Appendix G. Vegetation responses to ditch-blocking of a blanket peat bog

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1. Background and rationale

There is interest in how drainage and re-wetting or 'restoration' of peat bogs affects the composition of their vegetation and, therefore, their carbon budget. For example, it is often assumed that restoration of drained blanket bog will lead to an increase in the abundance of *Sphagnum* mosses at the expense of sedges such as the cotton grasses (Eriophora); it is further assumed that this change in plant functional type will lead to a decline in CH_4 flux following an initial spike in emissions in the few years immediately following re-wetting (e.g., **Lindsay (2010)**; see also Appendix A). However, there is little work on how water-table regimes vary between the different vegetation types that characterise peat bogs or on how drainage and drain blocking affect vegetation composition. In this paper we consider such drainage/re-wetting effects; specifically, we report on a study where the composition of the vegetation was measured in an area of blanket bog subjected to experimental damming and infilling of drainage ditches.

1.1 Water-table regimes in the microhabitats that characterise peat bogs

Baird (2013) and **Low and Baird (2015 in press)** have reviewed the evidence for water-table and drainage effects on raised bog and blanket bog vegetation, and the rest of this section is based heavily on those two grey literature reviews. Many raised bogs and blanket bogs have a surface characterised by raised mounds or hummocks separated by lower areas called lawns and hollows (**Belyea and Clymo, 2001**). Water tables are deeper in hummocks than in lawns and hollows and these differences correspond to differences in the mix and abundance of the plant species found growing on the different microforms or microhabitats. Despite this 'commonplace' observation, remarkably little is known about (a) the water-table depths and regimes that characterise different microhabitats, and (b) the sensitivity of particular vegetation types to changes in water table position. Two studies – **Belyea (1999)** and **Laine *et al*. (2007)** – provide some indication of (a) in particular. However, uncertainty in the quality of the water-table data in each study adds corresponding uncertainty to the associations between vegetation type and water-table regime reported in the two papers.

At Ellergower Moss, a raised bog in SW Scotland with a similar range of vegetation types to those found in blanket bogs, **Belyea (1999)** measured water tables in the following microhabitats (original terminology):

- *Racomitrium* hummock: *Racomitrium lanuginosum* Brid..
- *Sphagnum* hummock: *Sphagnum rubellum* Wils..
- Lawn: *Sphagnum papillosum* Lindb..
- Hollow: *Sphagnum cuspidatum* Ehrh. ex Hoffm..
- Pool: open water (no vegetation).
- Tussock: *Trichophorum cespitosum* (L.) Hartman.

Water tables were measured using conventional dipwells and polyvinyl chloride (PVC) tape attached to bamboo canes. Only data from the former are considered here because they were used by **Belyea (1999)** to calibrate the latter. Figure 1.1, taken from **Belyea (1999)**, shows the depth to water tables (on the *x* axis) measured monthly/bi-monthly using dipwells over a 15-month period (May 1993 to August 1994). The data provided by **Belyea (1999)** do not include information on medians or other average conditions, but nevertheless suggest that water tables in lawns and hollows differ by *c*. 10 cm, as do water tables between hollows and pools. Both hummock types have overlapping water tables and differ from lawns by as much as 5-25 cm. The water-table depth in tussocks appears to be very variable spatially. From these data, it would seem that a *significant* water-table change – defined as one sufficient to cause a change in vegetation type – would be of the order of 10 cm or more. This suggestion is based on the assumption that the vegetation responds in a simple way to water-table position and that a shift in water tables from those that characterise vegetation type a, for example, to those that characterise type b, will be sufficient for the vegetation also to change (from type a to type b). This assumption takes no account of plant competition effects or ecological inertia. It is possible, for example, that an area of peatland with vegetation type a would have to be subjected to the water-table regime of vegetation type b for several years before a corresponding shift in the vegetation took place. In other words, the assumption does not account for ecological resistance as defined by **Harrison (1979)**.

Although her study is useful in showing the differences in water tables between different vegetation types, **Belyea's (1999)** figure of *c*. 10 cm should be treated with some caution because she does not provide any details on dipwell design or installation, and because she notes that there may have been errors in her data:

> "The first reading (made 2 days after the installation of the dip-wells) was discarded because of concern that position of the water table in the well had not reached equilibrium with that in the surrounding soil".

These errors may not have been consistent between microhabitats because peat type differs between microhabitats and can affect the response time (as discussed in **Hanschke and Baird (2001)**) or responsiveness of dipwells.

