

Exmoor Mires Project: Initial analyses of post restoration vegetation monitoring data

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Abstract

The initial analyses of seven years of pre and post-restoration vegetation monitoring have revealed short and medium term effects of peatland restoration by ditch blocking on the botanical communities of damaged peatland. The vegetation data are interpreted in terms of National Vegetation Classification (NVC) communities at site and quadrat level, by the application of Ellenberg's indicator values and by employing indicator species lists.

Site level NVC communities for five of the seven re-surveyed sites show a change in botanical composition indicative of rewetting of the underlying peat. The analysis of Ellenberg values applied to the species found in all quadrats before and after restoration provide a detailed measure of change, and suggest that restoration has led to significant peatland rewetting. At site level, significant changes in Ellenberg values suggest successful restoration at four of the seven resurveyed sites, contradicting the site level NVC assessment for one site. Changes in the list of selected indicator species support the findings of the site level Ellenberg value analyses, and highlight the underlying changes in species occurrence. Our analyses suggest that site level NVC analysis has some value, but missed important detail which was picked up during the subsequent analyses.

Where restoration structures have remained intact, botanical communities have significantly changed, reflecting rewetting of underlying peat at all but one site. This indicates that the use of ditch blocking to re-wet peatlands is a successful hydrological rehabilitation strategy.

Vegetation community changes can also be used as indicators of changing greenhouse gas fluxes from peatlands as a result of restoration. These results enable the Exmoor Mire Project (EMP) to move towards the verification of the carbon emissions savings from peatland restoration on Exmoor, an essential step in the establishment of a Payment for Ecosystem Services (PES) reward scheme. A key EMP objective is to enable upland farmers and landowners to earn sustainable incomes from the provision of multiple ecosystems services.

Key Words: Exmoor, mires, peatland, re-wetting, vegetation, monitoring, Ellenberg, NVC, indicator species, PES.

Introduction

The Exmoor Mires Project aims to deliver multiple ecosystem service outcomes by restoring peatland areas of Exmoor previously drained as part of historic conversion to agriculture or during peat cutting activities (Exmoor Mires, 2010). Restoration is achieved through ditch blocking and water management measures designed to re-wet peat sites where drainage has led to the drying of peat and an associated change in vegetation communities.

The MIRE (Moorland Improvement and Restoration on Exmoor) Project was initiated in 1998 as a pilot project, focused on habitat restoration and river headwater management by means of ditch blocking techniques. A small partnership of the Exmoor National Park Authority (ENPA), the Environment Agency (EA) and Natural England (formally English Nature) (NE) initiated pre-restoration monitoring of the vegetation and hydrology at two moorland sites at Exe Head and Blackpitts (on Exmoor). This was followed by small scale (12ha) ditch blocking restoration action at the sites in the period 2001-3. In 2006 South West Water (SWW) joined the partnership and co-funded the Exmoor Mire Restoration Project (EMRP) a four year programme of restoration and monitoring on 14 sites and 325 ha of restoration (ENPA, 2010). Since 2010 SWW have led the Exmoor Mires Project (EMP) a further phase of restoration through their progressive 'Upstream Thinking' initiative which promotes innovative ecosystem services (clean and sustained water supplies) from catchment management projects (Grand-Clement et al, 2013). By the end of March 2014 the EMP had undertaken 1,015 ha of restoration at 13 sites, with a target of 2000ha by April 2015. This scale of landscape restoration is targeted at achieving extensive habitat changes across these degraded peatlands. The ongoing vegetation monitoring programme reflects a need to develop an effective and efficient method of monitoring these changes.

SWW have a business interest in blocking historic moorland drainage ditches and peat cuttings as re-wetted peat provides regulatory ecosystem services (Bonn et al, 2009). Restored areas are known to increase storage capacity for rainfall on moorlands and promote gradual release into catchment watercourses (Wilson et al 2010). Initial post restoration monitoring on Exmoor has confirmed these predictions with less peak flow runoff during periods of precipitation, reduced water colour (Dissolved Organic Carbon, DOC) and sustained base flows from the re-wetted peat (Luscombe et al, 2014).

Ecosystem services-focused peatland restoration has been proven on Exmoor to recreate active peatland communities (Langton, 2009; Hand, 2009; Glendinning, 2013) which are now rare as a result of centuries of agricultural drainage (Bray, 2014). These changes are under reported in the literature. A recent evidence review of ditch blocking practice by NE found few citable papers. This investigation of the Exmoor Mires vegetation monitoring data seeks to redress this imbalance, and present some initial findings with a view to developing further analyses over time.

Integral to the EMP has been the comprehensive and high resolution monitoring both before and after restoration in order to track the resulting changes in hydrology, greenhouse gas fluxes and biodiversity (Arnott, 2010; Luscombe, 2014; Hornibrook, 2014; First Ecology, 2012, 2014). A key part of the biodiversity monitoring has been the post restoration monitoring of botanical assemblages, which can be used to infer underlying changes in the peatland hydrology (Bellamy et al. 2012; Lunt et al 2010).

This paper focuses on identifying the post restoration changes in the botanical communities at the restoration sites, which can be used in conjunction with the other ongoing monitoring programmes to indicate the underlying hydrological and greenhouse gas changes (Ramchunder et al, 2009; Couwenburg et al, 2011) across the whole of the 2500 ha restoration area. The EMP is developing a rapid assessment method for monitoring hydrological change across the moorland landscape based on the proxy measure of ongoing vegetation changes. Demonstrating success is a pre-requirement of the EMP funding arrangements and a necessity if the greenhouse gas emissions savings arising from the restoration work are to be verified under the newly emerging Peatland Code (IUCN, 2013).

