MoorLIFE: Active Blanket Bog Restoration in the South Pennines Moors

Monitoring Programme – Mid-Term Report

November 2013

Executive Summary

MoorLIFE is a five-year project with a primary aim to protect the remaining active peat forming vegetation. It has three main objectives:

1. Stabilise inactive bare peat (through establishment of nurse crop on bare peat)
2. Restore moorland vegetation on these, and previously stabilized sites, and onto active blanket bog communities (through plug planting and application of *Sphagnum* propagules); and
3. Reduce peat and water flow and restore hydrological integrity (through gully blocking.)

Works are being undertaken to protect active blanket bog across four sites: Bleaklow, Black Hill, Rishworth Common and Turley Holes (Figure 1).

The MoorLIFE project has an extensive, landscape scale, scientific monitoring programme. It has been designed to monitor and assess the impact that the conservation works have had on vegetation succession, water table and erosion, and to quantify how successful they have been. In addition, a carbon audit of the works are being undertaken to determine the greenhouse gas emissions of project of this sort.

There are three main actions which contribute to the monitoring programme:

E2: Vegetation succession
E3: Water table, erosion and water quality monitoring
E5: Carbon audit of the works

E2 – Monitoring the success of vegetation establishment and succession

Vegetation is monitored through annual surveys of 288 fixed quadrats. These have been established on a range of peat status types including treatment areas of bare peat and 'late-stage' revegetated sites, and reference sites of bare peat and intact blanket bog.

In addition to the quadrats, transect surveys have been undertaken on some sites to provide information for application and to create a baseline dataset of *Sphagnum* abundance and distribution.

Sphagnum beads are monitored through fixed quadrats to enable future assessment of the success of this treatment.

E3 – Monitoring changes to the water table and carbon budget of restored blanket bog

Water table

The MoorLIFE project represents the first water table monitoring on MFF sites that has been undertaken prior to, and during conservation works. It will enable a comparison of pre- and post-works water table condition. In the first three years of the MoorLIFE project the following actions have been undertaken:

- Installed 26 automated dipwells, which take water table measurements at hourly intervals,

- 390 manual dipwells installed and water tables measured in autumnal monitoring campaigns.

Water tables are being monitored across four sites and four treatment scenarios (6 treatment sites, 2 peat pan sites, 4 late-stage restoration sites, 4 bare peat reference sites and 3 intact sites).

Data analysed from Bleaklow and Rishworth Common are showing patterns of extremely variable water table in gullied areas. Mean water tables in these areas are as low as 484 mm, with maximum depths of over 800 mm recorded on both sites. Peat pans and intact areas have much higher water tables with means all within the top 120 mm of peat. Peat pans have median water tables above the surface of the peat.

Late-stage restoration sites show characteristics of having mean water tables between those of untreated areas and intact areas, and a lower degree of spatial and temporal variability than degraded areas.

Carbon content of water

To date, 318 water samples have been collected from 6 treatment areas, 4 late-stage restored areas, 4 bare peat areas and 3 intact areas.

Data analysed from Bleaklow and Rishworth Common show patterns of high water colour and carbon content across all sites, but with indications that the water colour of intact sites is lower than that of degraded sites.

MoorLIFE gains considerable added value through further monitoring on works areas through the Woodhead Gully Block Monitoring Project which is monitoring the episodic loss of POC through storm sampling, water tables adjacent to gully blocks.

E5 – Carbon audit of the project

The monitoring programme includes a carbon audit of the MoorLIFE project. In the last three years, the scope of the audit has been defined and will include data on all activities undertaken under the C1, C2 and C3 action codes.

In addition, the Defra GHG Conversion Factors tool has been identified as the most suitable tool for the carbon audit. Data on works actions have been collated and carbon emissions calculated through use of Defra’s conversion factors.

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1 Introduction to the MoorLIFE monitoring programme

The South Pennines Moors and Peak are designated as a Special Area of Conservation for its blanket bog. Blanket bog is a rare and internationally important habitat. It tends to occur in cool, wet climates, under conditions that inhibit decomposition of plant matter which then accumulates peat. In addition to this, it is important for both its wildlife and the ecosystem services it provides, such as carbon storage, drinking water provision, and water regulation.

The importance of the South Pennines Moors as an area for wildlife is reflected in its designation as a Special Protected Area for the populations of golden plover, merlin and short-eared owls that breed here.

The blanket bog of England's South Pennines is one of the most degraded peatland habitat in the world. Two hundred years of atmospheric pollution from surrounding industrial towns and cities, combined with wildfires and overgrazing have left a lunar landscape of bare and eroding peat, and extensive gullying. This damage has had impacts on the biodiversity, hydrological functioning and carbon storage of the South Pennines.

MoorLIFE is a five-year project with a primary aim to protect the remaining active peat forming vegetation. It has three main objectives:

1. Stablise inactive bare peat (through establishment of nurse crop on bare peat)
2. Restore moorland vegetation on these, and previously stabilized sites, and onto active blanket bog communities (through plug planting and application of *Sphagnum* propagules); and
3. Reduce peat and water flow and restore hydrological integrity (through gully blocking.)

Works are being undertaken to protect active blanket bog across four sites: Bleaklow, Black Hill, Rishworth Common and Turley Holes (Figure 1).

1.1 MoorLIFE monitoring programme

The MoorLIFE project has an extensive, landscape scale, scientific monitoring programme. It has been designed to monitor and assess the impact that the conservation works have had on vegetation succession, water table and erosion, and to quantify how successful they have been. In addition, a carbon audit of the works are being undertaken to determine the greenhouse gas emissions of project of this sort.

There are three main actions which contribute to the monitoring programme:

E2: Vegetation succession
E3: Water table monitoring and erosion
E5: Carbon audit of the works

This monitoring programme is not designed to give operational feedback to conservation works managers in real time. It is designed to be as statistically robust as possible, and falls between the two categories described by Brown (2001) of ‘environmental effects monitoring’ and ‘manipulative field experiments’. There are several replicates of treatment sites and reference sites which are being monitored simultaneously. The use of reference sites (as distinct from control sites which implies strict control of conditions) allows a more thorough assessment of the causes of environmental changes being monitored. Water table monitoring and vegetation monitoring began as early as possible and much of it began before any treatments were applied. The combination of these elements means that the MoorLIFE monitoring programme will be better positioned to make stronger associations between the capital works and changes in vegetation and water table.

Five scenarios are represented in the monitoring locations across the four sites:

1. Bare peat sites left untreated as a reference site.
2. Treatment sites – treated with brash, lime, seed and fertiliser
3. Late-stage restoration sites – sites that were treated between 2003 and 2006.
4. ‘Intact’ sites – i.e. those sites that have not been eroded and on which vegetation has not been lost. These areas of vegetation may still be of poor diversity.
5. Peat pans – on the flat areas of blanket bog…

This mid-term report details the work undertaken in establishing the monitoring programme, the methods used, and presents some of the data collected over the first three years of the project for two sites, Bleaklow and Rishworth Common. For more detailed information on the methods used for each restoration action, see the Technical Report (Moors for the Future, 2013).

A considerable amount of data has been collected and forms the baseline to which post-works data can be compared. Works are still ongoing, and so more comprehensive ‘Before-After-Control-Intervention’ analyses will be presented in the final report in March 2015.

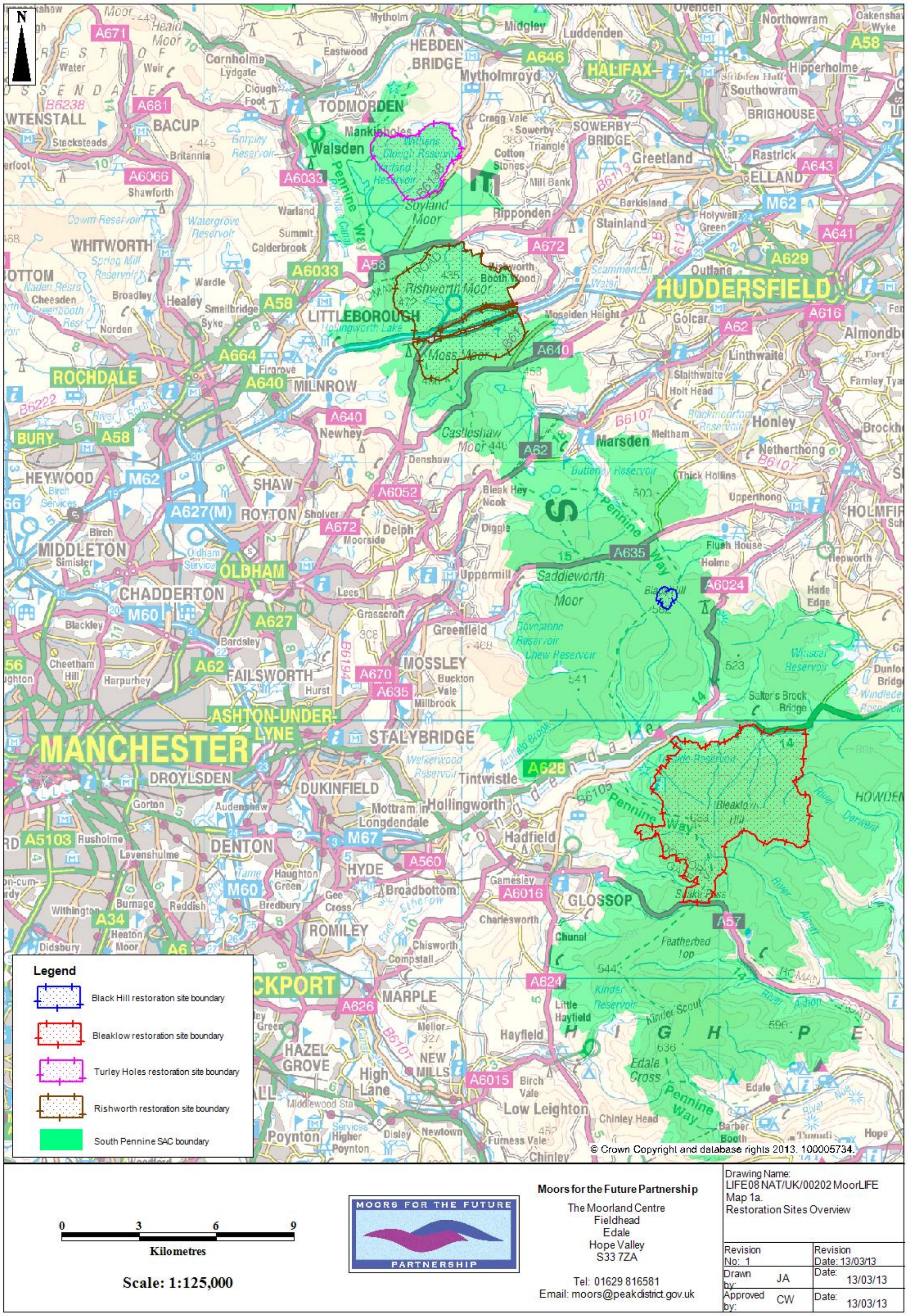


Figure 1 Overview of MoorLIFE works areas within the South Pennines Special Area of Conservation

1.2 MoorLIFE sites

Bleaklow

Bleaklow is the second highest hill in the Peak District National Park with a summit of 630m. Extensive areas of bare peat have been revegetated through conservation works. As such some areas of Bleaklow are considered here as being in a state of ‘late-stage’ revegetation, having had initial works undertaken between nine and ten years ago. Table 1 summarises the historic and current conservation works that have been undertaken across each site. However bare and eroding peat remains over a wide area of the plateau (Figure 2). Peat stabilisation works (geotextiles, heather brash, lime, seed and fertiliser), diversification (plug planting and *Sphagnum* applications) and gully blocking are being undertaken across the plateau by the MoorLIFE project. In addition, late-stage revegetated sites are also to be treated with *Sphagnum* applications to enhance the development of typical blanket bog vegetation community.

Figure 2 Part of the Bleaklow plateau, showing large areas of bare and eroding peat. The area of pale green to the top right of the image shows Alport Moor, which has already undergone peat stabilisation treatments. The MoorLIFE project is enabling the Moors for the Future Partnership to stabilise the last expansive areas of bare peat on the plateau.

Vegetation and hydrogical monitoring is being undertaken across Bleaklow, with four restoration scenarios represented: intact reference, untreated bare peat reference, treated bare peat areas, and late-stage revegetated. All reference sites are outside the works areas. The monitoring undertaken on Bleaklow during the first three years of the MoorLIFE project is summarised in Figure 3.