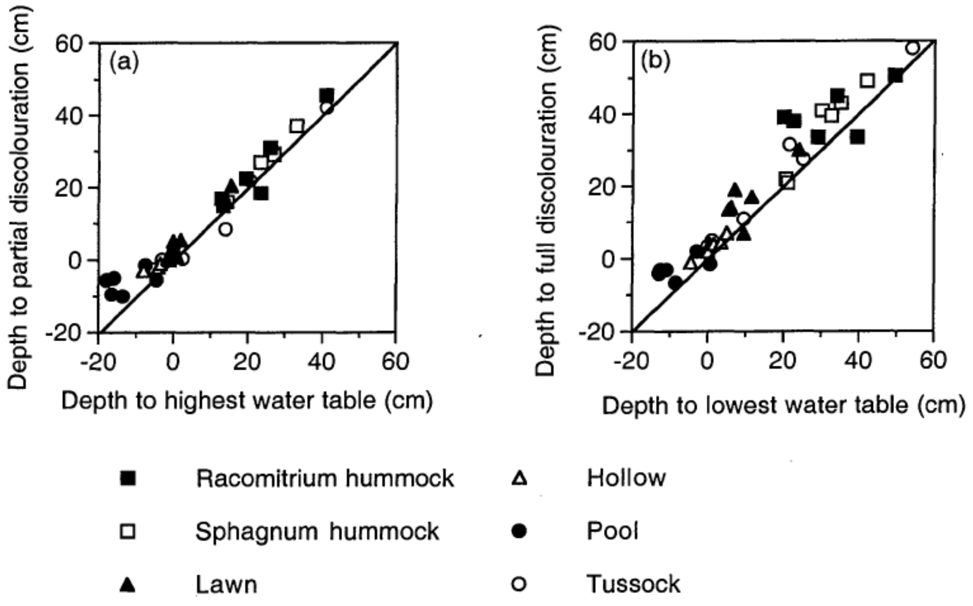

Figure 1.1. *The highest and lowest water tables measured using dipwells (x-axis data) in the named microhabitats in a 15-month study carried out by* ***Belyea (1999)*** *(reproduced unaltered from* ***Belyea (1999)*** *– her Figure 1).*

In a study of methane (CH_4) fluxes from a lowland blanket bog (Glencar) in Ireland, **Laine *et al.* (2007)** measured water tables in a range of microhabitats using dipwells lined with perforated PVC tubes. No details are given about the tubes or how they were perforated and installed. The microhabitats investigated were (original terminology):

- Hummock (HU): mosses: *Racomitrium lanuginosum*, *Sphagnum rubellum*, and *Sphagnum papillosum*; vascular plants: *Calluna vulgaris* (L.) Hull., *Erica tetralix* L. and *Molinia caerulea* (L.) Moench.
- High-lawn (HL): "vigorous cover" of *Schoenus nigricans* L., *M. caerulea*, *E. tetralix* and *Rhynchospora alba* (L.) Vahl..
- Low-lawn (LL): mainly dominated by *R. alba*.

- Hollow (HO): "sparse cover" of range of species including *Sphagnum cuspidatum*, *Sphagnum auriculatum*[1], *Menyanthes trifoliata* L., *S. nigricans*, *Carex limosa* L. and *Eriophorum angustifolium* Honck.

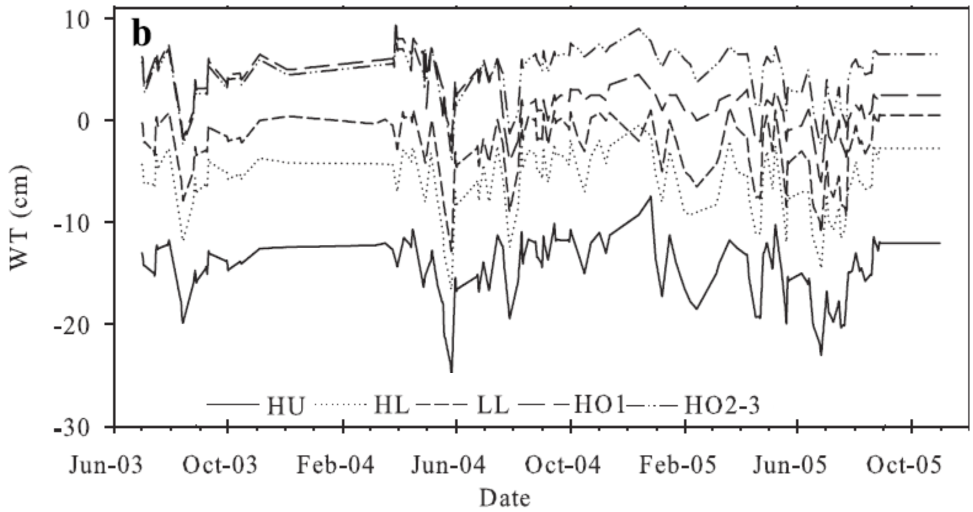

Figure 1.2. *Water tables for the named microhabitats at Glencar. With the exception of the trace for HO1, the data represent the means from at least two wells. Linear interpolation was used between fortnightly to monthly measurements. From the original (Figure 1 from* **Laine et al. *(2007)****), with minor modifications. Codes explained in main text above: HU is hummock, HL high lawn, LL low lawn, and HO hollow.*

The data from **Laine *et al.* (2007)** suggest a similar value to **Belyea (1999)** for a significant water-table change. As can be seen from Figure 1.2, water tables consistently differ by 5-10 cm between lawns and hollows and by 10-15 cm between lawns and hummocks. Notably, even the two types of lawn (HL and LL) are separated by a reasonable difference in water-table level: *c*. 4 cm. As with **Belyea (1999)** there is uncertainty over the reliability of the data because no information is given on well performance. Nevertheless, provisionally, from the two papers **we might set a threshold for significant water-table change at 10 cm, with half this value probably providing a conservative lower-end**.

The above definition of significance assumes that it is change from one microhabitat to another that matters, when sometimes changes in the abundance of different plant species **within a microhabitat** might also be important, especially if such changes are permanent. For example, a blanket peatland hollow dominated by *Sphagnum cuspidatum* with a sparse cover of sedges might undergo change to a hollow with a relatively high cover of sedges and this change might lead to substantial and undesirable changes in the methane (CH_4) budget (e.g., **Green and Baird (2012)**) even though the microhabitat remains a hollow.

