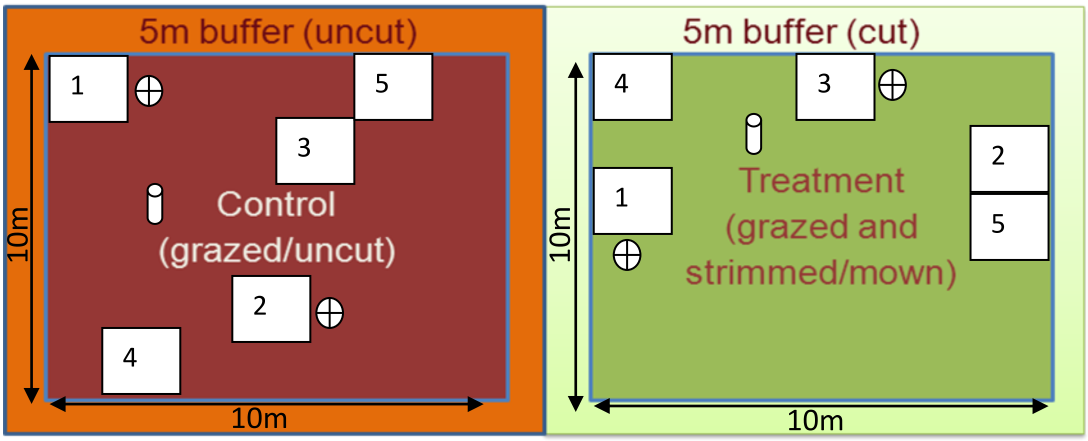

Figure 1. Schematic diagram of 10 m^2 paired vegetation plots showing 2 m^2 quadrats, randomly assigned within them. Circular symbols with cross indicate piezometer locations and cylinders indicate dipwell locations.

were re-surveyed after cutting and biomass removal between 30 July 2012 and 20 August 2012. A second post-treatment survey was undertaken between 17 July 2013 and 8 August 2013. Five 2 m^2 quadrats were randomly assigned within each plot, and 2 dipwells were installed randomly to 2 quadrats per plot, (Figure 1). Plant surveys were undertaken by assigning all rooted taxa a percentage cover estimate as assessed by eye. Bryophyte data were collected but are not included in this paper.

Mowing was undertaken once in the *Cladio-Molinietum* plots using a Pistenbully soft tracked harvester (see Llion Jones and Hanson, this volume) between 3 February 2012 and 28 March 2012, which cut the vegetation and collected the majority of the litter and standing biomass. Mowing height was observed to be between 5-10 cm; this varied slightly depending on water depth, peat structure and woody root density.

The M13 *Schoenus nigricans-Juncus subnodulosus* community plots were hand cut using petrol powered strimmers due to the nature of the sensitive tussock vegetation. These were then hand raked the same day as cutting, using pitch forks and rakes which removed cut biomass from the site. One application of hand cutting was undertaken in the M13 plots between 8 November 2011 and 29 March 2012.

Water Sampling
Piezometers were installed between 15 and 17 December 2011 to a 20cm depth, and were constructed using 1 mm slotted pipe, so pore-water could be sampled at a consistent depth (10-20 cm). This was undertaken by drawing up water in a 60 ml syringe which was attached to flexible piping to reach a 20 cm depth. After sampling, each piezometer was purged until

evacuated or 120 ml, if re-charge was instant. Water sampling was undertaken monthly across all control and treatment plots (2 samples per plot) on the same day. Samples were collected in acid washed bottles and pH was recorded at the end of the sampling day. Within 24 hours electrical conductivity (EC) was recorded and all samples were filtered using Whatman sterile membrane filters 0.45 μm pore size, 47 mm diameter with a laboratory vacuum pump. On completion of filtering, samples were stored in 20 ml sealed bottles and refrigerated in darkness at 4ºC to await further chemical analysis. Dipwells are DN35 (1.25") 1 m Geoscreen FT SL 1 GR150' wells with 42 mm MDPE push on caps and 42 mm DN35 PVC plugs (Marton Geotechnical Services Ltd) and were installed on 25 April 2012 equi-distant from quadrats to a 0.95 m depth within each control and treatment plot in the *Cladio Molinietum.* Head space (the height of the well liner above peat) and dip depth were measured monthly using a 15 m Hydrokit dip meter and recorded to the nearest 0.5 cm.