Site name	Year of initial restoration activity	Restoration status in 2010	Treatments monitored under MoorLIFE	Monitoring actions under MoorLIFE
Bleaklow – Peaknaze				
Joseph Patch Shining Clough Sykes Moor Shelf Moss	2003 2003 2004 2004	Late-stage revegetated	Sphagnum	Vegetation (quadrats, Sphagnum surveys) Hydrology
Bleaklow – National Trust	2006	Late-stage revegetated	Sphagnum	Sphagnum surveys
Black Hill	2006	Late-stage revegetated	Sphagnum	Vegetation (quadrats, Sphagnum surveys) Hydrology
Bleaklow – Woodhead	2010	Untreated	Brash Lime, seed, fertilizer Sphagnum	Vegetation (quadrats, Sphagnum surveys) Hydrology
Rishworth Common	2010	Unrestored	Brash Lime, seed, fertilizer Sphagnum	Vegetation (quadrats, Sphagnum surveys) Hydrology
Turley Holes	2010	Unrestored	Brash Lime, seed, fertilizer Sphagnum	Vegetation (quadrats, Sphagnum surveys) Hydrology

Table 1 Summary of sites in MoorLIFE, the capital works being undertaken, and the monitoring taking place. Bleaklow is divided into subsites to represent its history of restoration works.

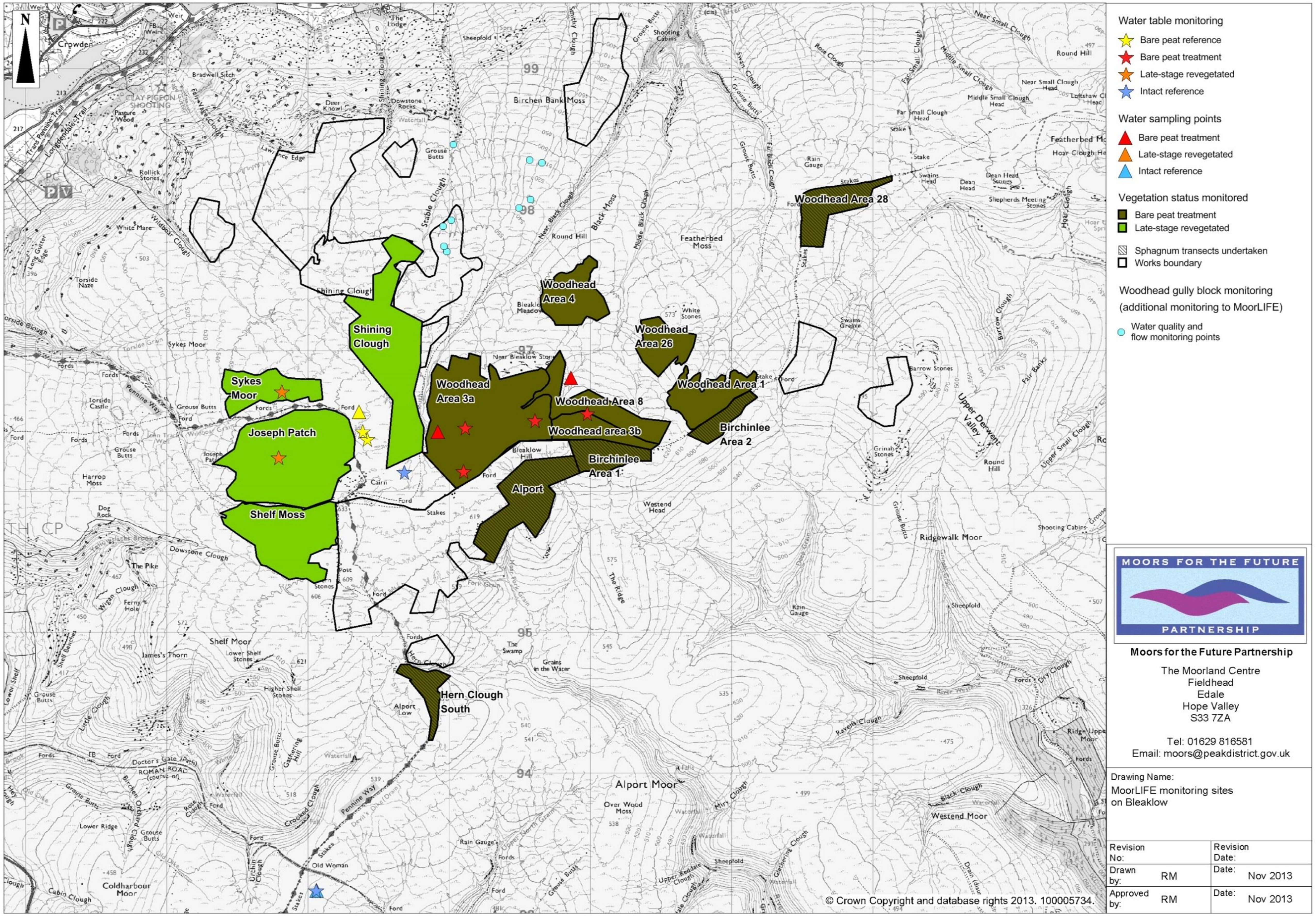


Figure 3 MoorLIFE monitoring sites on Bleaklow

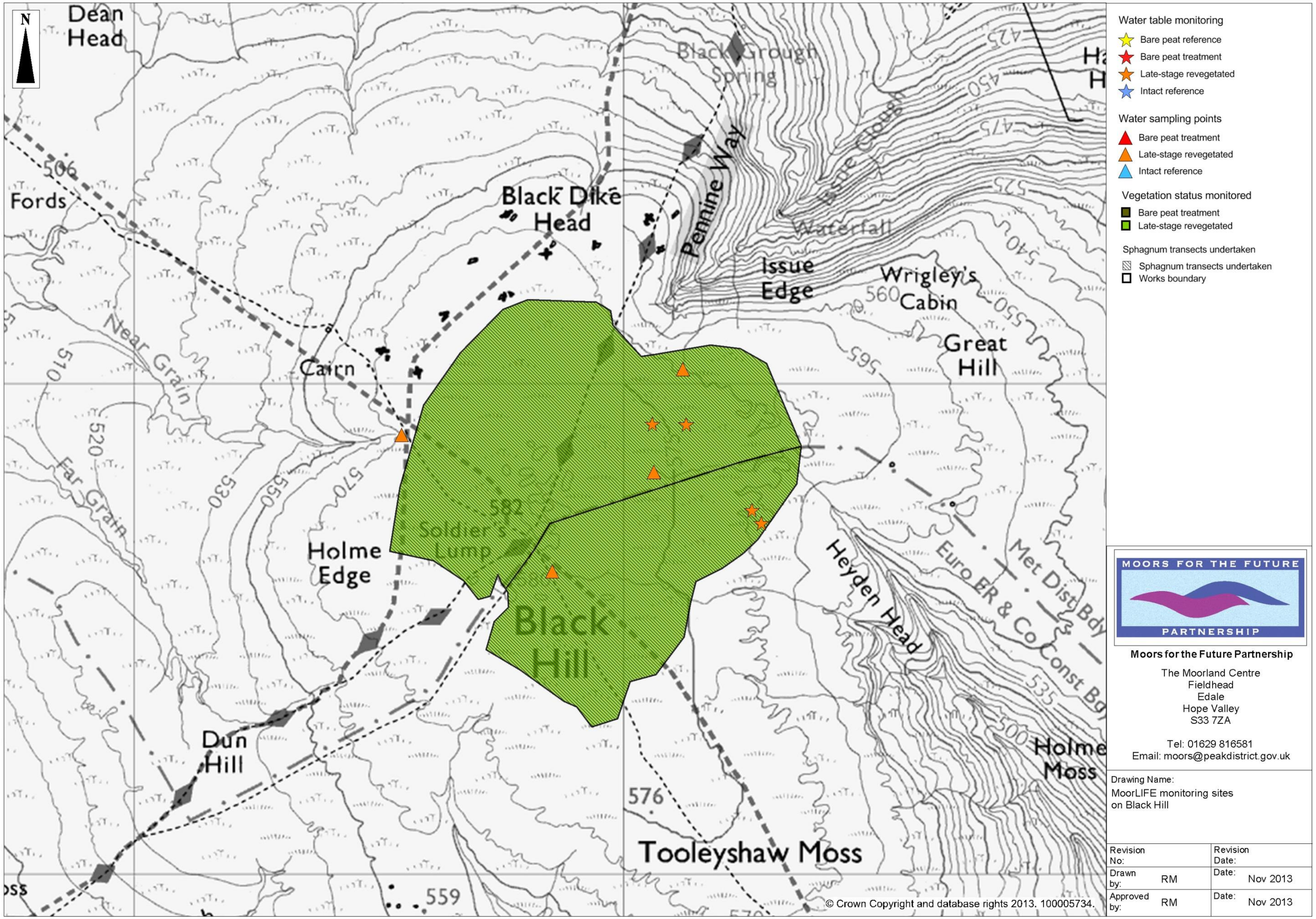


Figure 4 MoorLIFE monitoring sites on Black Hill

Black Hill

To the north of Bleaklow, Black Hill (Figure 5) is also considered here as a late-stage revegetated site, having undergone initial stabilisation treatments in 2006. The MoorLIFE project will treat Black Hill with *Sphagnum* propagules. The vegetation and hydrological monitoring on Black Hill represents late-stage revegetation only and has no reference sites.

Figure 5 Aerial view of Black Hill

The monitoring undertaken on Black Hill during the first three years of the MoorLIFE project is summarised in Figure 4.

Rishworth Common

Rishworth Common, to the north of the Peak District National Park, is receiving full bare peat stabilisation and diversification. Vegetation, water table and water quality monitoring has been established across three main areas of bare peat that are being treated with brash, LSF applications, and *Sphagnum* propagules. A small 'reference' area of bare peat within the main treatment area has been left untreated to enable a reference site to be retained. This area is essential to enable a robust assessment of the impact of the peat stabilisation works on vegetation and hydrology. In addition, a large flat area of Rishworth Common consists of 'peat pans' which can be clearly seen in Figure 6. Water table monitoring is undertaken on the north side of the M62 motorway to monitor the hydrology of these peat pan areas. An 'intact' reference site approximately 500 metres from the main works area enables a comparison to an area relatively undamaged by erosion.

The monitoring undertaken on Rishworth Common during the first three years of the MoorLIFE project is summarized in Figure 8.

Figure 6 Aerial view of Rishworth Common looking west, showing the M62 motorway to the north of the site. Rishworth Common has substantial areas of bare and eroding peat on its north-facing slopes. On the flat tops the degradation takes the form of peat pans.

Turley Holes

Turley Holes (Figure 7) is the most northerly of the MoorLIFE sites, situated approximately 30 km north-west of Bleaklow. The site has the similar expansive areas of bare peat on its slopes, with peat pans dominating on the flatter areas. As with Rishworth Common, a small area of bare peat has been left untreated to enable a better evaluation of the impact of the works on the water table and vegetation on treated areas.

The monitoring undertaken on Turley Holes during the first three years of the MoorLIFE project is summarized in Figure 9.