1.2 The effect of ditches and ditch blocking on the vegetation of blanket bog

To our knowledge only two studies have been published on the effect of ditches and ditch blocking on the vegetation of blanket bog: **Stewart and Lance (1991)** and **Bellamy *et al*. (2012)**.

Stewart and Lance (1991) report on an investigation of the effect of ditches on both water tables and vegetation on two areas of blanket bog at Moor House in the N Pennines, N England. Their study sites were drained with parallel ditches running obliquely to the contours. The authors take a long-term perspective (> 20 years) on how drainage affects vegetation and also report results of a short-term (less than two month) study on water-table behaviour between the ditches. They found that, within 20 years of the drains being cut at one of the sites – Burnt Hill – *Sphagnum capillifolium* (Ehrh.) Hedw. had disappeared from ditch edges and virtually disappeared from inter-ditch areas (the distance between ditch being 15 m). For other blanket peatland species **Stewart and Lance (1991)** found that the effects of ditches appeared to be more

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[1] As given by the authors; they presumably mean *Sphagnum inundatum* Russow.

local to the drain or to vary over time since drainage, perhaps because of variations in meteorological conditions. One problem with **Stewart and Lance's (1991)** study is that the representativeness of the baseline condition is not known. That is, the vegetation composition at the beginning of the study may have reflected a damaged condition because of previous land management. Burnt Hill was so-named because of a severe fire on the site two years before the drains were cut in 1952. The vegetation plots at the site were also fenced off from grazing animals (presumably they had been open to grazing animals prior to the vegetation plots being established). These events almost certainly had some effect on the vegetation in subsequent years and will have complicated the picture of how the vegetation responds to drainage.

In a short-term study of water tables between ditches in the summer of 1979, **Stewart and Lance (1991)** found that average water-table depths varied spatially by as much as 15 cm, with the deepest water tables close to the ditches and shallowest in the mid-points between the ditches. They also found a difference in drainage effects between the area upslope and downslope of each ditch. The influence of a ditch extended further downslope than upslope, due, it seems, to the ditches acting as interceptors, effectively 'starving' areas downslope of water, so making them drier. Although only a short study, the hydrological data collected by **Stewart and Lance (1991)** confirm that at least 20% of the area between drains can be affected by the drain (i.e., are drier than would be the case in the absence of the drain). It is difficult to compare their hydrological data with their vegetation data because of the different timescales involved; certainly their *Sphagnum capillifolium* data accord with the hydrological data in that it disappeared from drain edges where drainage effects are greatest. However, that it also disappeared in the areas between drains may suggest that drains cause all of the inter-drain area to be drier than would be the case naturally, although, as noted above, the vegetation data of **Stewart and Lance (1991)** should be treated with some caution.

Bellamy *et al*. (2012) looked at drainage and re-wetting effects on blanket peatland vegetation at four sites in NE Sutherland, Scotland: two sites where ditches had been blocked and two where the ditches remained open. Vegetation composition was measured in transects perpendicular to the long-axis of the study ditches at distances of 0.5, 2.5, 6.5 and 14.5 m. At each distance, a 1-m cane was laid on the ground and the percentage cover of all main species was estimated to the nearest five percent. In their data analysis, the authors looked at four response variables. All were based on vegetation composition, and represented: (a) wet conditions, (b) dry conditions, (c) ‘bog recovery’, and (d) ‘bog degradation’. Species indicative of bog recovery included a *Sphagnum cuspidatum* group, a *Sphagnum papillosum* / *Sphagnum capillifolium* group, *Eriophorum angustifolium*, dead *Calluna vulgaris* and open water. Species indicative of degradation included live *Calluna vulgaris*, *Molinia caerulea*, *Hypnum* spp. and *Sphagnum tenellum* (Brid.) Bory. The authors note that the latter grouping is more indicative of heath than bog. A generalized linear modelling approach appears to have been used for the data analysis, in which various confounding factors (e.g., slope and whether or not the vegetation cover was measured on the ditch spoil 'throw' side of the ditch) were considered as well as whether or not the ditch was blocked.

The results from the study were somewhat 'messy', with **Bellamy *et al*. (2012)** noting:

> “The results of this study provide some support for the hypothesized effects of drain-blocking on vegetation, based on documented hydrological changes. Almost all the differences were due to effects at one of the blocked sites only, with little evidence of the predicted responses to blocking at the second blocked site.”

The authors found that the:

- Wet vegetation index varied significantly with spoil, mean distance between drains, site, and distance from drains.
- Dry vegetation index varied significantly with site and distance from drains. There was a significant interaction between site and distance from drain.
- Bog recovery vegetation index varied significantly with site and distance from drains.
- Bog degradation vegetation index varied significantly with spoil and site. There was a significant interaction between site and distance from drain.

A possible problem with the study concerns the time since ditch blocking. On one of the blocked sites ditches had been blocked for only three years, while at the other blocked site ditches had been blocked for at least four years, with some having been blocked for five or 11 years. As the authors note, the effect of ditch blocking may take some years to be reflected in the composition of the vegetation.