Results

Plant Response

Mean species richness (number of species in 2 m^2 quadrats, excluding bryophytes) was calculated for each plant community across all 3 sites (Figures 2 and 3). In the *Cladio-Molinietum* plant community, control plots remain constant between 2011 and 2013 at 6.26 and 6.22 species respectively. However, the *Cladio-Molinietum* plant community showed a marked increase (particularly *Eupatorium cannabinum, Cirsium palustre, Galium palustre* and *Hypericum pulchrum*) in post-treatment plots, and species richness is significantly higher (7.91 mean +/-.1 S.E.) in the 2013 survey compared with the control (6.22 mean +/-.1 S.E, Figure 2). Species richness in the M13 was observed as 12.13 and 13.43 species respectively in the control and treatment plots in 2013 (Figure 3).

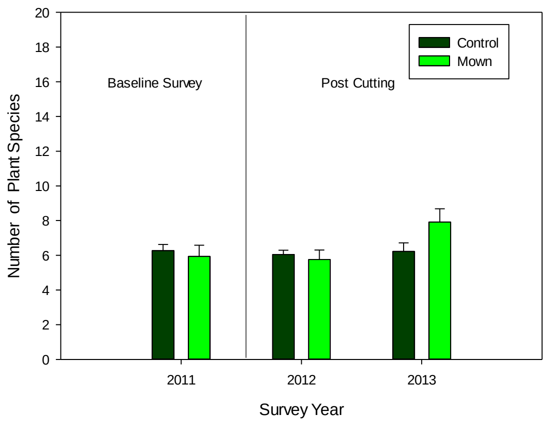

Figure 2. Mean species richness (ericoids/sub shrubs, graminoids and herbs) in *Cladio-Molinietum* plots. Error bars are +/-.1 S.E.

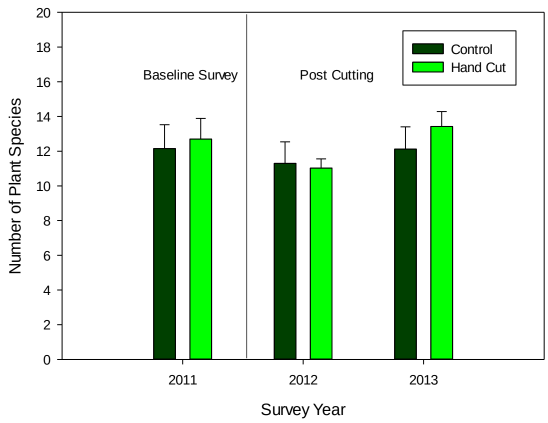

Figure 3. Mean species richness (ericoids/sub shrubs, graminoids and herbs) in M13 plots. Error bars are +/-.1 S.E.

The percentage cover of specific vegetation components in the *Cladio-Molinietum* control plots remains relatively constant over time (Figure 4). In contrast, the mown plots show that litter and graminoids have decreased by 58.51% and 60.83% respectively in the 2012 compared to 2011 (baseline data). Graminoids have increased in the following year (2013) in the mown plots by 8.1%,, compared to 2012, and litter has decreased by 4.9%. Bare ground has increased from 0% cover in the baseline study to 16.22%, and herbs have increased in the mown plots compared to the baseline from 0.54% to 3.88% in 2011 and 2013 respectively (Figure 5).