Figure 7 Aerial view of Turley Holes

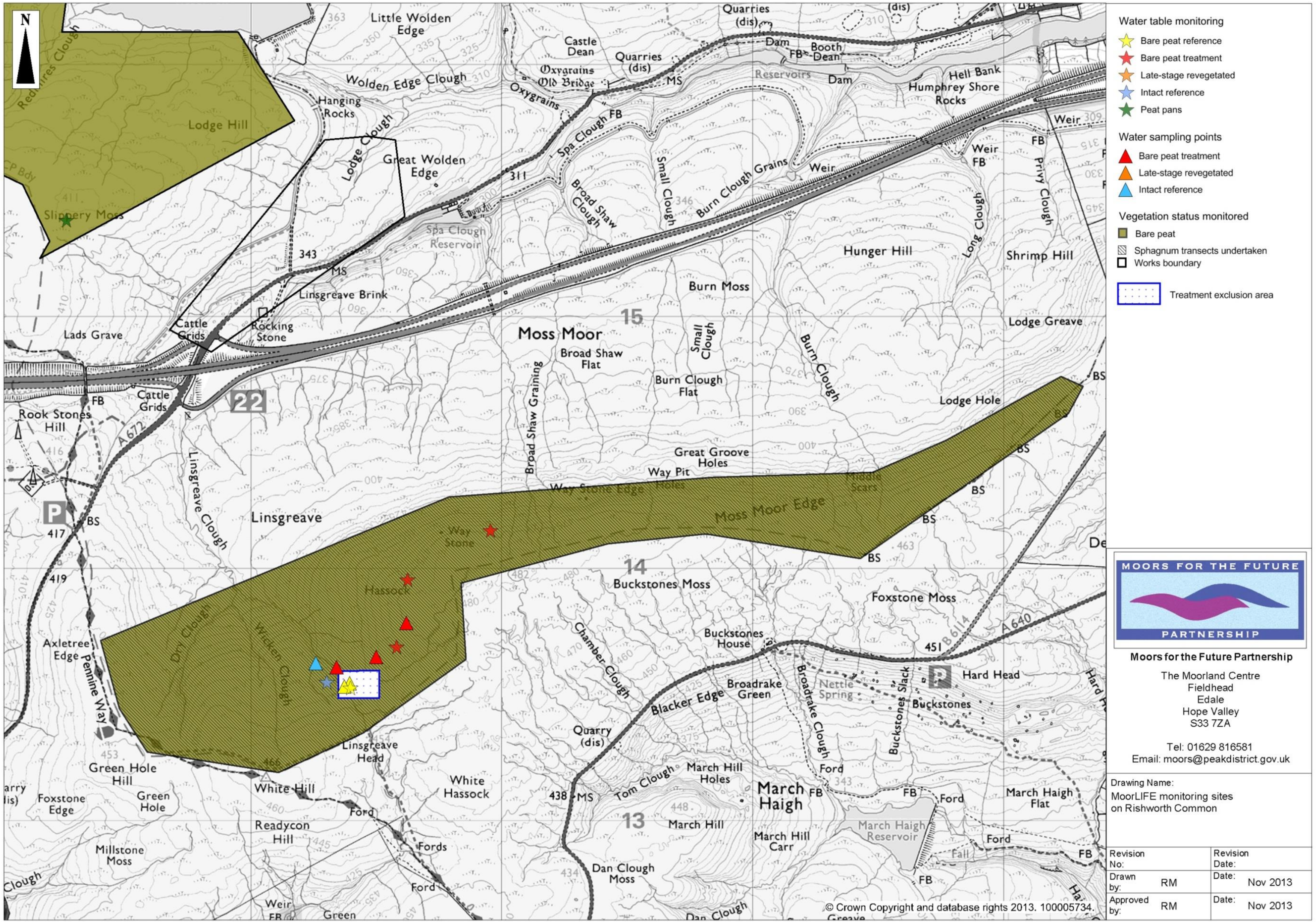


Figure 8 MoorLIFE monitoring sites on Rishworth Common

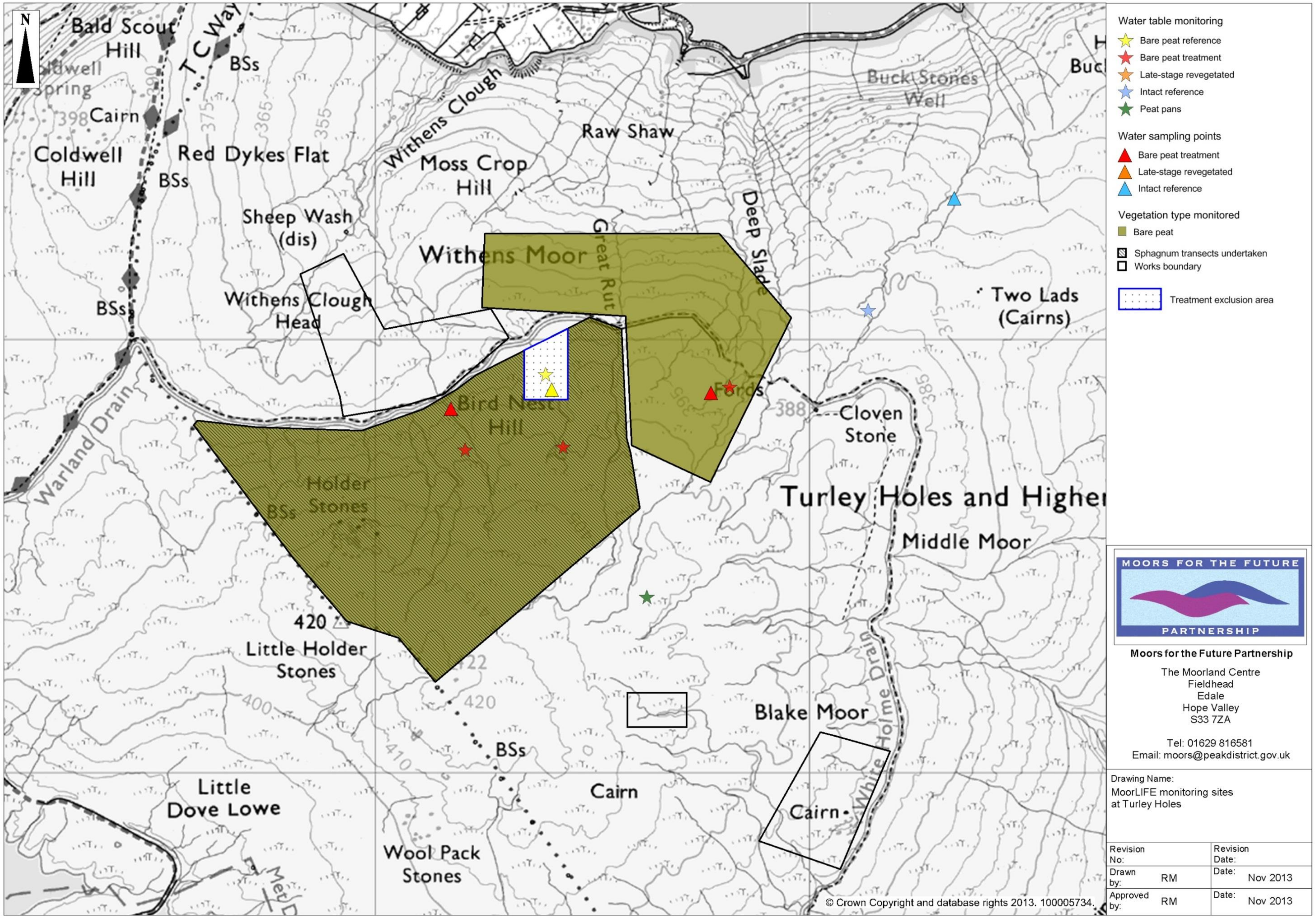


Figure 9 MoorLIFE monitoring sites on Turley Holes

1.3 Learning for monitoring

Scheduling with restoration works

Establishing 'before' monitoring in the first year of the project was a particular challenge as the brashing of several sites, notably Rishworth Common, was brought forward by the Conservation Works team by one year. Despite the large volume of preparation and installation of equipment involved, vegetation quadrats and water table monitoring were installed just as works began.

Volunteer input

The MoorLIFE monitoring programme is also greatly enhanced by considerable volunteer input into the water table monitoring. Effort is made wherever possible to measure water tables on different hills on the same day, or at least no more than one day apart to reduce the effect of differing hydrological conditions. This enables better comparison of water tables on different hills. This is only possible with the help of volunteers who enable data to be collected on such a large, landscape scale within a narrow time period.

Between 2010 and 2013 volunteers have helped collect thousands of manual dipwell measurements. With their help the MoorLIFE project team are able to effectively monitor 390 dipwells simultaneously, under the same hydrological conditions.

Data challenges

This report represents the successful collation and processing of a small selection of the datasets collected in the three years to date of the MoorLIFE project. In processing the datasets, the team have become increasingly aware of the need to update and learn new skills to automate the data processing stage. For example the data loggers collect over 4000 water table readings a week. Repetitive data processing tasks need to be addressed to deal more efficiently with these datasets for the final project report.
The data collected to date provides a good baseline with which success of the conservation works can be assessed. The MoorLIFE team will continue to implement lessons learned from the first three years of monitoring to the remaining two years of the project.

Knowledge exchange

The installation of water table monitoring equipment and collection, processing and analysis of data has been a considerable body of work and has enabled MFF monitoring staff to learn new monitoring techniques that can now be incorporated into a standard monitoring programme. Collaborations with University of Manchester and Manchester Metropolitan University is enabling the transfer of knowledge and expertise gained from academic research into a practical, robust monitoring programme that will inform restoration practices, as well as contribute to our scientific understanding of upland peatland systems.

This monitoring programme has enabled the MoorLIFE team to facilitate further added benefit. We continue to identify areas where we can build on our university collaborations – for example through student projects on MoorLIFE sites. Such collaborations give added value and provide mutual benefit for both early career researchers and land managers.

Recording the area and timing of works

During the last three years of conservations works, it has become apparent that there is a considerable difference in the level of detail required in the recording of works – often in the delivery and areas of works. The conservation works team act as the link between the monitoring team and the contractors delivering works on the ground.

Often in the case of the conservation works team, it is sufficient to record that the work has taken place within the appropriate timescale requested of the contractor. Work is inspected, evaluated for quality and signed off. Since the introduction of water table and water quality monitoring, the importance of narrowing down the treatment of monitored sites has increased. Although this has always been understood by both teams, the mechanisms for ensuring this information is recorded have not been in place. This has meant gathering the necessary information to inform the monitoring data has perhaps been more difficult than necessary.

This has highlighted the need for a tight communication strategy between monitoring and conservation works teams, and a clear protocol for recording works to the desired timescale.

Added value

The scope and scale of the MoorLIFE conservation works presents difficulties in monitoring. In designing a robust monitoring programme there are some method of monitoring that are not possible within the budget or scope of this project. Moors for the Future are able to bring added value to the MoorLIFE monitoring by integrating datasets from other monitoring projects. These provide both valuable information but also an essential context in which to view the data.

An example of this is the additional monitoring being undertaken on Woodhead of gully blocking works undertaken as part of the MoorLIFE project. Additional funding has been secured to install water quality and flow monitoring within MoorLIFE areas to enable the assessment of the impact of these works. These monitoring points are illustrated above in Figure 3.

1.4 Definitions of terms used in this report

Treatment sites – sites of bare and eroding peat that are undergoing full treatments under Actions C1, C2 and C3 of MoorLIFE

Late-stage restoration sites – sites that have been historically revegetated through restoration actions by MFF. These sites, if being treated, are to receive maintenance treatments of fertiliser and Sphagnum propagules.

Intact sites – vegetated sites with relatively little damage from erosion gullies. These sites are not generally in target areas for restoration, although some drift of lime, seed or fertiliser might occur.

Peat pan sites – sites that are situated in areas dominated by peat pans rather than large areas of bare and eroding peat. They are generally enclosed by vegetation.

2 Action E2 – Monitor vegetation establishment and succession

2.1 E2 Introduction

The primary aim of the MoorLIFE project is to protect remaining areas of active blanket bog in the South Pennines SAC by revegetating surrounding areas of bare and eroding peat.

Blanket bog in the South Pennines has suffered from significant and extensive vegetation loss and erosion. Wildfires and overgrazing have contributed to the loss of vegetation while high levels of acidity remain due to historic air pollution. This, combined with the high erosion rates of exposed peat prevent, or at least impede, the natural recovery of the vegetation.

The South Pennines SAC is now a mosaic of various erosion types with a low diversity of plant species. Many of the drivers of moorland degradation in the South Pennines have been addressed and ameliorated – such as issues of grazing and air quality. However natural recovery is extremely slow and erosion rates are so high they threaten what intact areas of active blanket bog remain.

The plant communities that remain on intact areas of South Pennines blanket bog are generally a mix of M19 *Calluna vulgaris – Eriophorum vaginatum* blanket mire and M20 *Eriophorum vaginatum* blanket mire. The species that are typically found in these habitat types are common heather (*C. vulgaris*), *Vaccinium* spp., Ericaceous dwarf shrubs, cloudberry (*Rubus chamaemorus*) and feather (pleurocarpus) mosses (Rodwell, 1991). *Sphagnum* mosses are also key blanket bog species as they are the main peat building species. *Sphagnum* was largely lost in the South Pennines blanket bog habitats due to atmospheric pollution, to which these mosses are particularly sensitive because of their ability to take in water from the atmosphere.

The MoorLIFE project will help to protect the remaining areas of active blanket bog and increase biodiversity through stabilisation and revegetation of eroding surfaces. Application of *Sphagnum* propagules will also boost the recovery of this key plant group on both intact and restored areas of vegetation.