The study of **Bellamy *et al.* (2013)** adds to that of **Stewart and Lance (1991)** in that it covers a different type of blanket peatland (lower altitude and lower rainfall) and compares blocked and unblocked ditches directly for areas that are in relatively close proximity. The results from **Bellamy *et al.* (2013)** are, however, somewhat equivocal. While for one ditch-blocked site there were substantial differences in vegetation from open-ditch sites, such differences were not evident for the other ditch-blocked site. It may be that periods of more than three years are required to see ditch blocking effects reflected in the composition of the vegetation. Given the uncertainty in the results from **Bellamy *et al.* (2013),** and the limitations of the vegetation work by **Stewart and Lance (1991)**, more work is required on how both drainage and ditch blocking affect blanket peatland vegetation. We have partly addressed this research gap by investigating vegetation composition in a replicated field trial on ditch blocking at a blanket peatland site in N Wales. The study was set up mainly to consider ditch blocking effects on peatland-atmosphere exchanges of methane (CH_4) and CO_2 (**Green *et al.* (2016)**; Appendix D), but it also presented the opportunity to study how ditch blocking affects the hydrological regime of blanket bogs (**Holden *et al.* (2016)**, Appendix C) and the composition of their vegetation, and it is the latter that is considered here.

2. Materials and methods

2.1. Study site

The field trial was carried out on part of the Migneint blanket bog in N Wales, UK (52.97°N, 3.84°W). The field site was located near the top of a hillslope at *c*. 500 m above sea level, with a total area of *c*. 2 ha drained by a set of 12 parallel ditches running approximately downslope, which are believed to have been dug in the 1980s. The ditches had a mean spacing of 16 m (range 11 to 26 m), mean slope of 4.5° (range 3.9 to 5.1°), and a mean length of 99 m (range 84 to 107 m). The ditches were mostly shallow (*c*. 50 - 70 cm deep) and in some cases overgrown by vegetation, although all were found to be hydrologically functional at the start of the experiment. Measured peat depth in the study area ranges from around 0.5 m to 2.5 m. The peat overlies Cambrian mudstones and siltstones (**Lynas, 1973**) but these appear to be largely hydrologically isolated from the overlying peat.

In February 2011, eight of the 12 ditches were blocked using two different methods, and four open ditches retained as controls. Ditches were assigned to treatments by first placing them into four groups of three based on their measured pre-blocking discharge rate, and then randomly assigning one ditch from each subset into one of the three treatment/control categories. The two ditch-blocking methods used were damming and re-profiling plus damming (henceforth simply referred to as ‘re-profiling’). For the dammed treatment, peat dams were constructed at regular intervals along the ditch using peat extracted from ‘borrow pits’ adjacent to the ditch, creating a sequence of pools behind the dams. For ditches in the re-profiling treatment, ditch vegetation was removed, the peat base compressed to destroy any natural pipes that may be present, the ditch partially infilled with peat scraped from inter-ditch areas, and the vegetation replaced. This treatment also involved the construction of peat dams, but pools tended to be shallower or absent due to the partial infilling of the ditch.

2.2. Vegetation sampling

The vegetation at the site was monitored in two ways: (a) using permanent 1 m × 1 m quadrats established at the end of the growing season in 2010 before the ditch blocking took place, and (b) in permanent 14.95-cm-diameter cylindrical collars used for flux chamber tests to measure CH_4 and CO_2 exchanges between the peatland and the atmosphere (see **Green *et al.* (2016)**; Appendix D). The collars enclosed an area of 0.07 m^2.

Forty eight permanent quadrats were set up to the east and west of each ditch. Two quadrats were placed 2 m either side of the ditch edge (i.e., 2 m east and west – see Figure 2.1 in the main part of the report), while two were placed closer to the central area between the ditches. Here we focus on the 24 2-m quadrats because, being close to the ditches, these are most likely to show any changes in vegetation as a result of ditch blocking. Also, the hydrological analysis (**Holden *et al.* (2016)**; Appendix C) revealed quite complicated changes to water flow across the site after ditch blocking, making it difficult to assign the quadrats beyond 2 m to a particular treatment.

The permanent quadrats were monitored as follows:
(a) The abundance of **all sedges** (including the Eriophora and *Rhynchospora* alba (L.) Vahl.) and **all *Sphagnum* spp.** was estimated using a nested frequency measure. These groups of species were chosen because they are believed to be important controls on methane (CH_4) emissions from peatlands (see literature review in Appendix A) (see also below). The measurement of nested frequency involved noting the presence or absence of each target sedge and *Sphagnum* species in each of the 100 'imaginary' 10 cm × 10 cm squares comprising each quadrat. Using this method, a species present in, for example, 46 of the 100 squares, would have a nested frequency of 46% or 0.46. On a species by species basis, this method will give a value that is correlated to cover (and which becomes closer to cover as square size decreases). For any single species, or group of related species, it provides a simple and objective measure that allows abundance to be compared over space (between locations or management treatments) or over time (across successive years after management change). It is, however, unreliable for comparing abundance between different species. For example, a species like Cranberry (*Vaccinium oxycoccos* L.) has thread-like branches which often form a 'net' underneath taller shrubs. A species such as this could produce a very high nested frequency even though its real cover was rather low. In contrast, tussocks of sedges such as *Eriophorum vaginatum* L. might have a relatively high true cover but occupy rather few 10 cm × 10 cm squares. As such, it makes little sense to compare these species using nested frequency.
(b) **Species richness** in each quadrat was recorded by noting the presence of all plant species, including the bryophytes, and lichens.
(c) The **'vigour' of the sedges** within each quadrat was also recorded by measuring, for each sedge species, the height and maximum width of the ten leaves nearest the centre of the quadrat. Where there were fewer than ten leaves, measurements were still made (and the number of leaves noted).
(d) Each permanent quadrat was monitored once per year at the end of the growing season (late August to early October).