Somerset Wildlife Trust and its consultancy, First Ecology have been involved in the botanical monitoring of the restoration sites since the baseline monitoring was initiated in 1998 at Blackpitts and Exe Head (SERC, 1998). Since 2011 First Ecology has been contracted to lead the annual monitoring and reporting campaigns, supported by the project team and volunteers (First Ecology; 2012, 2014).

Field survey

A total of seven post-restoration sites were re-surveyed during the 2013 survey season. The sites are presented in Table 1 and Map 1

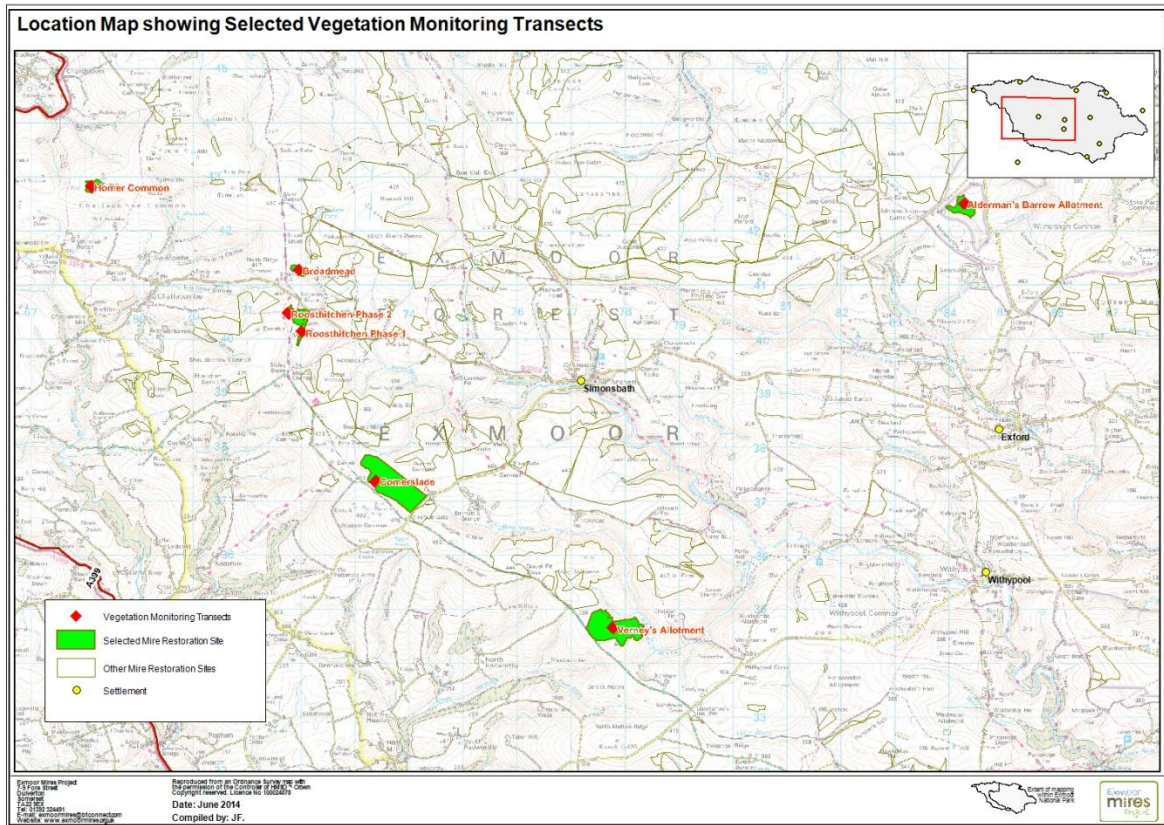
Table 1: Site summary 2013, with National Grid References

Site Name	Transect NGR		Quadrats	Re-survey
	Start	End		
Alderman's Barrow	SS8429242504	SS8433242495	40	x
Broadmead	SS7197441280	SS7197241275	32	x
Comerslade	SS7341037384	SS7337637362	40	x
Homer Common	SS6812042820	SS6814842813	30	x
Roosthitchen Phase 1	SS7203740125	SS7201940134	30	x
Roosthitchen Phase 2	SS7176440482	SS7178940460	15	x
Verney's Allotment	SS7781034640	SS7777634663	40	x

A field survey methodology has been developed which is designed to collect accurate and comparable species data across the time-scale of the project. The central objective was to enable the analysis of community change at re-surveyed sites in terms of the following:

- National Vegetation Classification communities; both for the site as a whole and at quadrat level where possible;
- Ellenberg (1974) values; this method allows for finer scale interpretation and comparison of results between years, based on several different parameters;
- Indicator species; using groups of species agreed by the project staff as being typical of "rich" and "poor" sites.

Map 1: Site locations for the 2013 surveyed transects



Consistency in data collection is particularly important, although changes to data collection have been made over the duration of the project to improve quality (e.g. movement from presence absence data to percentage cover). The field method employed in 2013 mirrors that employed the previous year, and is broadly as follows.

- Sites are selected by the project staff for restoration, and a mapped ditch is targeted for blocking, across which the transect will be established. The site is visited prior to restoration and the transect marked out by measuring 15 meters perpendicular to either side of the ditch, with the transect ends being marked by two short wooden pegs one metre apart. The total length of the monitoring transects has varied from site to site depending on the original baseline surveys, and whether it was necessary to monitor both sides of the ditch, but 15m each side is the default length.
- When the site is surveyed, either to establish a baseline or to make a post restoration monitoring visit, a 30 metre measuring tape is run across the transect and tied off tight at either end. Along the length of this tape the 1m square quadrat is placed, totalling 30 separate samples for a standard 30m transect. The quadrat itself is subdivided into 4 sub-quadrats, and all species occurring in each sub-quadrat are recorded separately on a percentage cover basis. Species not identified in the field were taken back to the office for identification using light microscopy. Standard reference texts were used.