Vegetation surveys are being undertaken across all four MoorLIFE sites to monitor the success of vegetation establishment and succession resulting from treatments under the MoorLIFE restoration works. The objectives are:

1. To monitor revegetation following treatment with heather brash, lime, seed and fertiliser.
2. To monitor the succession of vegetation on restoration sites from nurse crop to more typical moorland species.
3. To monitor the establishment of *Sphagnum* following applications of propagules.

The aim of this report is to provide an overview of the various vegetation survey methodologies used in the MoorLIFE monitoring programme. An update is given on the progress of vegetation monitoring to date, and a subsample of the data gathered between 2010 and 2012 are presented. While the aim of the monitoring programme is to monitor succession of vegetation, the timescales of this project and the ongoing capital works mean that it is only possible to present a baseline data set. Longer term monitoring will be necessary to fully understand and measure the impacts of the MoorLIFE capital works.

2.2 E2 Methods

The surveys are designed to take into account certain indicators such as target species, vegetation structure, heather condition etc allow assessment of habitat condition using Common Standards Monitoring used by Natural England and the Joint Council Conservation Committee (JNCC, 2009).

Analysis of historical MFFP vegetation data in combination with walkover surveys indicates that a combination of survey methodologies is required to fully determine the impacts of all different restoration techniques on vegetation establishment and succession. Three survey methods have been selected to monitor the early development of vegetation and to establish baseline datasets which can be used to determine succession in the long-term and beyond the end of the MoorLIFE Project. This monitoring also builds upon the historical data from Bleaklow and Black Hill. Table 2 summarises when and where each of the three monitoring techniques have been used. The methodologies are described below.

Table 2 Summary of the sites where each monitoring technique has been used, and the years in which they were undertaken

Site	2010	2011	2012	2013
Bleaklow – Peaknaze	Fixed point quadrats	Fixed point quadrats	Fixed point quadrats	Fixed point quadrats
Bleaklow – Woodhead	New fixed point quadrats set up	Fixed point quadrats	No vegetation monitoring – weather constraints	Fixed point quadrats
Bleaklow – National Trust	No vegetation monitoring	No vegetation monitoring	Sphagnum transects Fixed point quadrats	Fixed point quadrats
Black Hill	Fixed point quadrats	Fixed point quadrats	Sphagnum transects Sphagnum bead monitoring.	Fixed point quadrats
Turley Holes	New fixed point quadrats set up	Fixed point quadrats	Sphagnum transects only – access for quadrats not possible due to access issues	Fixed point quadrats
Rishworth Common	No vegetation monitoring	New fixed point quadrats set up spring and monitored again in summer.	No vegetation monitoring – weather constraints	Fixed point quadrats Sphagnum bead monitoring

Objectives 1 and 2: Stabilisation of bare peat and establishment of moorland vegetation

Fixed point quadrats have been set up across most of the MoorLIFE areas in such a way as to allow a full ‘before-after, control-impact’ design. Four treatment scenarios are represented:

1. Bare peat sites left untreated as a reference site.
2. Treatment sites – treated with brash, lime, seed and fertiliser
3. Late-stage restoration sites – sites that were treated between 2003 and 2006.

4. 'Intact' sites – i.e. those sites that have not been eroded and on which vegetation has not been lost. These areas of vegetation may still be of poor diversity.

Black Hill and Bleaklow have quadrats that pre-date MoorLIFE and have been monitored for several years. These quadrats are those that represent the late-stage restoration sites and the untreated bare peat reference site. Data from these quadrats provide a baseline to which *Sphagnum* applications can be assessed. It also allows for a space-for-time comparison of sites and enables inferences to be made as to the progress of sites newly treated under MoorLIFE.

On MoorLIFE sites that have no previous restoration history (Woodhead, Turley Holes and Rishworth Common) 2 x 2 m quadrats have been installed prior to restoration works where possible. Quadrats are set out in a stratified grid pattern across the areas identified for brash and LSF treatments (Moors for the Future, 2013). Quadrats were set up on areas of bare peat, on flat or gently sloping ground, with a north-south orientation. Hardwood tree stakes were placed in the north-east and south-west corners, and the coordinates, altitude and slope recorded for each quadrat. It is the intention for all quadrats to be monitored annually during the MoorLIFE project. The distribution of quadrats and the variables collected closely follows the methodology used to monitor historic quadrats on Bleaklow and Black Hill. The following variables are recorded upon each repeat visit:

- Percentage cover of bare peat
- Percentage cover of standing water
- Percentage cover of main vegetation types: grasses, sedges and rushes; nurse crop species; dwarf shrub; herbaceous species; invasive species; tree and shrub species; mosses and lichens. These are broken down further into plant species wherever possible
- The average heights of dwarf shrub, moorland graminoids and nurse crop.
- Presence of grouse, hare or sheep droppings
- Fixed point photos are taken of each quadrat

Due to the complexity of vegetation structure it is possible for percentage cover of vegetation to be over 100%.

It is important to emphasise that the monitoring programme is designed to evidence the impact and success of broad, landscape-scale restoration actions, as opposed to assessing the impact of specific treatments.

In total 288 quadrats are monitored on MoorLIFE sites as part of Action E2. The distribution of these across the different sites are detailed in Table 3. In addition to these, there are also vegetation quadrats within dipwell clusters (see section E3) which provide information on vegetation changes associated with any changes in water table behaviour that might be observed. Data from the dipwell clusters are not considered here, but will be used in analyses for Action E3 – water tables.

Late-stage restoration sites on Bleaklow and Black Hill were monitored in 2010 to provide a baseline of vegetation data for the MoorLIFE project. New quadrats were set up in winter 2010/2011 across Woodhead, Rishworth and Turley Holes. These were monitored again in 2011 along with the historic quadrats.

In summer 2012, while it was the intention to monitor all fixed quadrats, it was decided to use resources to undertake the *Sphagnum* transects and propagule monitoring. This was especially important as treatment of Black Hill with *Sphagnum* was brought forward. As well as Black Hill, *Sphagnum* transects were undertaken on the Alport Moor area of Bleaklow. This, along with access issues for Turley Holes, meant that no data was collected for quadrats set up on new MoorLIFE treatment sites. (See Table 2 above for a summary of monitoring across sites and years).

Table 3 Breakdown of fixed quadrats established on each MoorLIFE site.
***31 of these quadrats are on vegetation to monitor the impacts of LSF treatments on the present vegetation**

Site	Types of site present					Total number of quadrats
Distributed quadrats	**Bare peat reference**	**Intact reference**	**Late stage restored**	**Treatment**	**Peat pans**	
Bleaklow – Peaknaze	10	13	94	-	-	117
Bleaklow - Woodhead	-	-	-	58	-	58
Black Hill	-	-	-	17	-	17
Rishworth Common	-	-	-	24	-	24
Turley Holes	10	-	-	62*	-	72
Totals	**20**	**13**	**94**	**161**	**-**	**288**

Objectives 2 and 3: Establishment of moorland vegetation including Sphagnum mosses

Fixed width transects are one of the methods used to monitor success of *Sphagnum* mosses on restoration sites and to create a baseline against which long-term changes can be monitored. These are undertaken on sites prior to treatment with *Sphagnum* fragments or beads and are designed to be a rapid assessment of a site, rather than as an extensive survey.

The method used follows that used by Moors for the Future on a number of projects.

Transect routes are mapped on an area of interest and the start and end points uploaded onto a handheld GPS unit. Transects are mapped with a distance of 50m between them. Initially only every third transect line is surveyed to ensure an evenly distributed coverage of the area. If time permits, it is the intention that surveyors will walk the transects in between to increase the area surveyed. Transects are orientated either north-south or east-west, so as to cut across the gullies present on the sites. The width of transects depends on the abundance of *Sphagnum*, and the structure of the vegetation and how much it obstructs a surveyor's view.

The following variables were recorded for each patch of *Sphagnum*:

- Species
- Approximate area of the *Sphagnum* patch
- Lengths of the longest and shortest axes of the patch
- Situation type (undulating ground, hagg top, gully side or gully floor)
- Gully width and depth (where applicable)
- Surface gradient (Shallow 0-10 degrees, moderate 11-30 degrees; steep 31+ degrees)
- The presence of standing water within two metres of the *Sphagnum* patch
- A list of other plant species present within a 2 x 2 m quadrat centred on the *Sphagnum* patch
- A list of other plant species present within a 2 x 2 m quadrat centred on the *Sphagnum* patch, with an estimate of their relative cover using the DAFOR scale.
- Coordinates of the *Sphagnum* patch

The total area of *Sphagnum* cover is calculated by estimating the total area of *Sphagnum* patches recorded and can be expressed as a proportion of the total area surveyed (the product of transect length and distance scanned by surveyor) in order to compare sites.

The *Sphagnum* patches are mapped using MapInfo v.10 to assess the spatial distribution.

Objective 3: Establishment and spread of Sphagnum moss propagules

Quadrats are used within MoorLIFE to assess the shorter term success of *Sphagnum* propagule application. These surveys involve a much more detailed survey and involves counting individual beads within a quadrat. These surveys are better able to assess success of *Sphagnum* at a smaller scale than the transect surveys. Surveyors accompanied *Sphagnum* spreaders along pre-mapped application transects. These transects were orientated east to west and were spaced 14 metres apart. Surveyors installed 1 x 1m quadrats in areas observed to have been treated with *Sphagnum* beads. Quadrats were located every 150 m along the spreading transects on flat, well-vegetated areas. Quadrats were placed on particular vegetation types dominated by either dwarf shrub, cotton grasses, other grasses or mosses, with a surveyor alternating between a different vegetation type wherever possible.

Quadrats were orientated north-south, and marked with a single wooden stake in the south-west corner. For each quadrat the surveyor noted the coordinates, percentage cover of the four plant types, percentage cover of bare peat and standing water within the quadrat, and the proximity of any standing water, ponds or pools within sight of the quadrat.

2.3 E2 Results

Late-stage restoration sites – Year 1 of MoorLIFE

Five sites within the MoorLIFE works programme are monitored as late-stage restoration sites. These will be treated with *Sphagnum* propagules in Action C3.

The JNCC's Common Standards Monitoring uses the presence of certain indicator species as one way of assessing the condition of a habitat. The indicator species for blanket bog habitats that are often found in the South Pennines are shown in Table 4, with an indication of which late-stage MoorLIFE sites these species were found in 2010.

Table 4 Occurrence of JNCC blanket bog indicator species across late-stage restoration sites.

	Indicator species for blanket bog habitats									
Site	Common heather	*Erica spp.*	*Vaccinium spp.*	Common cottongrass	Hare's-tail cottongrass	Cloudberry	*Sphagnum* spp.	Pleurocarpus mosses	Non-crustose lichens	Total number of indicator species
Joseph Patch	✓	✓	✓	✓	✓	✓	✓	✓	✓	9
Shining Clough	✓	×	✓	✓	✓	✓	✓	✓	✓	8
Sykes Moor	✓	×	✓	✓	✓	×	✓	✓	✓	7
Shelf Moss	✓	×	✓	✓	✓	×	✓	✓	✓	7
Black Hill	✓	×	✓	✓	✓	×	✓	✓	✓	7

Analysis of the species composition of historically restored sites shows the variability in vegetation structure and species composition that exists among the sites.

Initial figures indicated that invasive/ruderal species such as rosebay willowherb (*Chamerion angustifolium*) and tree/scrub species such as willow (*Salix* sp.) and birch (*Betula* sp.) were only present in extremely low figures – less than 1% of all quadrats contained these species. Therefore these were left out of graphs for simplicity.

Figure 10 shows that the bare peat reference site on Bleaklow still has substantial areas of bare peat and little else. Black Hill also appears to have a relatively large area of bare peat – more so than the other monitored sites. Reasons for this are unclear and require further investigation. Quadrats set on 'intact' vegetation (i.e. vegetation that occurs on peat haggs) appears to be broadly similar to the other sites, but with herb species present in higher proportions. These figures are a representation of the relative dominance of vegetation groups (a complex vegetation structure means that totals often added up to more than 100%). Median percentage cover values are presented in Table 5.