The collars used in the flux chamber tests were photographed every time a flux chamber test was conducted (approximately every three to six weeks). A selection of these photographs was analysed for nested frequency. In the selected photographs, a grid of 100 squares was placed over the 14.95-cm-diameter collars (see **Green *et al.* (2016)**; Appendix D) and a note made of the presence or absence in each square of the following target species:

- Shrubs: *Calluna vulgaris*, *Empetrum nigrum* L., *Erica tetralix*, *Vaccinium myrtillus* L., *Vaccinium vitas-idaea* L..
- Grasses and sedges: *Agrostis canina* L., *Carex nigra* (L.) Reichard, *Deschampsia flexuosa* (L.) Trin., *Eriophorum angustifolium*, *Eriophorum vaginatum*, *Juncus squarrosus* L., *Molinia caerulea*.
- Non-*Sphagnum* bryophytes: *Aulacomnium palustre* (Hedw.) Schwägr., *Racomitrium lanuginosum*.
- Sphagna: *Sphagnum capillifolium*, *Sphagnum cuspidatum*, *Sphagnum fallax* (Klinggr.) Klinggr., *Sphagnum papillosum*.

If a species of *Sphagnum* or vascular plant not in the list above was an important component (> 10% of squares) of the collar's vegetation, its abundance was also measured (i.e., its nested frequency was measured). This addition to the target list included only Sphagna and vascular plants; lichens or bryophytes other than the Sphagna were not included.

Because of the very different size of the nested squares within the collars and the quadrats and the large difference in collar and quadrat area, the data from them are not comparable. Additionally, while it was possible when doing in-field measurements of the quadrats to look at layering of the vegetation, this was not possible from the collar photographs (some species occurring under a layer of another species would be missed). The data from the collars were collected mainly to help with the development of the CO_2 and CH_4 flux models (see **Green *et al*. (2016)**; Appendix D). Some additional post-project analysis of the collar data will be undertaken, but these data are not considered here. Similarly, while species richness data were collected for the quadrats, we consider only the abundance data at this stage because it is these data that are of most use in understanding controls on carbon fluxes at the site (see section 1).

As noted above, we grouped the quadrat data on abundance into a sedge group and a *Sphagnum* group. The sedge group was, in practice, dominated by *Eriophorum vaginatum*, while the *Sphagnum* group comprised, in order of importance: *Sphagnum capillifolium*, *Sphagnum fallax*, and *Sphagnum papillosum*. These three species have a tendency to occupy different microhabitats (e.g., **Belyea and Clymo (2001)**), so a case could be made for separating them in any analysis. However, we chose to lump them into a single category for two reasons. First, all were relatively sparse at the beginning of the project, and overall *Sphagnum* abundance can be taken as an indicator of site wetness (with wetter sites often having a higher overall *Sphagnum* abundance than drier sites). Secondly, although they can occupy different microhabitats in undisturbed sites, the conditions under which they grow well can be quite variable and will depend on facilitation by, and competition with, other species. Thus, while a species may be associated with a particular water-table regime in a natural site, it is by no means clear that the same species will reliably indicate that water-table regime when it colonises a restored site. **Wheeler *et al*. (2002)** note, for example, a study that showed that *S. fallax* , which is usually associated with hollows and wet lawns, was capable of colonising 'dried-out' bogs, this being facilitated by a cover of *Polytrichum alpestre* Hoppe and *Eriophorum vaginatum*.

2.3. Data analysis

For the data from the 24 quadrats, we investigated whether blocking treatment (control or open ditches, dammed, or re-profiled), position (east or west of the ditch) and time (year of measurement) had any effect on the nested frequency of the sedges and the Sphagna. For each plant group, a factorial, repeated-measures ANOVA was used for the analysis (in IBM SPSS Statistics version 21). The sedge data were transformed (cubed) because they failed the test for normality. Where Mauchly's test indicated a violation of the sphericity assumption, changes were made to the degrees of freedom using a Greenhouse Geisser correction to reduce the chances of a Type I error. Where $p \leq 0.05$, Tukey's HSD (honest significant difference) test was used to identity which blocking treatments, sides (east or west) or times (year of survey) were significantly different from each other.

We separated position (east or west of the ditch) in the analysis because of uncertainty about which side might show the greater drainage effect in two of the control ditches. As is shown by **Holden *et al*. (2016)** (see Appendix C), after ditch blocking water could track across some blocked ditches towards the control (open ditches). Because of the orientation of the ditches this tracking of water meant that there was a possibility the eastern sides of the two of the open ditches could become wetter after blocking took place and not act as reliable controls.

Sedge vigour data from the 24 quadrats were collated and graphed according to treatment, position, and year. As noted above, by far the most common sedge at the site was/is *Eriophorum vaginatum*, with the other recorded species (*Eriphorum angustifoilium* and *Carex nigra*) only appearing in a few quadrats and then not all of the time. Therefore, we restricted our attention to the leaf statistics from *E. vaginatum*. In addition, leaf width in *E. vaginatum* was found not to vary with leaf length (it was often 0.5 mm or less) so we considered leaf length as the main indicator of vigour. As well as graphing the leaf length data, we investigated the effects of treatment, quadrat position (east or west) and year using the same type of ANOVA as applied to the nested frequency data.