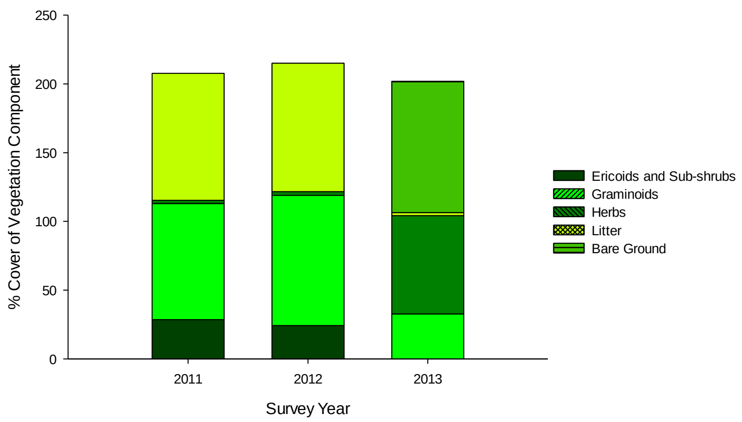

Figure 4. Contribution of main vegetation components in the *Cladio-Molinietum* control plots.

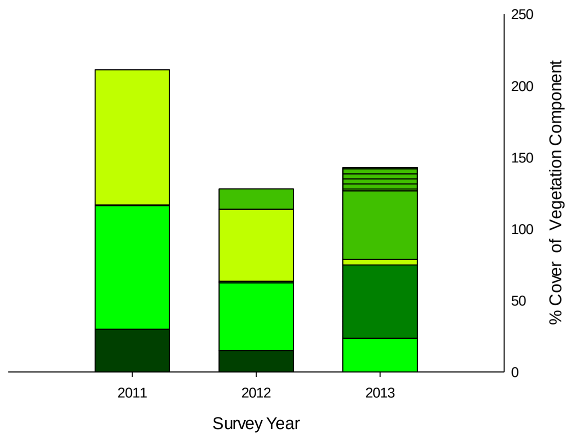

Figure 5. Contribution of main vegetation components in the *Cladio-Molinietum* treatment plots.

Figure 6 shows the percentage cover of vegetation in the M13 grazed only control plots. This shows an increase in the cover of bare ground in the first year post-treatment (2012) from 0.55% to 23.12% compared to 2011, although this subsequently decreases in 2013 to 17.77%. Herb cover has increased from 5.01% in 2011 to 18.67% in 2013. The cut plots shown in Figure 7 have a larger increase in bare ground after cutting, which is maintained in 2013 and a substantial reduction in litter and increase in herbs compared to grazed only plots.

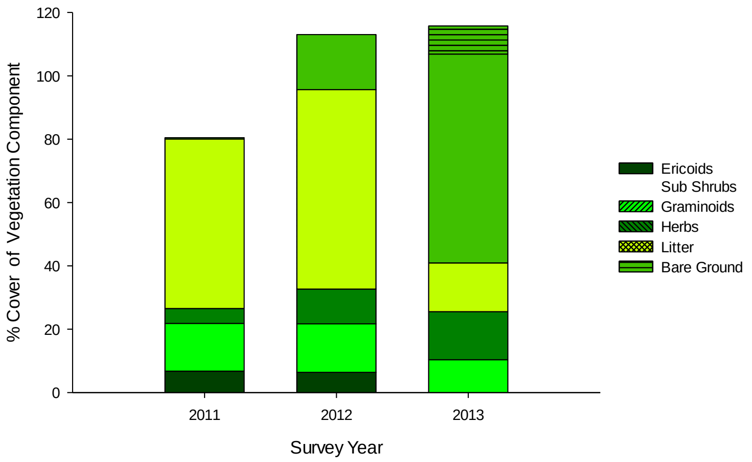

Figure 6. Contribution of main vegetation components in the M13 control plots.