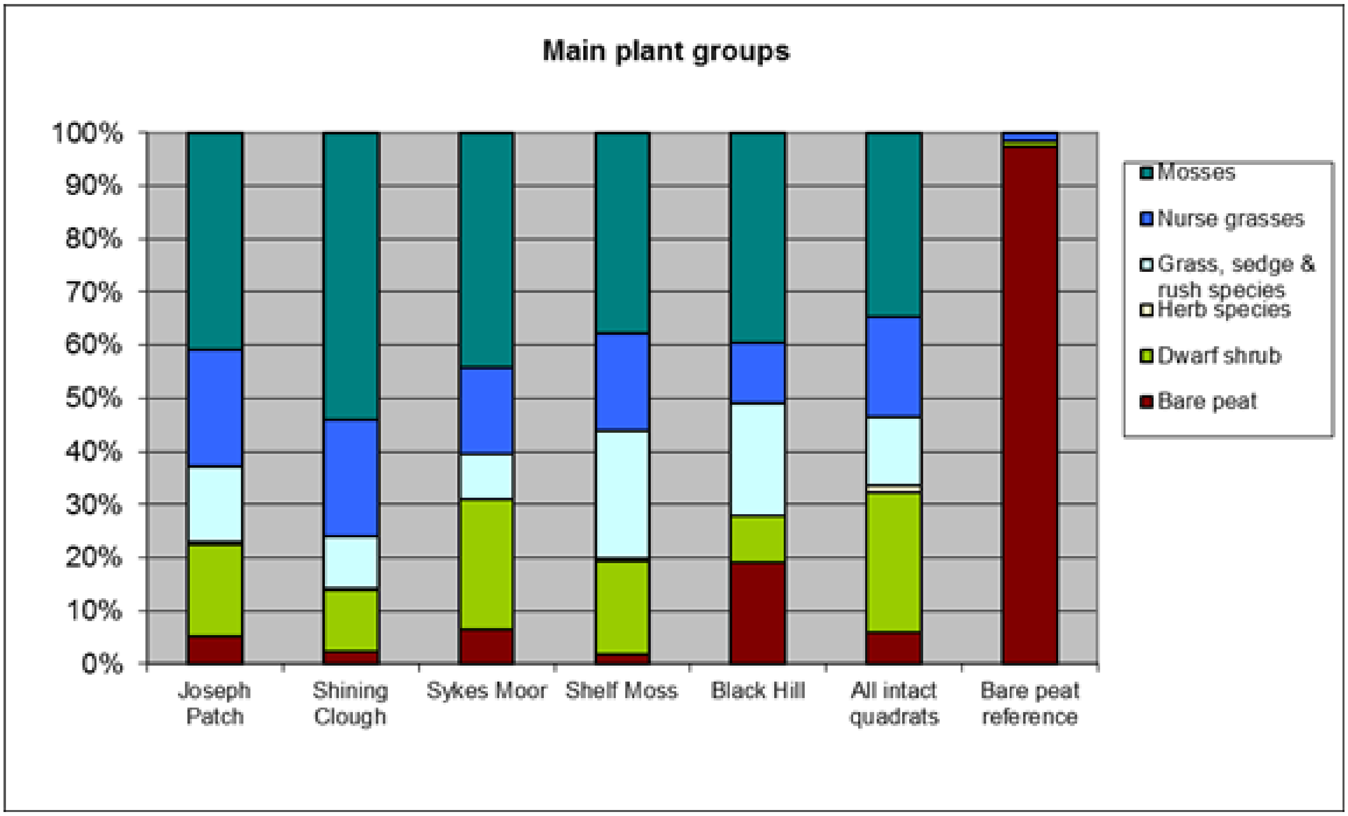


Figure 10 Percentage composition of main vegetation cover types on late-stage restoration sites

A visual inspection of the species composition data from vegetated areas showed that several other species within the main groupings, while present, occurred in such low numbers as to warrant leaving out of the graphs for ease of interpretation. These plants included Lichens, liverworts, ferns, purple moor grass (*Molinia caerulea*), mat-grass (*Nardus stricta*) and cross-leaved heath (*Erica tetralix*).

Figure 11 shows the species composition of the late-stage restoration sites, along with intact hagg tops within those sites. Again it is important to note that these charts do not present mean percentage covers – simply a representation of the relative abundance of each species within the vegetation.

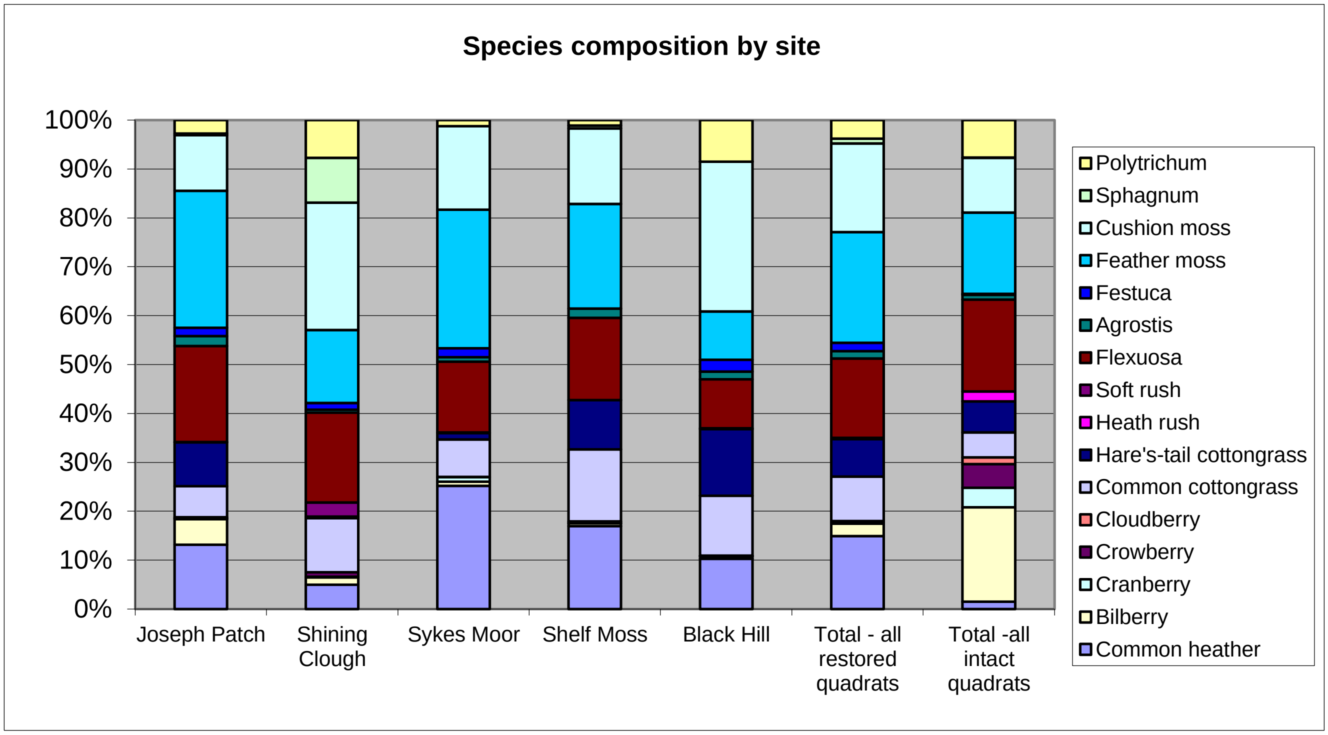


Figure 11 Percentage composition of the most common species and species groups found on late-stage restoration sites

Again the variability of species composition can be observed, but with broad patterns. The most abundant species occurring were common heather, bilberry, common cottongrass, hare's-tail cottongrass, and wavy hair grass. Within the bryophytes, both feather mosses and cushion mosses (those excluding *Polytrichum* sp.) were present in high proportions.

The main observed difference among restored sites appears to be in bryophyte composition. Feather mosses were generally more predominant than cushion mosses, with the exception being Black Hill where the reverse appeared to be true. *Sphagnum* mosses were not abundant on any site with the exception of Shining Clough where they appear to make up a relatively large proportion of the vegetation. Examination of the data however shows that just three out of 15 quadrats contained *Sphagnum*, with one quadrat having 90% cover – indicating that one quadrat could be responsible for the high figures.

Quadrats placed on stands of intact vegetation appear to have the greatest species diversity. Several species occur in greater proportions in intact quadrats than any others, for example, heath rush (*Juncus squarrosus*), soft rush (*J. effusus*) and cloudberry – these species tended not to occur on revegetated areas. Common heather is noticeably low on intact quadrats, with bilberry being the more abundant dwarf shrub on these areas.

A Kruskal-Wallis test was undertaken on the groupings and species that represented more than 1% of the cover or species composition on restored sites. These tests show that there are significant differences in the occurrence of all species among the sites. The results of this test are shown in Table 3.5 for ground cover and Table 3.6 for species composition.

Table 5 Median percentage cover of the main vegetation types found on late-stage restoration sites and results of Kruskal-Wallis test for differences among the sites.

Ground cover type	Median percentage cover						Kruskal-Wallis test
	Joseph Patch	Shining Clough	Sykes Moor	Shelf Moss	Black Hill	Reference – bare peat quadrats	
Bryophyte	70	84	87	62	70	0	H = 33.60, p < 0.001
Nurse crop	35	22	26	21	15	1.50	H = 36.13, p < 0.001
Graminoid	16	16	7	40	25	0	H = 29.51, p <0.001
Dwarf shrub	25	5	43	21	2	1.10	H = 41.30, p < 0.001
Bare peat	1	0	1	2	12.5	97.00	H = 35.16, p < 0.001

Further analysis and post-hoc testing is required to find where the sites differ. Visual examination of the data (Figure 12) suggests that the biggest differences are between areas of restored vegetation and the site being used as a bare peat reference.

Table 6 Differences in species composition among the late-stage restoration sites.

Species	Median percentage cover						Kruskal-Wallis test
	Joseph Patch	Shining Clough	Sykes Moor	Shelf Moss	Black Hill	Reference – bare peat quadrats	
Common heather	2	3	42.5	17.5	2	0	H = 20.96, $p < 0.001$
Bilberry	3	0	0	0	0	0	H = 25.67, $p < 0.001$
Common cottongrass	3	15	5.5	20	4	0	H = 5.42, $p < 0.247$
Hare’s-tail cottongrass	10	0	0	15	5	0	H = 28.90, $p < 0.001$
Wavy hairgrass	25	20	25	20	10	0	H = 18.52, $p < 0.001$
Agrostis species	2	0	1	1	0	0	H = 20.40, $p < 0.001$
Festuca species	0	0	0	0	0.5	0	H = 14.80, $p < 0.001$
Feather mosses	50	5	37.5	37.5	1	0	H = 27.75, $p < 0.001$
Cushion moss	7	35	20	17.5	40	0	H = 6.28, $p < 0.001$