3. Results

3.1. Permanent quadrats: abundance of sedges and Sphagnum *spp.*

As noted in section 2.2, only the permanent quadrat data from the quadrats 2 m either side of each ditch are considered here. Summary data from these quadrats have been separated according to plant functional type (sedge and *Sphagnum*) and whether the quadrat was to the east or west of the ditch and are shown in Tables 3.1-3.4. The data in the tables suggest the following:

- For the quadrats to the east of the ditches:
  - Sedge: sedges were very abundant across all of the treatments during the period of the experiment. There is also the suggestion of an up-tick in abundance in 2014; differences in abundance between the other years are less obvious.
  - *Sphagnum*: there were year-on-year increases in nested frequency of the control and dammed treatments, but no obvious pattern over time for the re-profiled treatment. The initial difference in average *Sphagnum* abundance between the control and dammed remained over time as abundance in both increased broadly in parallel.
- For the quadrats to the west of the ditches:
  - Sedge: the nested frequency of sedges was consistently high across all years in the control and dammed treatments. The re-profiled treatment had somewhat lower nested frequencies between 2011 and 2013 than the other treatments.
  - *Sphagnum*: the nested frequency of *Sphagnum* spp. increased in all treatments between 2010 and 2014. *Sphagnum* abundance was consistently higher in the control (open ditch) treatment than in the two re-wetting treatments. Both re-wetting treatments had a similar level of *Sphagnum* abundance.

The ANOVA test on the sedge abundance data revealed that there was no treatment effect ($p = 0.564$) or position (east, west) effect ($p = 0.441$). Time (year of measurement) has a significant influence ($p = 0.007$) with 2014 > 2011 = 2012 (both other years are deemed equal). There is no interaction effect between time, treatment and position ($p = 0.566$). The analysis of the *Sphagnum* nested frequency data revealed no treatment effect ($p = 0.086$) or effect of position ($p = 0.219$). Time has a significant influence ($p = 0.001$), with 2014 > 2012 = 2011 = 2010 (2013 was not significantly different from any other year). There is no interaction effect between time, position and treatment ($p = 0.989$).

In short, these results suggest (a) that drainage/blocking treatment has had no effect on sedge and little if any effect on *Sphagnum* abundance and (b) that significant inter-annual changes in sedge and *Sphagnum* abundance can occur.

Table 3.1. *Nested frequency (%) of sedges (mainly* Eriophorum *spp.) from the permanent quadrats 2 m to the east of the ditches (*n *= 4).*

		2010	2011	2012	2013	2014
Control	Mean	**98**	**96**	**86**	**90**	**106**
	Median	94	95	87	93	97
	Max	114	115	117	109	142
	Min	89	80	55	64	87
Dammed	Mean	**73**	**85**	**94**	**87**	**102**
	Median	92	89	92	92	101
	Max	109	98	106	100	120
	Min	0	63	86	63	85
Re-profiled	Mean	**94**	**91**	**82**	**90**	**97**
	Median	97	95	84	94	100
	Max	100	99	97	98	100
	Min	84	76	62	72	87

Table 3.2. *Nested frequency (%) of* Sphagnum *spp. from the permanent quadrats 2 m to the east of the ditches (*n *= 4).*

		2010	2011	2012	2013	2014
Control	Mean	**40**	**46**	**50**	**52**	**67**
	Median	39	41	50	57	74
	Max	70	83	79	92	90
	Min	12	19	20	0	28
Dammed	Mean	**15**	**19**	**24**	**30**	**36**
	Median	10	23	28	35	34
	Max	41	27	35	48	65
	Min	0	1	6	4	10
Re-profiled	Mean	**31**	**20**	**23**	**27**	**33**
	Median	24	19	24	20	37
	Max	60	39	43	67	59
	Min	15	1	0	2	0

Table 3.3. *Nested frequency (%) of sedges (mainly* Eriophorum *spp.) from the permanent quadrats 2 m to the west of the ditches (*n *= 4).*

		2010	2011	2012	2013	2014
Control	Mean	**92**	**90**	**84**	**95**	**94**
	Median	94	97	91	96	95
	Max	101	98	98	96	103
	Min	81	69	58	94	82
Dammed	Mean	**92**	**90**	**94**	**94**	**95**
	Median	91	91	93	97	98
	Max	97	100	99	98	100
	Min	88	80	90	83	85
Re-profiled	Mean	**95**	**63**	**79**	**86**	**89**
	Median	93	61	82	86	101
	Max	102	96	100	100	108
	Min	92	34	52	71	46

Table 3.4. *Nested frequency (%) of* Sphagnum *spp. from the permanent quadrats 2 m to the west of the ditches (*n *= 4).*

		2010	2011	2012	2013	2014
Control	Mean	**18**	**37**	**35**	**38**	**50**
	Median	21	40	34	50	53
	Max	28	66	71	54	92
	Min	2	0	0	0	0
Dammed	Mean	**5**	**15**	**16**	**24**	**33**
	Median	3	4	8	9	26
	Max	13	51	46	73	57
	Min	1	0	4	4	21
Re-profiled	Mean	**9**	**9**	**10**	**22**	**27**
	Median	5	3	4	8	5
	Max	24	29	32	73	97
	Min	0	0	0	0	0

3.2. Vigour (leaf length) of Eriophorum vaginatum *in the quadrats*

The leaf length (vigour) data from the 24 quadrats 2 m either side of each ditch are shown in Figures 3.1 and 3.2. The graphs suggest that leaf length did not vary with treatment or position, but that there is a possible trend of decreasing leaf length over time. The statistical analysis confirms these visual impressions. The repeated measures ANOVA revealed no treatment ($p = 0.913$) or position ($p = 0.465$) effects. Time (year of survey) did have a significant influence ($p < 0.0001$), with 2010 = 2011 = 2012 > 2013 = 2014. There was no interaction effect between time, position and treatment ($p = 0.322$).