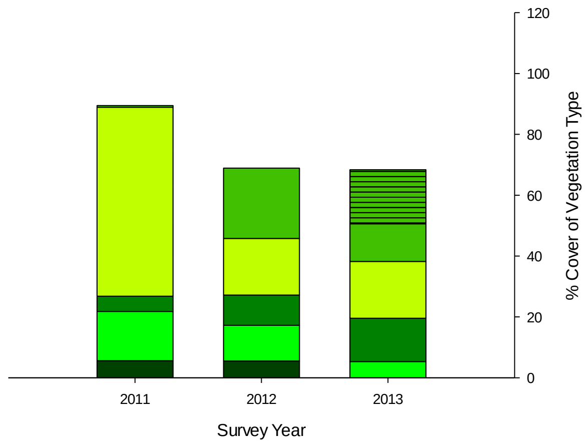

Figure 7. Contribution of main vegetation components in the M13 treatment plots.

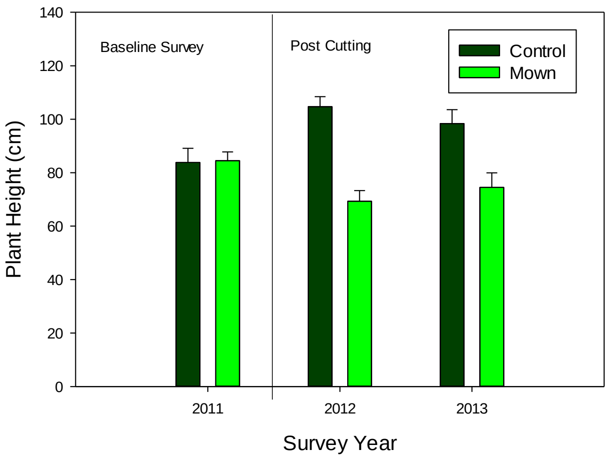

Figure 8. *Cladio-Molinietum* mean canopy height.

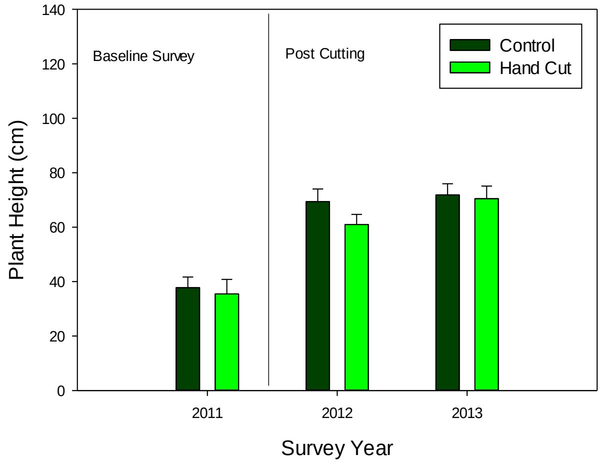

Figure 9. M13 mean canopy height.

In the *Cladio-Molinietum* (Figure 8) mean canopy height in 2013 is significantly higher in the control (98.4 cm) compared to the mown mean canopy height of 74.5 cm in 2013 post-mowing, although this is increasing slowly (69.33 cm in 2012). In contrast, the M13 plant community has not seen a marked difference in height post treatment (Figure 9).

Water Chemistry

Strong treatment effects were observed in the water table depth (WTD) and water chemistry results, which for the latter are shown here for EC, DOC and total organic nitrogen (TON). Figures 10-16 illustrate water table and water chemistry measurements over time showing mean +/-.1 S.E. The dotted vertical line indicates when treatment commenced and the black vertical line when treatment ceased. EC yielded very interesting results (see Figure 10-11) as it was not expected that it would change significantly after the application of treatments. This increase in total ions appears to be correlated with an increase in calcium (not shown here) in the treatment plots of each plant community. Note the difference in EC between each plant community; control EC concentration for *Cladio-Molinietum* ranges between 277 µS cm^{-1} and 409 µS cm^{-1} and control EC concentration for M13 is between 458 µS cm^{-1} and 589 µS cm^{-1}. These differences in EC demonstrate that M13 has a closer proximity to groundwater than *Cladio-Molinietum* and the latter is also more influenced by rainfall.