Surveys were conducted between June and November, with the majority of sites being visited in July and August when most plants are flowering and can be identified rapidly. For non-flowering species vegetative identification should allow accurate recording of the vast majority of species present, and inter-year variation in the timing of surveys is not considered likely to compromise the accuracy of results significantly.

Data analysis

Allocation of NVC communities

The National Vegetation Classification system (Rodwell, 1991) is a widely used to categorise dominant British vegetation in homogenous stands. It has been employed as part of this analysis both because it allows a broad classification of vegetation types and therefore underlying hydrological conditions, and because it is an accepted system which allows comparison of this study with others.

While the traditional method of assigning NVC communities usually employs hand-keying homogenous stands in the field, for this analysis we wanted to apply a consistent and impartial method of classification for all sites, some of which had been surveyed and hand-keyed several years ago. The most commonly used approach for this kind of problem is to employ a program such as MATCH (Malloch, 1990), TABLEFIT (Hill, 1991) or MAVIS (Smart, 2000), which allocates NVC communities to data entered and supplies 'goodness of fit' values for how closely data matches the standard NVC community types.

TABLEFIT and MAVIS were both employed in our analysis, dependant on the nature of the data to be classified. For the 2013 surveys, for which species data was collected in percentage-cover values, TABLEFIT was used to generate a whole site NVC community, a process then repeated using MAVIS to check both programs were in agreement. TABLEFIT was then used to generate NVC communities for every quadrat across the length of each transect, giving a finer scale picture of variation.

During initial comparison of 2013 NVC communities to historic NVC records for the same sites, it became apparent that this had limited value since many of the older NVC classifications (2006-2010) were generated using hand keying only in the field. This meant that it wasn't possible to confidently compare repeat surveys of the same sites due to the additional element of human interpretation. To make comparisons more reliable, the older site surveys were re-classified using the methodologies employed with the newer data.

An additional complication was that the data collected prior to 2010 was collected in a presence/absence format, as opposed to the percentage cover system used subsequently. Nevertheless, MAVIS can still be used to generate constancy values for each species based on occurrence in quadrats across whole transects from which NVC communities could confidently be generated. One limitation of this older presence/absence data is that it lacks the granularity needed to generate NVC communities at quadrat level, but whole site comparisons can be more confidently made once reclassification using MAVIS has taken place.

Application and interpretation of Ellenberg's indicator values

Ellenberg's indicator values (referred to as Ellenberg values henceforth) are values allocated to individual species in a set of five scales: light; moisture; pH; nitrogen; and salinity. Given the anticipated nature of change in botanical communities after restoration, moisture, pH and nitrogen scales have been employed in this analysis. The values generally range from 1 to 9 (higher in some revisions), and are designed to indicate what the species in question reveals about that particular element of its environment. A species with a nitrogen (N) value of 1 for instance is indicative of extremely N poor sites (e.g. *Drosera rotundifolia*), whereas a species with an N value of 9 is indicative of heavily enriched or polluted sites (e.g. *Rumex*

obtusifolius). The system was developed by Heinz Ellenberg (1974) and the values used in this analysis were revised specifically for the United Kingdom by Hill et al. (1999).

Applying Ellenberg values to the botanical data circumvents the problems caused by data being recorded in different formats between years. Ellenberg values for wetness (F from the German Feuchtigkeit), reaction/pH (R) and nitrogen (N) were applied to every species within each quadrat for all transects. These values were then averaged to give F, R and N values for each quadrat. Ellenberg values were included in the calculations for each quadrat on the basis of presence of a species in any single sub-quadrat, regardless of coverage; this allows direct comparison of the more recent percentage cover values with the older presence/absence data.

A number of comparisons were then made to detect changes in these indicator values as a result of restoration works. Paired T-tests were used to compare the pooled F, R and N values of all sites prior to restoration with the values from the most recent re-surveys to detect significant ($p < 0.05$) changes. Additionally the same process was performed for each site individually to find significant changes which would further refine site level NVC designations.

Indicator species analysis

A streamlined list of mire habitat indicator species (Table 2) has been drawn up by project staff over the course of the project and continually refined based on field observations. It is designed to allocate species to one of five categories; acid grassland/dry heath, wet heath/acid mire, meso/minerotrophic mire and fen, agricultural grassland and woodland.

Table 2: Indicator species lists developed by the project for analysis of changes at the sites re-surveyed in 2013

Positive Indicators	Negative Indicators
<i>Narthecium ossifragum</i> (Bog asphodel)	<i>Calluna vulgaris</i> (Ling)
<i>Carex demissa</i> (Common yellow sedge)	<i>Potentilla erecta</i> (Tormentil)
<i>Carex echinata</i> (Star sedge)	<i>Vaccinium myrtillus</i> (Whortleberry)
<i>Carex panicea</i> (Carnation sedge)	<i>Agrostis</i> spp. (Bent grasses)
<i>Eriophorum angustifolium</i> (Bog cotton-grass)	<i>Festuca</i> spp. (Fescues)
<i>Sphagnum capillifolium</i>	<i>Molinia caerulea</i> (Purple moor grass)
<i>Sphagnum cuspidatum</i>	<i>Rhytidiadelphus squarrosus</i>
<i>Sphagnum papillosum</i>	<i>Pleurozium schreberi</i>
<i>Sphagnum palustre</i>	<i>Hypnum cupressiforme</i>
<i>Sphagnum subnitens</i>	
<i>Sphagnum denticulatum</i> (Broadmead only)	
<i>Sphagnum fallax</i> (Broadmead and Homer Common)	
<i>Viola palustris</i> (Marsh violet, Broadmead only)	
<i>Carex rostrata</i> (Bottle sedge, Broadmead only)	
<i>Juncus bulbosus</i> (Bulbous rush, Homer Common)	

This list was applied to the species recorded in the 2013 monitoring surveys and their comparable baselines to provide broad scale indication of directional change in terms of site wetness. To reconcile the different data formats between years, species occurrence has been scored based on presence of the species in all sub-quadrats within each transect, so for a 30 quadrat transect, occurrence is scored out of a potential maximum of 120.