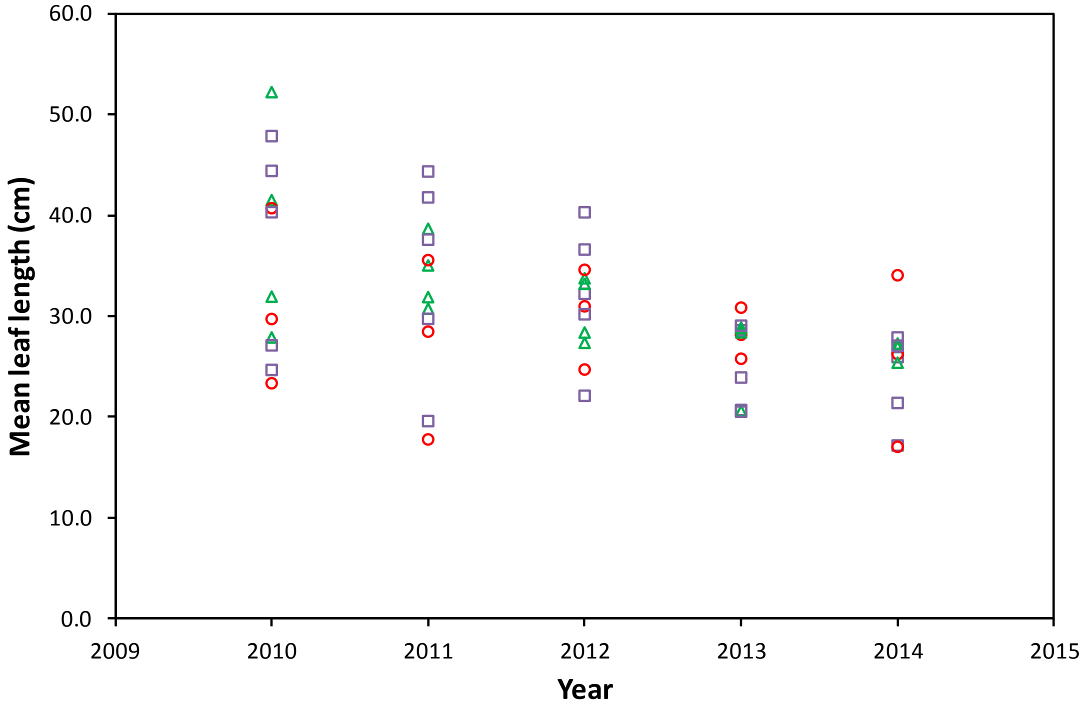

Figure 3.1. *Mean leaf length (per quadrat) of* Eriophorum vaginatum *in the quadrats 2 m to the west of the ditches.* △ *control,* **o** *dammed,* □ *reprofiled.*

Figure 3.2. *Mean leaf length (per quadrat) of* Eriophorum vaginatum *in the quadrats 2 m to the east of the ditches.* △ *control,* **o** *dammed,* □ *reprofiled.*

4. Discussion and conclusions

As noted in the Introduction (see also Appendix A) it is often assumed that ditch blocking will lead to an increase in the cover of *Sphagnum* and a reduction in the cover of sedges, particularly the cotton grasses (*cf*. **Lindsay (2010)**). Contrary to this expectation, our data have shown no treatment effects on the abundance of sedges and *Sphagnum* spp. We did find an effect of time, with the abundance of both sedge and *Sphagnum* varying significantly between some years. There is the suggestion that both *Sphagnum* and sedges, but the latter to a lesser extent, were more abundant at the end of the project than at any other time. However, there were no clear temporal trends (i.e., no systematic changes) in the data so it is difficult to attribute the inter-annual variability to anything other than inter-annual variability in other conditions, probably the weather. Although we have good weather data for the site, the length of the experiment was too short to undertake a time-series analysis of the data. It is likely that plant response to weather conditions shows lags of at least two years. Therefore, with a data set of five years in total it is not possible to investigate such lags and the relative contributions of different meteorological variables (rainfall amount and regime, growing season frost days and so on) on plant abundance. What is clear is that factors other than those associated with the ditch blocking have to be invoked to explain the variations seen in the data. Interestingly too, although **Stewart and Lance (1991)** found systematic changes in *Sphagnum capillifolium* with time since drainage, other species at their study site such as *Calluna vulgaris* and *Eriophorum vaginatum* waxed and waned in abundance over time, and these non-monotonic changes must have been caused by factors other than drainage (quite probably year on year variability in meteorological conditions).

Our analysis also revealed no significant effect of treatment or position on the leaf lengths of *Eriophorum vaginatum*. There is the suggestion in the data that leaf lengths, and, by implication, sedge vigour, decreases towards the end of the study period. This decline coincides with a dip in sedge abundance in 2013 followed by an increase in 2014. There is a danger of over-interpreting such data, but it is possible that the decline in leaf length in 2013 is associated with the decline in sedge abundance in 2013. Despite the 'bounce back' in sedge abundance in 2014, the new growth that this implies may not have been sufficient to give a significant increase in average leaf length. Another possible interpretation of the leaf-length data is that, while *Eriophorum vaginatum* has remained widespread across the site, it is slowly losing vigour, perhaps as *Sphagnum* mosses expand. However, the data, such as they are, suggest that any such changes occur widely across the site and are not restricted to the restored areas (the blocked ditches).