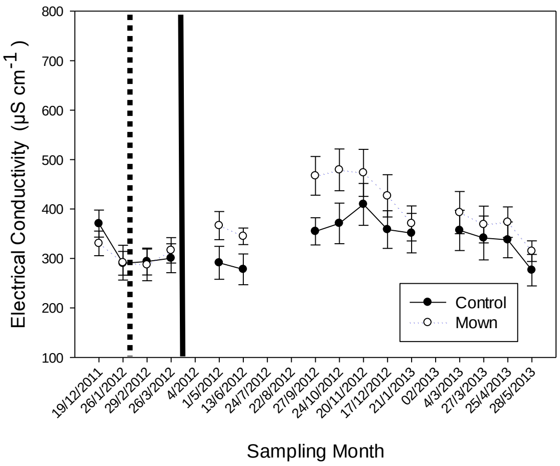

Figure 10. Electrical Conductivity in mire waters of the *Cladio-Molinietum* plant community.

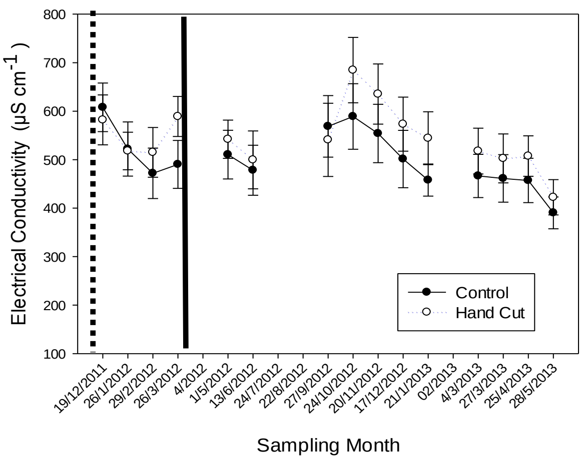

Figure 11. Electrical Conductivity in mire waters of the M13 plant community.

Dipwell measurements (shown here only for the *Cladio-Molinietum*) indicate that the water table is higher in the treatment plots, which also appears to correlate with an increase in total ions and calcium, see Figure 12.
Significantly higher concentrations of DOC were observed in the *Cladio-Molinietum* community post-treatment in the short term, whereas M13 does not show any clear treatment effects in DOC, Figures 13-14.

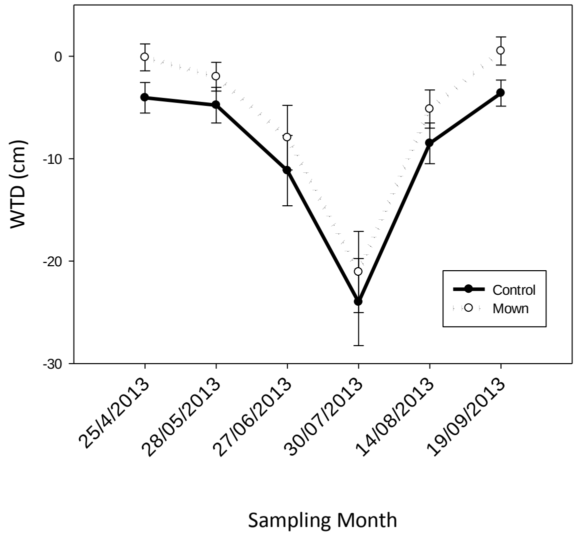

Figure 12. Water Table Depth (WTD) measured in the *Cladio-Molinietum* plots since April 2013.

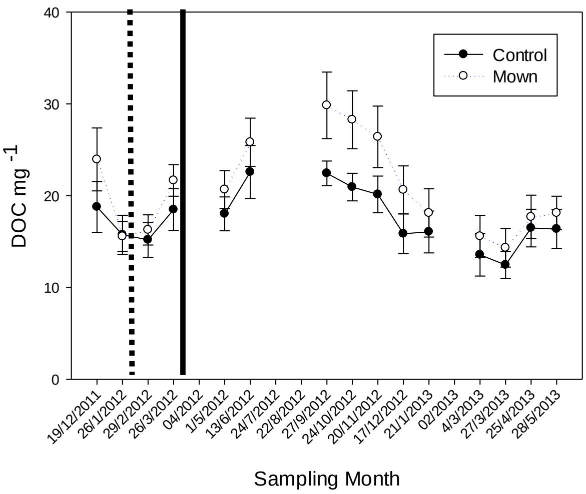

Figure 13. Dissolved organic carbon (DOC) concentrations in mire waters of the *Cladio-Molinietum* plant community.