Whilst the application of a bespoke indicator list may lack the rigour of the NVC community and Ellenberg indicator methods, it does have some advantages. Firstly, it keeps a graphical record of species occurrence across multiple years, which can be used as an adjunct to the NVC classifications to better understand changes. It also allows tracking of individual species fluctuations more easily, something which is inevitably lost in the ‘noise’ of the NVC community classification. Finally, evolving a list based on field observations allows a highly tailored approach to vegetation monitoring within the project area, which takes into account any variation from national norms which might be particular to the Exmoor area.

Results and Discussion

NVC community analysis - Site level

Classification of the 2013 re-survey data and re-classification of comparable baseline surveys generated results that indicate movement at the whole site level from drier to wetter communities at five of the seven sites resurveyed in 2013. Results of the classification process are given in Table 3, followed by a brief description of each community. Note that where two different communities are given for a single year (e.g. M15d/M17c) this is because the TABLEFIT and MAVIS analyses returned goodness of fit values within one point of each other for both of the communities listed.

Table 3: NVC communities for all sites re-surveyed in 2013, N.B. Community names only are listed and Rodwell (1991), should be referred to for their descriptions

Site Name	Monitoring Year				
	2006	2007	2008	2010	2013
Alderman's Barrow			M25 Restored		M25a
Broadmead	M25a	Restored		M6a	M6a
Comerslade		M15b		Restored	M15b/M17
Homer Common				M15d Restored	M15d/m17c
Roosthitchen Phase 1	M25	Restored		M6d	M6b
Roosthitchen Phase 2			M15 Restored	M15	M15d
Verney's Allotment		M15d	Restored	M15d	M15d/M17c

M25 *Molinia caerulea* – *Potentilla erecta* mire

M25a *Erica tetralix* sub-community

M17 *Scirpus cespitosus* – *Eriophorum vaginatum* blanket mire.

M17c *Juncus squarrosus* – *Rhynchospora alba* sub-community

M15 *Scirpus cespitosus* – *Erica tetralix* wet heath

M15b *Scirpus cespitosus* – *Erica tetralix* wet heath Typical sub-community

M15a *Carex panicea* sub-community

M15d *Vaccinium myrtillus* sub-community

M6 *Carex echinata* – *Sphagnum recurvum/auriculatum* mire

M6a *Carex echinata* sub-community

M6b *Carex nigra* – *Nardus stricta* sub-community

M6d *Juncus acutiflorus* sub-community

It is immediately apparent from Table 3 that Broadmead, Comerslade, Homer Common, Roosthitchen Phase 1 and Verney's Allotment all appear to have undergone changes in vegetation composition at a site level which indicate rewetting of the underlying peat. Some of these changes are particularly pronounced, Broadmead for example moved from a degraded M25a community to a mesotrophic poor-fen community in just three years following restoration in 2007. This site has undergone repeated cycles of work to facilitate restoration, and the botanical changes reflect the impact of these efforts on the underlying hydrology of the site. Roosthitchen Phase 1 has also undergone a large change in the dominant vegetation type having moved from degraded M25 vegetation to a M6b community in the six years since restoration.

However, there have also been sites at which vegetation change is less obvious. Verney's Allotment and Homer Common for instance have only changed slightly from M15d communities to M15d/M17c intermediate communities since restoration, although this does suggest some level of rewetting. The reasons for this cannot be determined from this analysis alone, the key may lie in the complexities of the site hydrology. However, it should be noted the baseline survey of these two sites recorded a less degraded community than was found at some other sites, M15d rather than the M25 which is often associated with the drained areas of the moor. In this sense, these sites are unlikely to have such marked vegetation changes as might be seen when restoring areas more severely degraded.

Two sites, Roosthitchen Phase 2 and Alderman's Barrow, showed little appreciable change in dominant vegetation. However, reasons for this may lie in failures of restoration structures at these sites, rather than indicating a problem with the restoration methods in general. At Alderman's Barrow for instance it was noted during the 2013 survey that a large portion of the ditch block had come away, and the site continued to be drained as a result. Roosthitchen Phase 2 has had similar problems, with part of the ditch block failing. Post-repair surveys should demonstrate whether further rewetting of the peat and corresponding vegetation change can be achieved. If so, the sites would demonstrate the importance of the integrity of the restoration structures.

NVC community analysis - quadrat level

Due to the differing ways in which past survey data has been collected, it is not possible to allocate NVC communities at quadrat level to sites initially surveyed prior to 2010. This process has been conducted for all of the 2013 surveys however, and the results demonstrate variation across quadrats on a fine scale when compared with the classification at site level. Tables 4 and 5 present quadrat level NVC communities for both Broadmead and Comerslade.

These tables show that the distribution of NVC communities varies widely across the sites, despite the site level classification. At Broadmead for example, which was classified as M6a at site level, one side of the transect appears significantly drier than the other, based on the prevalence of M25a communities on that side. This demonstrates how the hydrology and resulting vegetative communities vary over short distances.