The permanent quadrats will be maintained at the site, as will the site's weather station, and it is hoped that a longer run of data may be obtained that will allow a fuller picture to be drawn of the controls on vegetation. Discussions are also taking place with staff at Natural Resources Wales who undertook the vegetation surveys about additional analyses of the vegetation data. In particular, we plan to investigate whether species richness in the quadrats varies according to treatment or over time. We are also considering undertaking an analysis of the collar vegetation data in a similar way to the analysis of the quadrat data. As noted in section 2.2, the collar data were collected primarily for the purpose of analysing the greenhouse gas flux data, but there may be merit in analysing the collar data to see if they show a similar pattern (or lack of pattern) to the data from the quadrats.

In conclusion, **there is currently no evidence that drain blocking has had an effect on the vegetation at the site**. This conclusion may not apply to lower-altitude and lower-rainfall blanket bogs, but it does suggest caution in assuming that ditch blocking will invariably lead to a decline in sedge and increase in *Sphagnum* abundance.

5. References

Baird, A.J. 2013. *Critical Review of Widths of Drainage Influence Associated with Artificial Drains in Blanket Bog, with Particular Reference to the 2011 Update of the Scottish Government Carbon Calculator Tool*, Countryside Council for Wales (CCW) Contract Science Report 1015, University of Leeds, 12 pp..

Bellamy, P.E., **Stephen**, L., **Maclean**, I.S., and **Grant**, M.C. 2012. Response of blanket bog vegetation to drain-blocking. *Applied Vegetation Science*, 15, 129-135, doi: 10.1111/j.1654-109X.2011.01151.x.

Belyea, L.R. 1999. A novel indicator of reducing conditions and water-table depth in mires. *Functional Ecology*, 13, 431-434.

Belyea, L.R., and **Clymo**, R.S. 2001. Feedback control of the rate of peat formation. *Proceedings of the Royal Society of London B*, 268, 1315-1321.

Green, S.M., and **Baird**, A.J. 2012. A mesocosm study of the role of the sedge *Eriophorum angustifolium* in the efflux of methane—including that due to episodic ebullition—from peatlands. *Plant and Soil*, 351, 207-218, doi: 10.1007/s11104-011-0945-1.

Green, S.M., **Baird**, A.J., **Evans**, C., **Peacock**, M., **Holden**, J., **Chapman**, P., **Gauci**, V., and **Smart**, R. 2016. The effect of drainage ditch blocking on the CO_2 and CH_4 budgets of blanket peatland. Appendix D in: Green, S.M, Baird, A.J., Evans, C., Ostle, N., Holden, J., Chapman, P.J., and McNamara, N. *Investigation of Peatland Restoration (Grip Blocking) Techniques to Achieve Best Outcomes for Methane and Greenhouse Gas Emissions/Balance: Field Trials and Process Experiments Final Report*. Defra Project SP1202, University of Leeds, Leeds.

Hanschke, T., and **Baird**, A.J. 2001. Time-lag errors associated with the use of simple standpipe piezometers in wetland soils. *Wetlands*, 21, 412-421.

Harrison, G.W. 1979. Stability under environmental stress: resistance, resilience, persistence, and variability. *The American Naturalist*, 113, 659-669.

Holden, J., **Green**, S.M., **Baird**, A.J., **Grayson**, R.P., **Chapman**, P.J., **Evans**, C., and **Peacock**, M. 2016. The impact of ditch blocking on blanket peatland hydrology. Appendix C in: Green, S.M., Baird, A.J., Evans, C., Ostle, N., Holden, J., Chapman, P.J., and McNamara, N. *Investigation of Peatland Restoration (Grip Blocking) Techniques to Achieve Best Outcomes for Methane and Greenhouse Gas Emissions/Balance: Field Trials and Process Experiments Final Report*. Defra Project SP1202, University of Leeds, Leeds.

Laine, A., **Wilson**, D., **Kiely**, G., **Byrne**, K.A. 2007. Methane flux dynamics in an Irish lowland blanket bog. *Plant and Soil*, 299, 181-193, doi: 10.1007/s11104-007-9374-6.

Lindsay, R. 2010. *Peatbogs and Carbon: A Critical Synthesis to Inform Policy Development in Oceanic Peat Bog Conservation and Restoration in the Context of Climate Change*. RSPB Scotland with funding support from Scottish Natural Heritage, Countryside Council for Wales, Natural England and the Forestry Commission, 315 pp.

Lynas, B.D.T. 1973. The Cambrian and Ordovician rocks of the Migneint area, North Wales. *Journal of the Geological Society of London*, 129, 481-503.

Low, R., and **Baird**, A.J. 2015 in press. *Assessment of Hydrological Impacts Resulting from Drainage, Access Trackways and Related Windfarm Infrastructure on Blanket Bog and Upland Soligenous Mires*, Contract Number R004694 (Natural Resources Wales), Rigare Ltd.

Stewart, A.J.A., and **Lance**, A.N. 1991. Effects of moor-draining on the hydrology and vegetation of Northern Pennine blanket bog. *Journal of Applied Ecology*, 28, 1105-1117.

Wheeler, B, **Money**, R.P., and **Shaw**, S.C. 2002. Freshwater wetlands, in Perrow, M.R., and Davy, A.J. (eds), *Handbook of Ecological Restoration, Vol. 2: Restoration in Practice*, Cambridge University Press, Cambridge, 325-354.