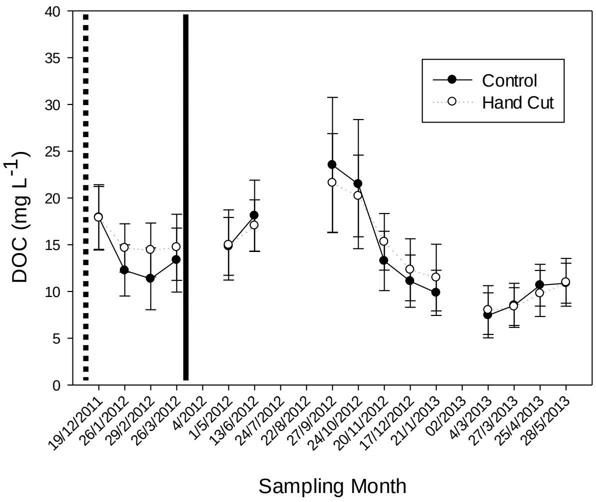

Figure 14. Dissolved organic carbon (DOC) concentrations in mire waters of the M13 plant community.

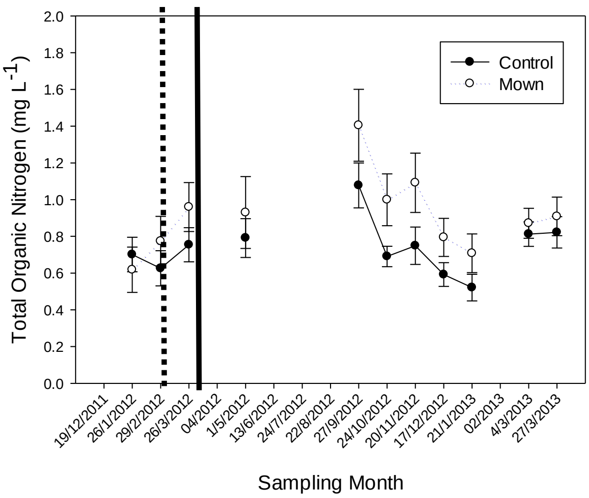

Figure 15. Concentrations of total organic nitrogen in mire waters of the *Cladio-Molinietum* plant community

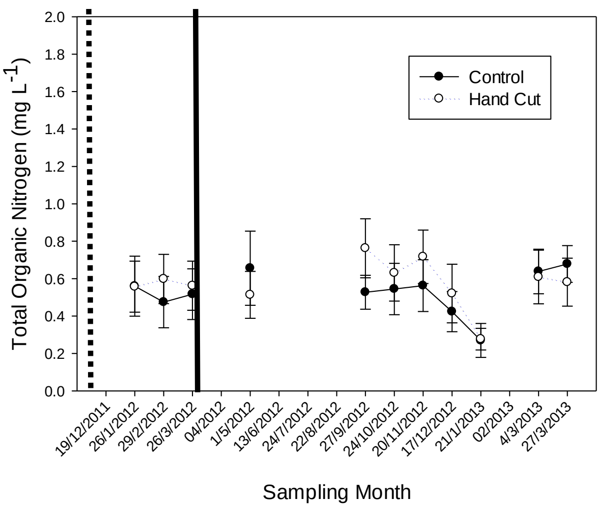

Figure 16. Concentrations of total organic nitrogen in mire waters of theM13 plant community