Looking at the results for Comerslade, which was classified as M15b/M17 at site level, variation across the site is also apparent. For example, surrounding the restoration feature, M6 and M6a communities are found, logical since this is the wettest part of the site. Elsewhere, away from the ditch, the site is characterised by M15b/M17 communities in tune with the site level classification.

Ellenberg's indicator value analysis – Landscape scale

The seven sites re-surveyed in 2013 comprised a total of 224 individual quadrats. The quadrat mean Ellenberg values for all 224 quadrats were first compared to their pre-restoration equivalents. Grouping the sites in this way has both advantages and disadvantages. The large sample size increases the power of any comparison, since anomalous results which might occur as a result of misidentification should have less effect on the mean, and a larger sample will always generate a sample mean more representative of the population mean. Conversely however whilst it can more confidently be said that restoration works are having an effect on sites if statistical tests reject the null hypothesis of no difference between years, we cannot identify, using this method, at which sites change may be less obvious or even non-existent. A paired-samples t-test was therefore conducted to compare quadrat mean Ellenberg F, R and N values at all restored sites to equivalent values at the same sites prior to restoration.

The results of the landscape scale analysis of Ellenberg values before and after restoration are:

- There was a highly significant increase in mean F values after restoration (baseline mean F = 6.88 SE \pm 0.04, restored mean F = 7.07 SE \pm 0.04; paired t-test: $t(223)=-4.96$, $p<0.001$);
- a significant decrease in mean R values after restoration (baseline mean R = 3.02 SE \pm 0.03, restored mean R = 2.96 SE \pm 0.03; paired t-test: $t(223)=2.50$, $p= <0.01$);
- and a highly significant decrease in N values after restoration (baseline mean N = 2.33 SE \pm 0.03, restored mean N = 2.24 SE \pm 0.03; paired t-test: $t(223)=3.89$, $p= <0.001$).

The implication of these statistics is that restoration work has made the sites wetter, more acidic, and has lowered nutrient levels. These changes further suggest that restoration is having the desired effect of rewetting the peat, as the changes in pH and nutrient level can both logically be associated with increased wetness and decreased lateral flow of water across site.

However, whilst this is very encouraging, several factors must be taken into consideration when interpreting these results. Firstly, it must be noted that these significant results only relate to Ellenberg values, and not real world hydrological change. These results are not direct evidence of re-wetting, but rather a botanical proxy measure. Whilst this may seem an obvious point, it is important to understand we are not measuring real world botanical parameters when using Ellenberg values, but rather imposing a set of values developed to monitor environmental change.

Additionally the lack of comparable controls at each site make it difficult to say with confidence that the observed changes in Ellenberg values can be attributed to the restoration work alone. Ideally, each site would have an additional control transect straddling an adjacent ditch which had not been restored. Comparison of the results between the two transects could then be used to support any conclusions that changes in Ellenberg values were due to restoration rather than local hydrological changes for example. Future survey and analysis should seek to include control transects to support these results.

Finally, controls which take account of regional scale variation and the inclusion of climate data from the project area covering the period of monitoring, could ascertain the impact of any link between changing Ellenberg values and broader climatic patterns. This could further support the conclusions relating to the success of restoration.

Ellenberg's indicator value analysis – Site level

The comparison of quadrat mean Ellenberg values at site level has the inverse advantages and disadvantages of the landscape scale comparison. Namely statistical power decreases due to the smaller effective sample size, but assessment of the impact of restoration per site is possible. Paired t-tests were conducted again, this time to compare quadrat mean Ellenberg F, R and N values for each restored site to equivalent values at the same site prior to restoration. Results are summarised in Table 6.

Table 6: Comparison of Ellenberg F, R and N values at each site before and after restoration work

Site	Ellenberg wetness (F)	Ellenberg pH (R)	Ellenberg nitrogen (N)
Alderman's Barrow	No change	Significant decrease in acidity (Baseline R=3.23 SE \pm 0.09, restored R=3.37 SE \pm 0.08; paired t: $t(39)=-2.83$, $p<0.01$)	No change
Broadmead	Significant increase in wetness (Baseline F=6.82 SE \pm 0.16, restored F=7.68 SE \pm 0.08; paired t: $t(29)=-5.84$, $p<0.001$)	No change	No change
Comerslade	No change	Significant increase in acidity (Baseline R=2.85 SE \pm 0.03, restored R=2.63 SE \pm 0.04; paired t: $t(39)=4.96$, $p<0.001$)	No change
Homer Common	Significant increase in wetness (Baseline F=6.86 SE \pm 0.07, restored F=7.14 SE \pm 0.12; paired t: $t(29)=-2.25$, $p=0.02$)	Significant increase in acidity (Baseline R=2.88 SE \pm 0.05, restored R=2.52 SE \pm 0.05; paired t: $t(29)=4.98$, $p<0.001$)	Significant decrease in fertility (Baseline N=2.40 SE \pm 0.05, restored N=2.02 SE \pm 0.03; paired t: $t(29)=7.86$, $p<0.001$)
Roosthitchen Phase 1	Significant increase in wetness (Baseline F=6.88 SE \pm 0.05, restored F=7.20 SE \pm 0.06; paired t: $t(28)=-5.54$, $p<0.001$)	No change	Significant decrease in fertility (Baseline N=2.62 SE \pm 0.07, restored N=2.38 SE \pm 0.06; paired t: $t(28)=3.55$, $p<0.001$)
Roosthitchen Phase 2	No change	Significant decrease in acidity (Baseline R=2.91 SE \pm 0.05, restored R=3.06 SE \pm 0.04; paired t: $t(14)=-2.56$, $p=0.01$)	No change
Verney's Allotment	Significant decrease in wetness (Baseline F=6.92 SE \pm 0.06, restored F=6.87 SE \pm 0.06; paired t: $t(39)=1.81$, $p=0.03$)	No change	No change

Referring to Table 6, results for the site level comparison of quadrat mean Ellenberg values are generally favourable, and to some extent correspond with the site level NVC classifications. Alderman's Barrow, a site which has not changed in terms of NVC classification since restoration work, unsurprisingly showed no favourable change in any of the compared Ellenberg values. Indeed, the quadrat mean Ellenberg acidity values have actually

moved significantly toward the alkaline end of the spectrum, indicating a possible further decline in acid mire condition. As previously mentioned, the lack of botanical community change at the site is probably due to the failure of the restoration structures on site. This effectively makes Alderman's Barrow an unintentional control site in our analysis. Roosthitchen Phase 2 showed similar results, which are probably also attributable to the structural failure of the restoration structures on site.