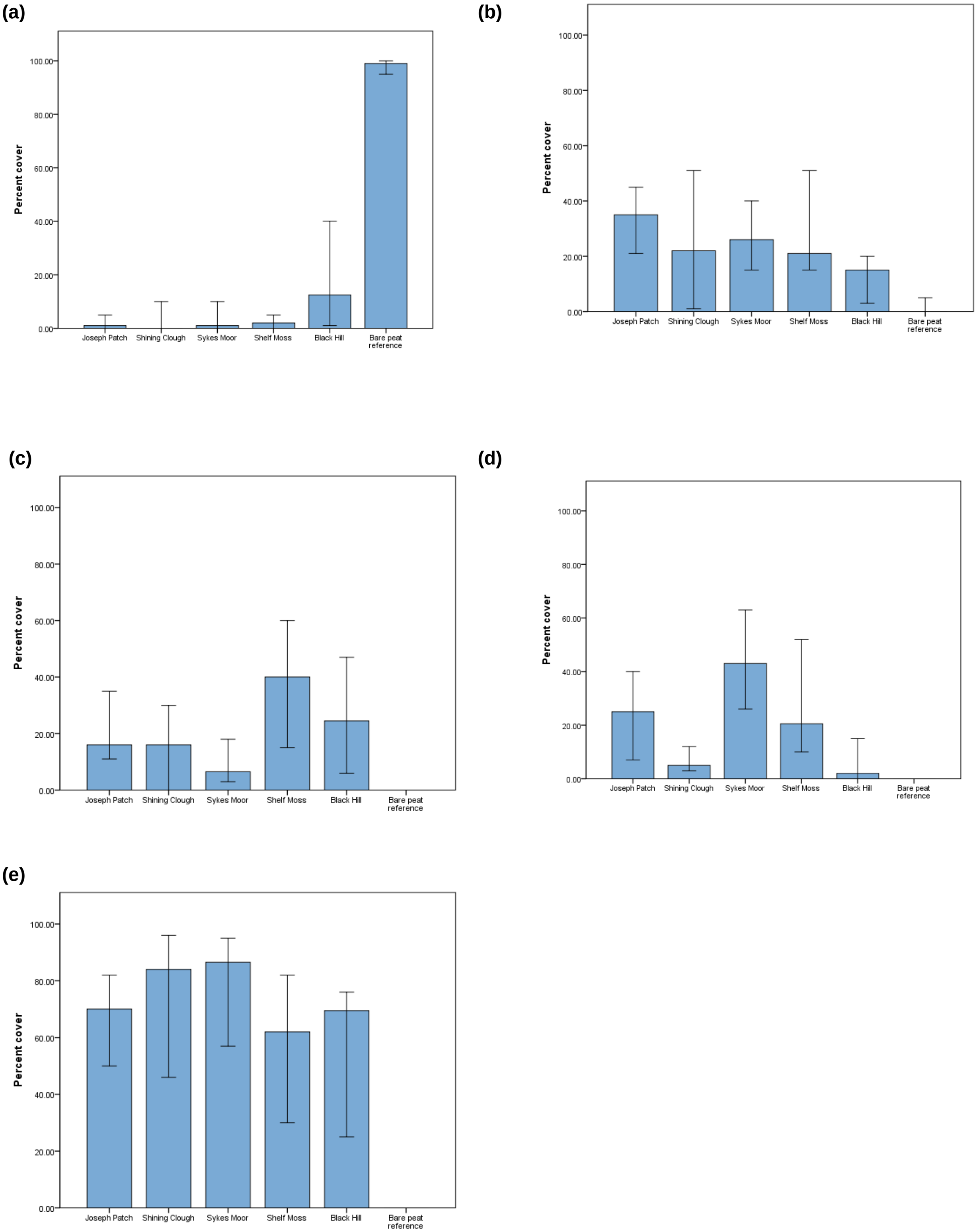
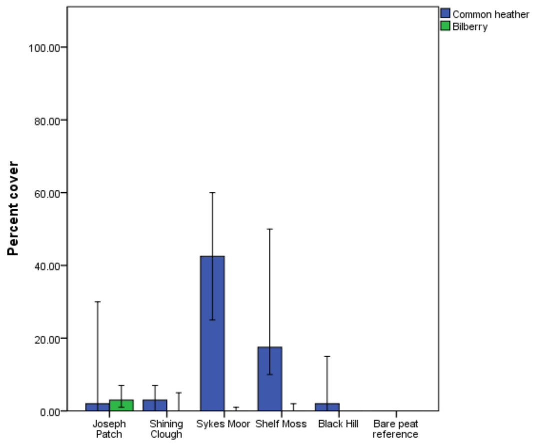


Figure 12 Median percentage cover of (a) bare peat (b) dwarf shrub (c) graminoid (d) nurse crop and (e) bryophyte cover in 2 x 2 m fixed quadrats in 2010. Error bars show 95% confidence limits.

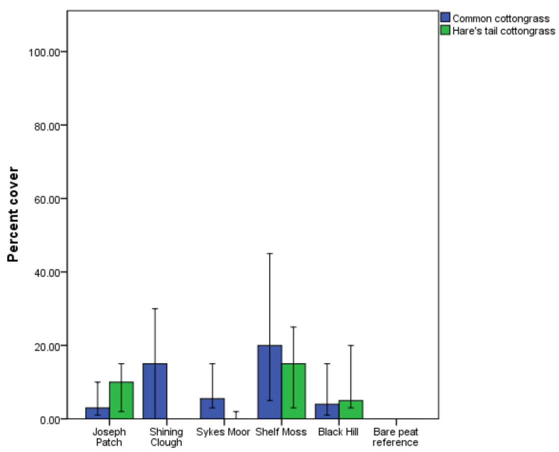
The graphs in Figure 13 show a visual exploration of the species composition in relation to the dominant dwarf shrub, graminoid and bryophyte cover.

Stands of restored vegetation across most sites appear to show a predominance of common heather over bilberry (Figure 13a). On Joseph Patch, Shelf Moss and Black Hill, common cottongrass and hare’s-tail cottongrass appear to occur in equal proportions (Figure 13b). On Shining Clough and Sykes Moor, common cottongrass appears to dominate over hare’s-tail. On all the treated sites on Bleaklow, feather mosses tend to be more abundant than cushion mosses (Figure 13c). This is especially the case on Joseph Patch. Black Hill shows the opposite, and cushion mosses appear to be more predominant. These patterns of vegetation composition and structure are explored in the next section.

(a)



(b)



(c)

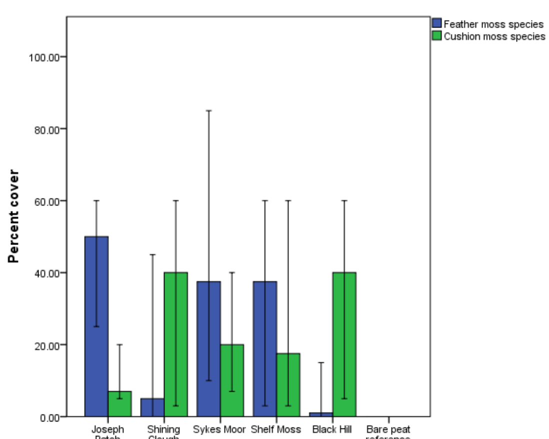


Figure 13 Median percentage cover of (a) dwarf shrub species (b) cottongrass species and (c) moss groups in late-stage revegetated quadrats and bare peat reference quadrats in 2010. Error bars represent 95% confidence limits.

Baseline conditions before treatment of MoorLIFE sites

In the autumn/winter period of 2010/11 (year 1 of the project), a total of 113 new quadrats were established on areas of bare and eroding peat across Bleaklow (Woodhead), Turley Holes and Rishworth Common. A further 31 were established on vegetated areas of Turley Holes to assess the impact of restoration actions on existing vegetation.

When these quadrats were monitored in 2011, brashing had not been completed, and lime, seed, fertiliser treatments had not yet taken place.

Brashing had only been partially undertaken on Woodhead (12 out of 58 quadrats brashed) and Turley Holes (15 quadrats out of 31). Rishworth Common was brashed in March 2011 just after quadrats had been established (22 out of 24 quadrats).

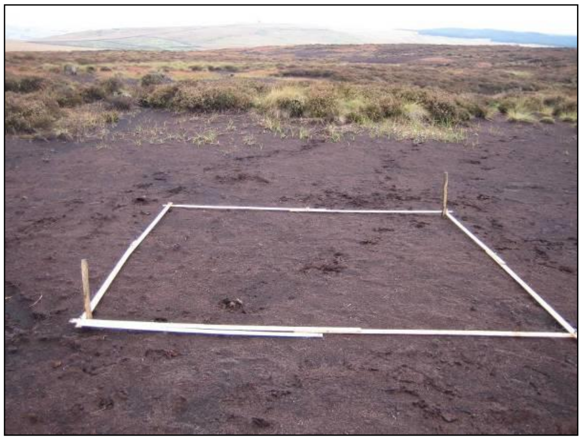
Monitoring of the new quadrats was hindered by poor weather and difficulties with access, which meant that no data is available from 2012. The most recent monitoring of these quadrats was undertaken in summer 2013. At this time, all sites had received brash, lime, seed and fertiliser treatments. At the time of writing, data was still to be analysed, and so is not presented in this report in any detail. Figure 14 illustrates the fixed point photography methodology that is being undertaken as part of the vegetation monitoring.

New quadrats were established on areas of bare peat which were typically 99% bare peat, with some containing small amounts of moss and cottongrass. Table 7 shows the presence of indicator species found on each site in areas of bare peat.

Table 7 Occurrence of JNCC blanket bog indicator species across areas of bare peat on MoorLIFE sites in 2010.

	Indicator species for blanket bog habitats									
Site	Common heather	*Erica* spp.	*Vaccinium* spp.	Common cottongrass	Hare's-tail cottongrass	Cloudberry	*Sphagnum* sp.	*Pleurocarpus* mosses	Non-crustose lichens	Total number of indicator species
Bleaklow – bare peat reference	✓	×	✓	✓	×	×	×	×	×	3
Bleaklow – Woodhead	✓	✓	✓	✓	×	×	×	×	✓	5
Turley Holes	✓	×	×	✓	×	×	×	×	✓	3
Rishworth Common	×	×	×	✓	✓	×	×	✓	×	3

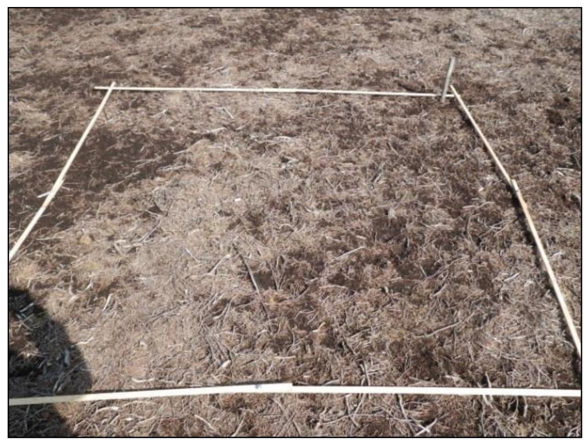
(a) 2010



(b)

(c) 2011

(d)



(e) 2013

(f)

Figure 14 Fixed point photography of quadrat 8 on Turley Holes in three years of data collection. Quadrats were established in winter 2010 (photos (a) and (b)), prior to any works being undertaken. Brash was spread over the site in the following months and can be clearly seen in photos (c) and (d) taken in the 2011 survey. The site was treated with lime, seed and fertiliser between 2011 and 2012, resulting in a covering of nurse grasses by 2013, shown in photos (e) and (f).

Sphagnum Transects

In 2012, three MoorLIFE sites were surveyed for *Sphagnum* to create a baseline against which long-term changes can be monitored. These were Black Hill, Turley Holes, and areas of Bleaklow. Prelimary results are presented in Table 8.

Table 8 Showing results of Sphagnum transect surveys on Black Hill (a late-stage restoration site) and Turley Holes (treatment site)

	Black Hill	**Turley Holes**
Survey		
Km walked in transects	3.2	3.4
% area surveyed	3.21	2.97
Total area surveyed (sq m)	14567	13685
***Sphagnum* stats**		
No. patches found	353	31
Total area of all patches (sq m)	446.45	7.48
Mean patch size (sq m)	1.27	0.24
Median patch size (sq m)	0.06	0.18
Maximum *Sphagnum* patch size (sq m)	176	1.26
% cover of *Sphagnum* on surveyed ground	3	0.002
Occurrence		
Undulating ground	93%	100%
Hagg top	0	0
Gully side	1%	0
Gully floor	6%	0

On Black Hill at least five species of *Sphagnum* were identified with confidence by the surveyors. Some uncertainty about *S. papillosum* and *S. palustre* remained as these species are often difficult to tell apart in some situations. Therefore these two species were grouped together. *S. fallax* occurred most regularly, with 135 definite identifications. This was followed by *S. fimbriatum* (39 records), *S. palustre/papillosum* (6), *S. subnitens* (2) and finally *S. cuspidatum* (1).

Sphagnum patches occurred on undulating ground in 93% of cases. *Sphagnum* was also recorded occurring on gully floors (6%) and on gully sides (1%). No *Sphagnum* was recorded on hagg tops.

The majority of the individual *Sphagnum* patches were under 2 square metres in size. Figure 15 shows the map of *Sphagnum* transects and locations of recorded patches. Locations of areas to receive heather brash are also mapped, revealing an overlap between records of *Sphagnum* and the heather brash spread in 2005.

Turley Holes had fewer patches of *Sphagnum* within the survey area. A total of 31 *Sphagnum* patches were found and measured.

Four (possibly five) species were idenitified on the site: *S. subnitens* (8 records), *S. fallax* (6), *S. fimbriatum* (6) and *S. palustre/papillosum* (6).