Discussion

Restoration Response in Cladio-Molinietum *Calcareous Fen*

The research undertaken on the restoration of the Anglesey rich fens have yielded some unexpected results in the hydro-chemical response to mowing in the *Cladio-Molinietum*, such as increased EC and, as hypothesised, increased species richness. Litter cover has decreased which is a short term response to management and it is estimated that litter depth has decreased from c. 0.5 m to c. 0-5 cm. This does not appear to deter colonisation of certain species, indeed bryophytes and *Drosera rotundifolia* are using it as a growth substrate; although un-raked litter may be a barrier to the establishment of low growing species such as *Cardamine pratensis* (Jensen and Meyer 2001). Increased light is a major environmental driver for smaller fen species and bryophyte colonisation (Kotowski, Andel et al. 2001; Kotowski and van Diggelen 2004). Mowing increases the space available for species to establish and increases light penetration to the peat surface (Schaffers, 2002; Billeter, Peintinger *et al*., 2007), which supports colonisation by light demanding species of small stature, providing there is close proximity to a good seed source or seeds are present in the seed bank (Billeter, Hooftman *et al*., 2003; Kolos and Banaszuk, 2013).

In the first summer after mowing (year 2 of the study) the treatment plots had fewer species than the control, although in year 3 a significant increase was observed in species richness, suggesting that after initial disturbance, the open canopy and perhaps also change in hydro-chemical conditions had provided a positive effect on species colonisation.

Treatment effects observed in the shallow pore water chemistry suggest that perturbations to these systems are substantial in the short term, particularly for DOC and mobilisation of ions in the groundwater (measured as EC). However, EC and DOC have decreased in the months following mowing and significant treatment differences have expired.

It is likely that the increase in EC in the mown plots is due to the physical compression caused by the Pistenbully. The compressed peat does not appear to have sprung back entirely after mowing, causing groundwater to be raised from lower depths providing ion rich water in the upper 20 cm of the peat profile. An increase in groundwater supply to the rhizosphere is likely to be a major contributing factor to increased species richness as supported by van Belle, Barendregt *et al*., (2006). Kolos and Banaszuk (2013) also suggest that extended inundation of ion-rich water, also observed here in mown plots, is an important driver for target plant colonisation. The restorative effects of the likely increased light and temperature to the peat surface, as a result of mowing, combined with groundwater connection are thought to have collectively increased species richness observed here in the *Cladio-Molinietum* (Kolos and Banaszuk 2013).

Concentrations of DOC rose significantly in the *Cladio-Molinietum* treatment plots and this may be cause for concern for water treatment companies, as restoration intervention has been undertaken in major water catchment areas. However, the extent of mowing for the purposes of this research is unlikely to have any deleterious effect on drinking water quality. This is due to dilution effects (Kraus, Bergamaschi *et al*., 2011) and mowing location (in the fen basin) which tends to be in the fen interior further away from drainage ditches and receiving waters (Jansen, Eysink *et al*., 2001; Middleton, Grootjans *et al.*, 2006). However, increased concentrations in DOC ought to be a consideration prior to future large scale mowing activities undertaken across the catchment over a short time scale. Mobilisation of DOC and DON is indicative of associated phosphorous and nitrogen losses respectively, and is likely to have implications for plant nutrient uptake (Nieminen, 2004).

Restoration Response in M13 <u>Schoenus-nigrcans - Juncus subnodulosus</u> *Mire*

The uncut but grazed plots in the M13 plant community exhibited an increase in bare ground and herbs which are likely to be attributable to differences in grazing pressure regimes across the site compartments, as well as an increase in EC. However, it is expected that there will be a significant difference in species richness in hand cut plots once the supplementary bryophyte data has been included as Sundberg (2011) reports brown moss cover tripling up to 6 years post mowing.

Unlike the *Cladio-Molinietum*, canopy height in the cut M13 does not show any marked differences after mowing. This is likely to be attributable to the survival of the basic tussock structure of the vegetation after mowing (indeed this was a key aim of mowing using hand-tools), vigorous re-growth of *Schoenus nigricans* and low grazing pressure. Grazing pressure will need to increase and/or an annual or at least regular cutting regime implemented to support species richness.