Broadmead showed a significant ($p < 0.001$) increase in mean Ellenberg wetness values post-restoration, as might be expected given the site level NVC community changes previously outlined (Table 3). The magnitude of change in Ellenberg wetness values at this site was also larger than at any other site. Interestingly, there was no significant change in quadrat mean Ellenberg pH or nitrogen values, which might be expected to accompany peat rewetting. However, Broadmead is a distinctly mesotrophic site, a fact reflected in the abundance of species such as *Carex rostrata* and *Viola palustris*. In tune with this fen-like character, a drop in pH would seem less likely as part of restoration at this stage, and nutrient levels are probably sustained by a spring, and a high level of lateral flow across the site which remains despite restoration structures.

Roosthitchen Phase 1 was the other site which showed dramatic changes in site NVC communities (Table 3), and this is supported by the results of the Ellenberg value analysis (Table 6). Significant increases in the mean wetness indicator values and decreases in mean nitrogen indicator values both add weight to the conclusion that restoration at this site is progressing successfully. No significant change in Ellenberg pH indicator values was recorded, with an apparent change indicative of increasing acidity falling just short of significance ($p = 0.09$). At Comerslade, comparison of quadrat mean Ellenberg values revealed significant change in indicators of acidity only, although this could be regarded as a potential indicator of restoration success. The NVC classification for the site was also rather inconclusive, showing possible change to an intermediate community only.

At Homer Common, however, another site with a relatively subtle change in site NVC communities, significant change suggestive of restoration success was identified in all three types of Ellenberg value analysis. This is unexpected, and may suggest that site level NVC assessment is lacking as a tool for measuring community change. Further examination of the site botany using the project indicator species lists may provide a better assessment of the situation at the site.

Finally, Ellenberg value analysis at Verney's Allotment show a significant decrease in quadrat mean wetness values, and no change in either quadrat mean pH or nitrogen values (Table 6). NVC classification for this site was also somewhat inconclusive (Table 3), and again reference to changes in indicator species abundance may help to elucidate botanical changes at this site, and determine whether restoration has been successful or unsuccessful so far.

Indicator species analysis

Examination of the occurrence of indicator species as detailed in Table 2 help to explain the botanical situation underling both the NVC and Ellenberg value analysis results. Detailed results from two contrasting sites are presented below, in Figures 1 to 4 as an example of this analysis. The units on the y-axis represent the number of sub-quadrats in which the species concerned was recorded.

Figure 1: Positive indicator occurrence at Alderman's Barrow over three surveys; 2008 (pre-restoration), 2010 and 2013.

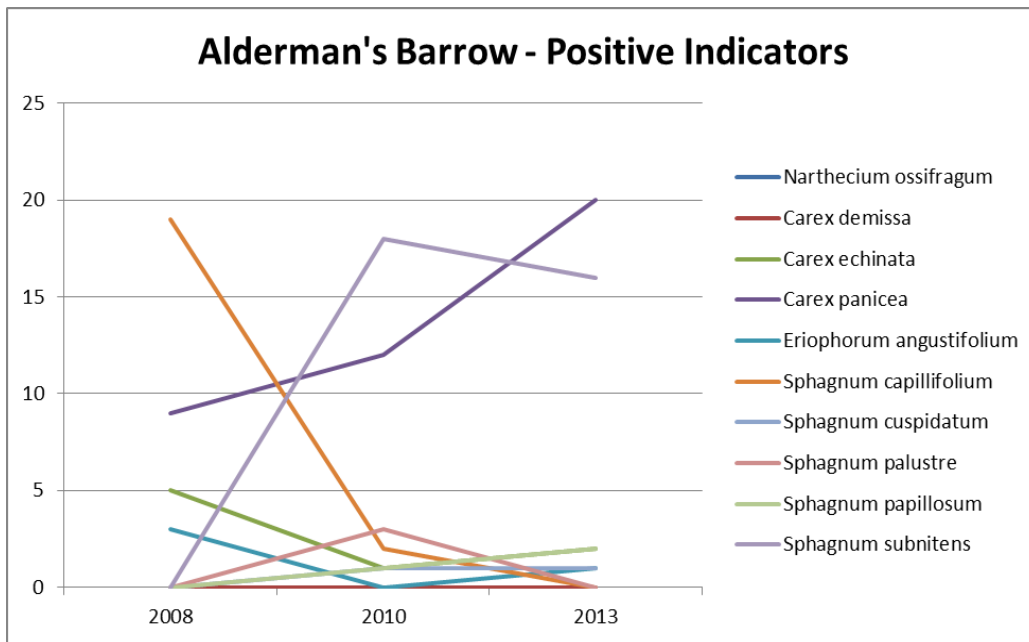
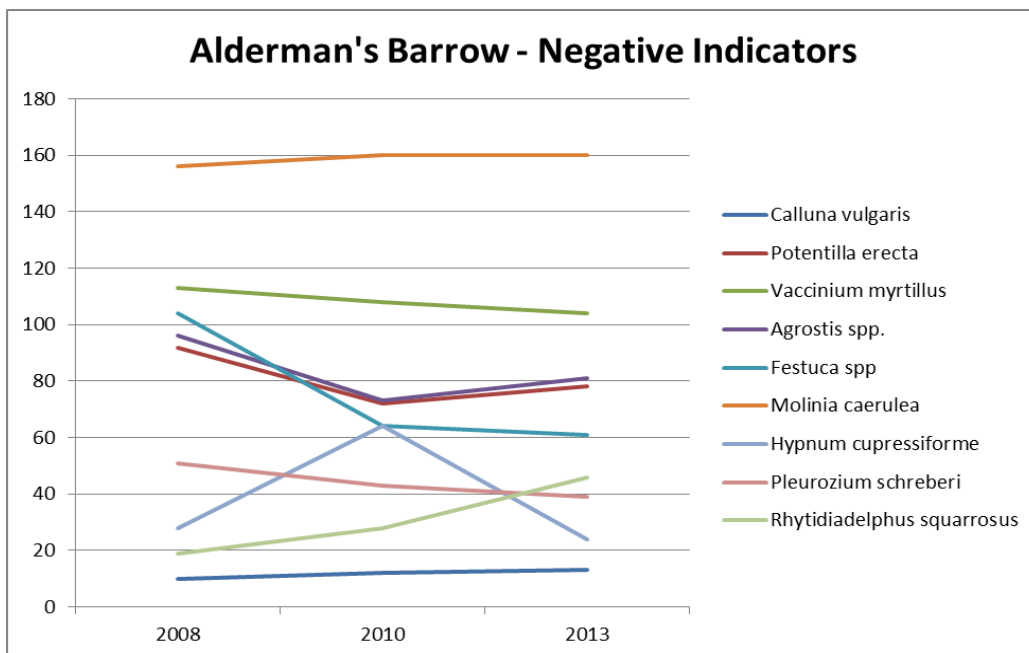