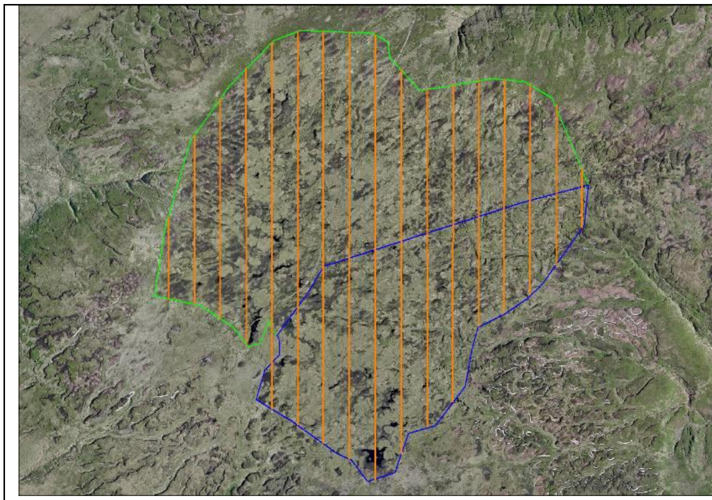
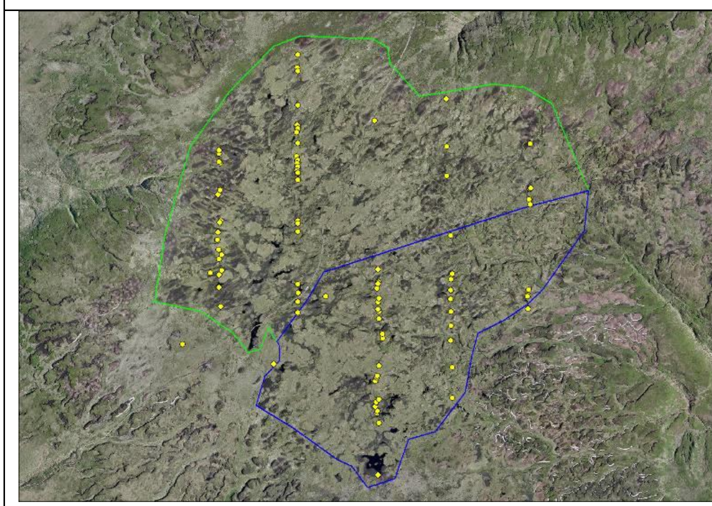
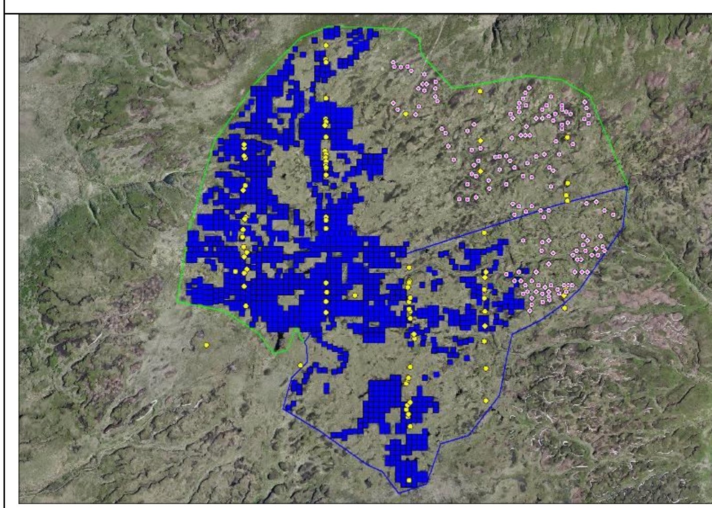
	**(a) GIS mapping of the intended survey transects across the MoorLIFE restoration area on Black Hill.**
	**(b) Every third transect was walked to ensure an even coverage of the site in the time available. Yellow circles represent the locations where *Sphagnum* patches were recorded.**
	**(c) The *Sphagnum* records were laid over GIS layers representing the spread of heather brash in 2005 (blue squares) and 2007 (white circles with red centres). The resulting map inferred that most *Sphagnum* records occurred in the areas where brash was spread in 2005.**

Figure 15 Mapping of *Sphagnum* recorded during transect surveys on Black Hill.

Sphagnum establishment

In order to more closely monitor the establishment of *Sphagnum* mosses from propagules, the spreading of beads was monitored by use of quadrats. Black Hill was the first MoorLIFE site to receive *Sphagnum* propagules. Spreaders were accompanied by surveyors who installed quadrats on vegetation treated with the beads. Figure 16 shows the transects walked by *Sphagnum* bead spreaders, and the locations of the quadrats.

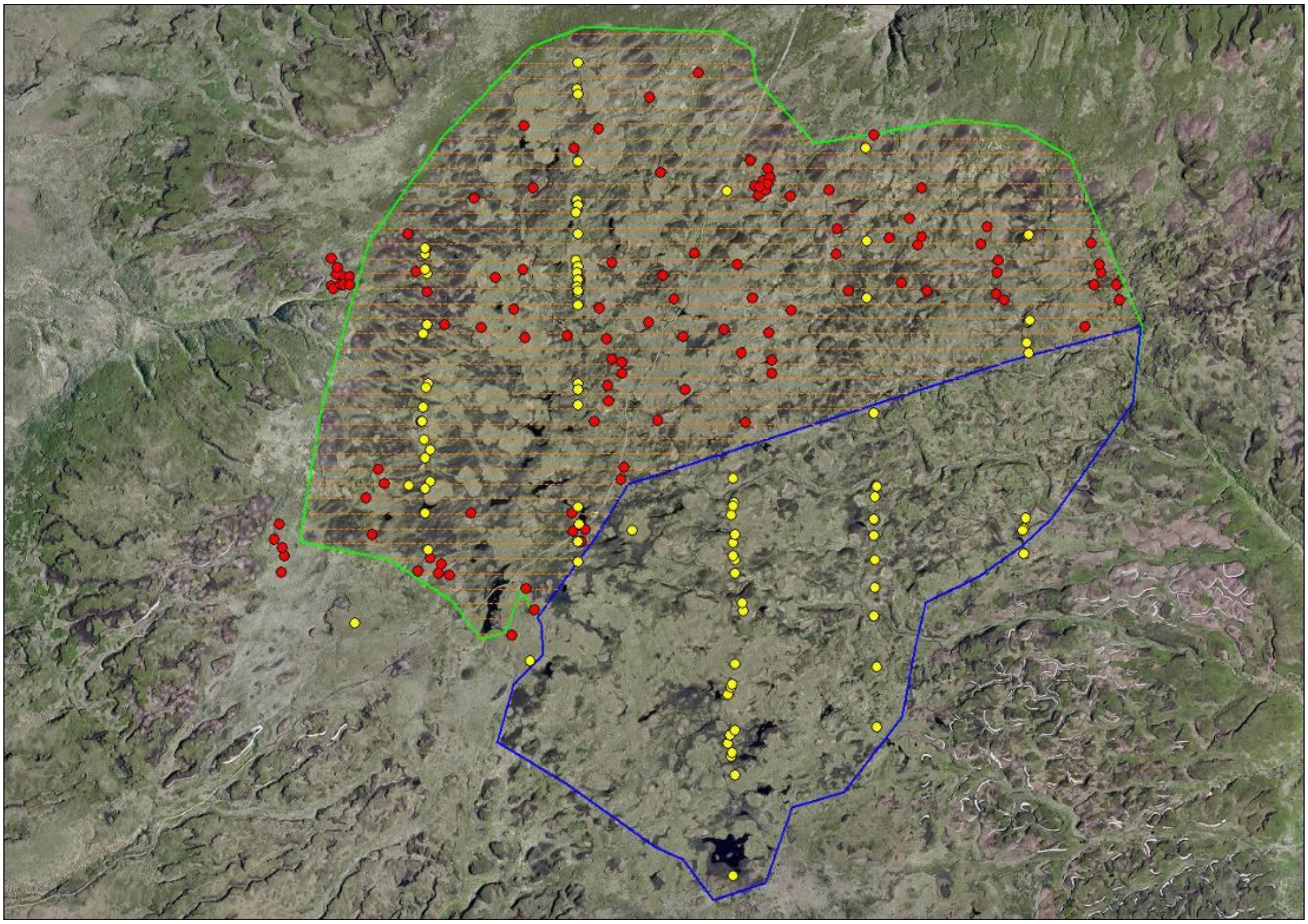


Figure 16 Distribution of 1 x 1 m quadrats on Black Hill to monitor the success of Sphagnum beads.

In total, 97 treatment quadrats were established, with 22 untreated, control quadrats. Application ranged from 2 – 200 beads, with a mean of 30 beads per quadrat. 50% of quadrats had 20 beads or fewer.

2.4 E2 Discussion

The vegetation surveys undertaken as part of the MoorLIFE project is a major part of the monitoring programme. Monitoring the changes in vegetation cover following the treatments with brash, lime, seed and fertiliser is essential to be able to assess the impact of the works. At the time of writing (July 2013), seeding work was still being undertaken across MoorLIFE sites. Therefore it is too early to assess the impact of works through the establishment of a nurse crop.

The data collected in 2010 shows that vegetation cover on revegetated sites was high, and ranged between 73% and 97%. Species composition varied among revegetated sites, but all sites have at least seven of the blanket bog indicator species listed in the JNCC Common Standards Monitoring methods (JNCC, 2009). When this is compared to the bare peat reference quadrats on Bleaklow, which have been monitored for several years it provides strong evidence that the revegetation treatments are highly effective. A more detailed analysis of the distribution and proportions of indicator species will be included in the final MoorLIFE monitoring report, as well as further investigation into the variability between late-stage restoration sites.

Further work needs to be done to characterise the intact areas of vegetation. While these areas appear to be some of the more diverse, but it is suspected that they might represent varying habitat types and species assemblages. This could include quadrats set on gully bottoms (shallow peat) and hagg tops (deep peat). Better characterisation of the topographic settings will enable improved interpretation of these data.

Ruderal/invasive species and tree/shrub species are present on revegetated sites, but in extremely low numbers. Walkovers suggest that patches of plants such as rosebay willowherb might be highly localised and it is possible that the fixed quadrats do not pick up this variation. However there is confidence that the quadrats represent the typical type of vegetation that has returned to once bare and eroding peat. As to what type of community the revegetated areas represent is a key question and one that is currently being investigated. Characterisation of intact and restored vegetation on late-stage restoration sites, with associated water table analysis, will facilitate the setting of realistic targets to be set for the vegetation communities re-establishing on areas of bare peat.

Sphagnum mosses do not occur in many quadrats – only 8 out of 143 vegetated quadrats. This gave early indications that *Sphagnum* was uncommon. However, walkovers of sites indicated that this might not be representative of the wider study area. Transect surveys were undertaken in 2012 to establish a baseline data set prior to application of *Sphagnum* propagules. The data from these transects have provided more information regarding *Sphagnum* diversity, abundance and distribution to that presented by the fixed quadrats. While Black Hill was found to have a relatively high abundance of *Sphagnum* patches and at least five species, the overall abundance and distribution of *Sphagnum* across all MoorLIFE sites has been found to still be very low. This evidence further supports the need for re-introduction or *Sphagnum* to large areas of the South Pennines.

The transect surveys were designed to enable a rapid assessment of the site and to take in the range of vegetation covers and topographies present on a site (unlike quadrats which are generally placed on either dome tops or hagg tops). The surveys are useful because, being quantative, they allow comparisons of sites. The methods can also be adjusted to suit time, budget and site constraints.

Some transects were found to have such an abundance of patches that the site proved very difficult to survey. On Turley Holes, with very few *Sphagnum* patches, the surveys were very quick and straightforward.

The surveys show that when *Sphagnum* reaches a certain level of abundance, it can take a long time to survey. Surveyors need to be aware of the limitations of the survey and accept the methodology as a rapid assessment. It is likely be an underestimate of the true percentage cover of *Sphagnum*. However, it will be capable of recording substantial changes in *Sphagnum* cover on sites such as Turley Holes, and therefore will certainly be of use for monitoring large changes over long periods.

The challenge that Black Hill presented in survey time and effort shows that this survey method has limitations and in future other methods of survey, such as remote sensing might need to be considered at a later date. Such techniques are not within the scope of the MoorLIFE project.

Mapping the distribution of *Sphagnum* on Black Hill gave some interesting results. The area of Black Hill with the highest proportion of *Sphagnum* patches appears to be associated with heather brash spread in 2005. Brash spread in 2007 does not appear to show the same level of *Sphagnum* cover. This could be a function of the shorter time since the brash was spread. But it is also interesting to note that the donor sites that provided the brash have potentially very important differences. The 2005 brash donor site is a wet, *Sphagnum* rich site. The 2007 brash donor site is a dry, *Sphagnum* poor site. This could suggest that donor sites differ in quality and the results that they give in terms of *Sphagnum*. Care is being taken in the MoorLIFE project to keep records of where donor site brash is spread. Repeat surveys of Black Hill in two years could help give further information on the importance of the relationship between brashing and *Sphagnum* recolonisation.

The *Sphagnum* maps of Black Hill were able to inform the Conservation Works team as to where to concentrate *Sphagnum* bead spreading.

The transect surveys compliment the fixed quadrat surveys and show how important it is to consider alternative survey methods that take account of different land covers and topographical settings. Such factors are likely to be extremely important in our understanding of *Sphagnum* establishment through both natural spread and introduction of propagules.