Recommendations

This paper has outlined significant effects resulting from mowing, including increased species richness and a decrease in litter cover. Moderate, carefully managed grazing on fens is considered to be an alternative conservation approach to mowing (Stammel, Kiehl *et al*., 2003). Seasonal grazing in these fragmented habitats is considered to increase seed dispersal (Couvreur, Christiaen *et al*., 2004) where seed sources are available (Matejkova, van Diggelen *et al.*, 2003). Where grazing is in place of mowing and compared to no management (abandonment), practitioners should be aware that grazing has been reported to reduce species richness and modify plant composition (Stammel, Kiehl et al. 2003). Invasions by unpalatable woody or inedible herbaceous species (Proulx and Mazumder, 1998; Middleton, 2002) have also been reported with grazing, which then compete against smaller herbs for nutrients and space, particularly where seed banks are depleted (Hald and Vinther, 2000).

It is recommended that a flexible mowing regime should be undertaken on a 2-5 year rotation to promote forb species diversity (Wheeler, 1980a; Leng, Musters *et al*., 2011; Valko, Torok *et al*., 2012). Early autumn mowing impedes shrub encroachment (Klimkowska, Dzierza *et al*., 2010; Sundberg, 2011) and removes accumulated nutrients in the standing plant biomass which inhibits nutrient cycling (Aerts and Chapin, 2000; Hovd and Skogen, 2005) and thus supports a fen's nutrient poor conditions. However, mowing in the Autumn deters tall forbs from establishing, such as *Succisa pratensis,* so alternate mowing regimes switching between autumn and summer would be most beneficial (Valko, Torok *et al.*, 2012; Kolos and Banaszuk, 2013). Moreover, mowing on rotation will manage biomass and litter accumulation (Diemer, Oetiker *et al*., 2001; Valko, Torok *et al*., 2012) which is one of the physical inhibitors for small stature herbs (Kolos and Banaszuk, 2013).

Furthermore, the data presented here records the response to 2 years post restoration of an abandoned fen to one application of mowing/hand cutting. Further statistical analysis will help to better understand the response to restoration so that existing heterogeneous differences in nutrient regimes within and between sites are better separated from treatment effects (Huhta and Rautio, 1998) and biogeochemical mechanisms which are causative to hydro-chemical response are also explained.

Heterogeneity between these hydrologically complex sites needs further investigation, as it is not clear which site data-set, if any, is driving these significant differences in species richness. This may relate to historical management (e.g. grazing pressure, burning, peat cutting etc.), so a site specific interpretation of the response to restoration needs to be clarified (Schmitz, 2012) and individual management regimes can be implemented. Site specific circumstances to address may include: eutrophication, proximity to alkaline seed source, hydrology or grazing regime; a blanket management approach is not recommended as it is likely to lead to an unsatisfactory and expensive outcome. Therefore, practitioners are advised to develop individual site plans in which limited resources can be targeted to those sites that demand more intense management, although these dynamic systems will need annual reviews.

Post monitoring of these study plots is also advised, as the change in species richness that have been observed here may be a short term response to management. It is difficult to predict the long term direction of the plant community without continued observations and each site is likely to evolve according to species dynamics at each site (Gusewell, Buttler *et al.,* 1998). In order to make decisions on what the target reference community composition should be, it is also suggested that this botanical data should be modelled with water chemistry and climate data in conjunction with ongoing management practice to better understand and agree on the end point community.

Finally, there is relatively little information about the hydroecological status of these plant communities in Wales particularly *Cladio-Molinietum,* which is surprising considering its rarity and conservation importance. More broadly, future research should focus on the long-term hydroecological management of rich-fens and their contribution to ecosystem services such as carbon sequestration, GHG emissions and biodiversity in order to ascertain how best to manage these sites in the future to support ecological services as well as conservation (Bullock, Aronson *et al*., 2011). Either way, being clear on the objectives will support practitioners' decisions on how to best manage these sites to their optimal potential.

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