Figure 2: Negative indicator occurrence at Aldermans Barrow over three surveys; 2008 (pre-restoration), 2010 and 2013.



Indicator species occurrence results for Alderman's Barrow largely reflect the lack of change identified in the site NVC and the quadrat mean Ellenberg value analysis. The decrease in positive indicators, particularly *Sphagnum capillifolium*, suggests the site is continuing to dry due to failure of the restoration structure.

Figure 3: Positive indicator occurrence at Broadmead over four surveys; 2006 (pre-restoration), 2008, 2010 and 2013.

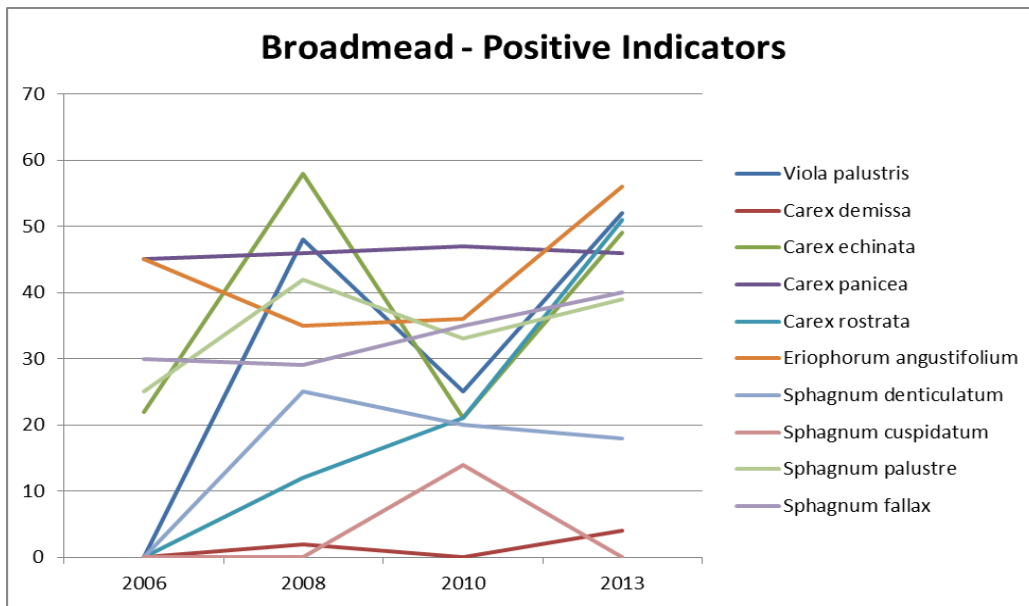
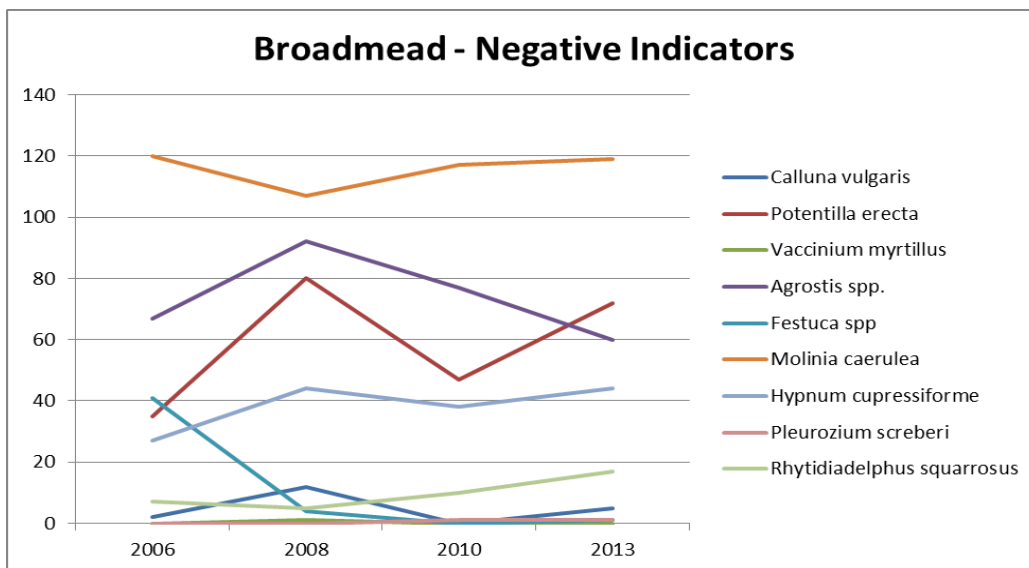


Figure 4: Negative indicator occurrence at Broadmead over four surveys; 2006 (pre-restoration), 2008, 2010 and 2013.



The indicator species occurrence changes at Broadmead differ from Alderman’s Barrow but equally supports the NVC and Ellenberg value analysis results. A progressive increase in most of the positive indicator species can be observed, with several species increasing in occurrence markedly since 2010. Negative species however remain broadly constant, although *Agrostis* spp. appears to be in decline since restoration.

The indicator species occurrence at the remainder of the sites is in line with the findings outlined in the two examples above and helps to explain the variation in results of the Ellenberg value analysis for the sites, which is only partially reflected in the NVC assessments. However, despite overall trends the fluctuation of species between years can still be very marked.

Conclusions and recommendations

The results presented permit a number of conclusions relating both to the success of the project restoration work to date and the effectiveness of analytical methods employed.

1. At five of the seven restoration sites resurveyed in 2013 there has been measureable change in the dominant NVC community at site level, suggesting a re-wetting of the underlying peat. Some of the community changes were however particularly subtle, with several sites appearing to move toward intermediate communities rather than entirely distinct wetter NVC types.
2. Analysis of pooled quadrat mean Ellenberg values across all sites showed significant changes in the values associated with wetness, pH and nitrogen levels after restoration. Ellenberg values for restored quadrats suggested that the restored sites were significantly wetter, more acidic and less nutrient-rich than before restoration.
3. Analysis of quadrat mean Ellenberg values at site level proved particularly valuable, and provided additional detail not shown in the site NVC assessments. Of the seven sites resurveyed in 2013, four demonstrated significant changes in Ellenberg values associated with rewetting, namely Broadmead, Comerslade, Homer Common and Roosthitchen Phase 1. Three sites returned results suggesting negative change and site drying, namely Roosthitchen Phase 2, Alderman's Barrow and Verney's Allotment. The two latter sites were not expected to show positive change because of the failure of the restoration features. The Ellenberg analysis which indicated drying at Verney's Allotment was however unexpected and contradicted the broader site level NVC analyses which indicated a change to a wetter community.
4. Application of the project indicator species lists to the data supported the Ellenberg value analysis fairly accurately, and visualised the changes in species occurrence which are central to the significant changes in quadrat mean Ellenberg values. This was particularly useful tool for detecting fine scale changes between monitoring years and its continuation is recommended.
5. It is therefore judged that whilst site level NVC approaches may in many cases give appropriate indication of change, finer scale examination of results is necessary to discern changes which may be missed. The Ellenberg value analysis employed here provides a more complete picture and would be worth taking forward in future analyses. The quadrat level NVC approach which was applied to the data from 2013 also highlighted the complexity of botanical communities across transects, and should be applied to botanical data in forthcoming surveys.
6. Taking into account the results outlined above, it is possible to make some central conclusions about the effectiveness of the restoration methods used by the Exmoor Mires Project:
 - a. At a landscape scale, restoration via ditch blocking results in an increase in species associated with re-wetting of underlying peat, increased acidity, and a decrease in nutrient levels;
 - b. At a site level this holds true for four of the seven re-survey sites from 2013, Broadmead, Comerslade, Homer Common and Roosthitchen Phase 1 ;
 - c. Failure of restoration structures has had an appreciably negative effect on the recovery of botanical communities at two sites, Roosthitchen Phase 2 and Alderman's Barrow;

Ongoing work

A further 10 post-restoration sites have been selected for re-surveying in the 2014 survey season, including control sites and the two sites (Blackpitts and Exe Head) first surveyed in 1998. This data will add considerable depth to the existing vegetation data base in term of temporal and spatial distribution. The initial analyses developed here will be further advanced with this data to develop more robust conclusions regarding the amount, distribution and rate of post restoration vegetation change on the Exmoor Mires.

Application of the results

The vegetation monitoring outlined in this paper forms part of the comprehensive EMP restoration monitoring programme. Understanding post-restoration changes in a wide range of ecosystem services including hydrology, greenhouse gas fluxes and biodiversity is a key project outcome. The monitoring of botanical assemblages is examined here in detail in order to understand if this can be used to indicate underlying changes in the peatland hydrology and greenhouse gas fluxes.

This information will be used to develop a rapid assessment (proxy) method for monitoring successful hydrological change across the moorland landscape based on vegetation change monitoring. The development of this system (based on the GEST methods of Couwenberg et al, 2011) is part of the ongoing work to verify the greenhouse gas emissions savings arising from the restoration work under the newly emerging Peatland Code (IUCN, 2013). Verification will enable the project to develop carbon off- setting and ecosystem service payments (PES) for the delivery of clean and sustained fresh water supplies. This is part of the EMP strategy of providing sustainable incomes in the uplands from multiple ecosystems services.

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