Quadrats established to monitor the application of *Sphagnum* beads will be monitored again 18-24 months post-application. Studies of the success of *Sphagnum* beads indicates that there is a significant lag between application and readily observable results (Rosenburgh, pers. comm.). The recommendation from these studies is that a return visit after 18 months is the most valuable, although readily observable results may take longer. Much depends on the time of sowing and weather conditions in the following weeks.

The application methods for the *Sphagnum* propagules are still quite new and vary between sites, topography and vegetation types. It is currently felt that it is necessary for surveys to be undertaken on the day of application wherever possible. This has several benefits. Firstly, it enables surveyors to observe where beads are being put down and so can situate a quadrat appropriately. Secondly, there is some concern that the green beads can be difficult to spot in fresh green vegetation so the sooner a quadrat can be set up the better. It is possible for a surveyor to return a day or so after a survey, but the concern would be that beads might be washed away or dry out and be more difficult to spot the longer time between application and monitoring. It is also beneficial to observe spreaders as there is potential for a ‘spreader bias’ to exist. Differences in spreading techniques can also be picked up on and could be useful in helping to improve monitoring or explaining results in the future.

Finally, accompanying and monitoring spreaders will be especially important because the hand application used on Black Hill is unlikely to be repeated in the same way. This makes it even more important for surveyors to continue accompanying spreaders so that we maintain an understanding of application processes.

The MoorLIFE team is looking to encourage students and volunteers to undertake research and projects on our sites to investigate *Sphagnum* occurrence further. MFFP are currently collaborating with Manchester Metropolitan University and University of Manchester to support a student project looking at the recolonisation of *Sphagnum* in relation to water tables.

Experience gained through the first three years of MoorLIFE vegetation monitoring has informed MFFP as to what issues might be encountered in the final year of the project, and has ensured that these are dealt with early on in our monitoring of newly treated areas. One issue for example, is the categorisation of grass species, and at what stages we categorise grasses as no longer being part of the nurse crop. In addition we are learning about the key species that are encountered in the Peak District and South Pennines, and the unusual species assemblages that can occur following disturbance. All of this information is helping to ensure our methodologies are suitable and effective for monitoring sites from their transition from bare peat, through the treatment stages and through successional stages towards more typical blanket bog assemblages.

Further actions under E2

- Vegetation surveys to be repeated across all sites in 2013 and 2014.
- Further *Sphagnum* transects will be undertaken on selected sites to provide baseline prior to application of propagules.
- As more sites are treated with *Sphagnum* propagules, more quadrats will be established to establish a more detailed baseline and to allow the future monitoring of establishment and success. Few of these surveys will be repeated, with the exception of Black Hill, which will have a repeat survey in late 2014/early 2015.
- Work is now underway to improve data processing and to enable efficient analysis of the large amounts of data generated by monitoring on such a landscape scale. These processes will be important in the efficient analysis of data following the final surveys in 2014 and will enhance the quality of the Project’s final monitoring report.

3 Action E3 – Monitor water table and carbon budget

3.1 E3 Introduction

The peat carbon cycle is a complex network of pathways of carbon loss and carbon sequestration (Worrall et al 2003). The MoorLIFE conservation works aims to reduce carbon loss by protecting areas of remaining active blanket bog in the South Pennines SAC. In addition, carbon losses could be avoided through raising water tables, revegetating bare peat, reintroducing *Sphagnum* species (an important carbon sequestering group of plants) and reducing erosion.

Water tables

An active blanket bog accumulates peat, and sequesters (stores) carbon. This process occurs because under the waterlogged conditions that characterize these habitats, the microbial process of decomposition of dead plant matter is inhibited.

The degradation of peatlands leads to water table lowering, which means that more oxygen can penetrate the upper layers of the peat profile. This speeds up the process of decomposition and enhances the breakdown of the organic material. This process results in an increase in a release of greenhouse gases such as carbon dioxide to the atmosphere.

There is evidence to suggest that gully blocking raises water table locally to individual gully blocks (Maskill *et al* 2012). Allot *et al* (2008) also collected preliminary data which suggests that revegetation leads to raised water tables. However there are very few studies that have monitored water table before, during and after works on severely degraded blanket peat.

Changes in water table height also have important consequences for the vegetation that occur on blanket bog (Lindsay, 2010). Drainage of blanket bog leads to plant communities dominated by more vascular plants and can have negative consequences for the more typical and specialized bog species. Re-wetting blanket bog can allow recolonisation of bog associated species, notably *Sphagnum* species. Therefore, as well as being important for the succession of vegetation from nurse crop to more typical blanket bog species, the raising and stabilization of the water table could be important factors in the success of *Sphagnum* bead applications being undertaken in Action C3 of the MoorLIFE project.

In addition, the lowering of the water table does not just occur in the areas of bare peat, but has been shown to occur over the plateau generally (Allott *et al* 2008). This means that the remaining areas of blanket peat are also at risk of water table drawdown, and susceptible to increased decomposition rates and oxidation of surface peat.

The MoorLIFE project is monitoring water tables to assess any changes that might occur while revegetation treatments take effect. The data gathered will be able to inform the succession of vegetation, the success of Sphagnum bead applications and answer the important questions of whether revegetation really does have an effect on average water tables or water table behaviour.

Erosion

Stabilisation of bare peat is a major objective of the MoorLIFE project. The continuing erosion of bare peat in the South Pennines presents a major threat to the remaining active areas of blanket bog. A summary of peat erosion rates measured using erosion pins is published in Holden *et al* (2007), with erosion rates of bare peat in the South Pennines being reported as being between 5.4 and 73.8 mm. Revegetation of bare and eroding peat has been shown to lead to decreased erosion rates (Evans and Warburton, 2005). Studies undertaken on Bleaklow have indicated that the carbon benefit of revegetation on Bleaklow is largely that of avoided loss (Worrall *et al* 2011).

POC and DOC content of water

Hydrologic loss of carbon in the form of particulate organic carbon (POC) and dissolved organic carbon (DOC) are important routes of carbon export from blanket peats. POC in particular has been shown to account for high proportions of carbon loss in several studies of degraded blanket bog catchments (e.g. Worrall, *et al* 2003), Pawson *et al* (2008) calculated that POC represented 80% of the fluvial export in one heavily eroded Bleaklow catchment.

Monitoring the carbon content of water leaving the catchments where work is taking place helps in the assessment of the relative loss of carbon from the peat systems and enables the monitoring of the impact of land management on this important component of the carbon cycle.

3.2 E3 Methods

Hydrological monitoring and analysis has been undertaken in collaboration with the University of Manchester.

Water table monitoring

Water tables are being monitored with the use of a combination of automated and manual dipwells, using a methodology developed by Allott *et al* (2008).

Manual dipwells are made using 1m lengths of 40mm plastic waste pipe, with holes drilled into the sides and the bottom covered with duct tape to prevent peat getting in. The pipe is sunk into the peat and water moving through the peat gradually fills the pipe to the level of the water table. The small open well allows for easy measurement of the water level inside using a length of flexible tubing. The tubing is inserted into the dipwell as a surveyor blows down and listens for bubbling (Figure 17). The point at which that bubbling is heard is the depth of the water. The length of pipe between the water and the top of the pipe is noted, and the length of the dipwell that is above the peat is then subtracted from this measurement to give the depth of the water table below the peat surface.

Figure 17 Measuring water table depth

Automated dipwells are made from WT HR 1000 capacitance probes from TruTrack. These are placed into plastic pipes of the same material as the manual dipwells, and the top covered over using duct tape. Ventilation holes are drilled into the approximately 30cm of pipe, containing the logging part of the capacitance probe. The capacitance probes are programmed to log water level every hour, and these provide a record of the temporal behaviour of water table.

Automated and manual dipwells are used together in dipwell 'clusters', consisting of one automated dipwell and fifteen manually measured dipwells within a 30 x 30 m area.

While the intensive hourly logging of water table allows the temporal behaviour to be assessed, the surrounding fifteen manual dipwells allow the variability of water table within a small area to be assessed. The manual dipwells are measured weekly during a 12 week campaign in the autumn months. Although the water table height varies, the temporal behaviour is broadly the same (i.e. responses to rainfall and drought).

Dipwell clusters have been installed across the four main works areas on Bleaklow, Black Hill, Rishworth Common and Turley Holes. Four restoration scenarios are represented: intact, late-stage restored, areas of bare, eroding peat in treatment areas, and areas of bare, eroding peat areas not undergoing treatment. These scenarios will allow a space-for-time analysis of the data collected from the monitoring programme to be undertaken. The intact areas and degraded, untreated areas, serve as reference sites by which to monitor changes to the water table in the treatment areas.

The sites where dipwells are located are described in Table 9.

Table 9 Summary of dipwell clusters across MoorLIFE sites. A cluster consists of one automated dipwell and 15 manual dipwells in a 30 x 30 m area.

Site	Bare peat reference	Intact reference	Late-stage restored	Treatment	Peat pan
Bleaklow	2	2	2	4	0
Black Hill	0	0	4	0	0
Rishworth Common	1	1	0	3	1
Turley Holes	1	1	0	3	1
Totals	**4**	**4**	**6**	**10**	**2**

Erosion

Rates of erosion were being monitored with the use of erosion pins using methods described by Evans *et al* (2006) and adapted for use on MoorLIFE sites. Clusters of 12 erosion pins were installed in autumn/winter 2010/11 situated in a 2 m x 2 m area adjacent to automated dipwells. These erosion pins were made from 50cm lengths of 4mm stainless steel rods, with the top bent round to form a hook. Erosion pins were marked near to the top and sunk into the peat to a depth of 10 cm from the tape.

It was found however that the erosion pins did not work as well as hoped and were found to be susceptible to disruption through the course of the capital works and also possible to frost heave. Therefore data collected from erosion pins has been deemed to be unsuitable for use in this project. Erosion rates on MoorLIFE sites will therefore use data collected from other MFFP projects using another methods of peat anchors – more substantial lengths of rod sunk into the peat and through to the bedrock. Data from these studies will be presented in the final MoorLIFE report.

Water quality

Water samples are taken from streams and gullies draining the restoration and reference sites. Tables 10 and 11 provide information on the sampling points, and locations are mapped in Figures 3 and 8. These catchments are a variety of sizes and included small headwater gullies as well as streams. Ease of access and the regularity of water flow were also important factors in the selection of catchments.

While reference catchments were also selected for each site, with one bare peat reference and an intact reference used wherever possible, due to the scale of the works and potential drift of aerially applied treatments, it was not always possible to find catchments that could be guaranteed to be totally free of any treatment.

Table 10 Summary of water sampling sites on Bleaklow

Site	Status	Notes
BL-BPR	Bare peat reference	Headwater site within untreated area of Bleaklow
BL-MBC	Treatment	Catchment drains large area of treatment site
BL-BC	Treatment	Catchment drains large area of treatment site
BL-Intact	Intact reference	Headwater site draining uneroded area of blanket bog

Table 11 Summary of water sampling sites on Rishworth Common

Site	Status	Notes
RC-BP-Ref-1	Bare peat reference	Headwater draining most of exclusion area – often dry
RC-BP-Ref-2	Bare peat reference	Downstream of A – drains part of exclusion area. Chosen for more reliable flow compared to headwater site.
RC-T1	Treatment	Headwater site
RC-T2	Treatment	Headwater site
RC-T3	Treatment	Larger catchment that drains large part of treatment area – chosen for more reliable flow compared to headwater sites
RC-Intact	Intact reference	Stream draining uneroded area of blanket bog

During the MoorLIFE Project, samples will be taken during two sampling programmes during the course of the monitoring programme, one taking place in autumn 2012, and the second in autumn 2014. The sampling campaigns take place in the autumn months as this is a critical period during which DOC is typically flushed from the blanket bog.

During the first campaign samples were analysed for TOC, DOC and POC by Scientific Analysis Laboratories, Manchester. In addition a portion of each water sample was filtered using syringe filters of pore size 0.45µm, and measured for absorbance at 400, 465 and 665 nm using a Jenway 7315 spectrophotometer at the Moors for the Future premises. The relationship between DOC and absorbance at 400nm will be characterized, and absorbance used to predict the DOC content of any future water samples. The other frequencies will be used to provide information about the type of organic carbon in the water.

During a second water sampling campaign set to take place in 2014, all samples will be tested for absorbance only. Differences in carbon content of the water will be used to assess whether the restoration works have had a noticeable impact on the amount of carbon being lost from the system.

3.3 E3 Results

The data and analyses presented in this section are selected to demonstrate what data has so far been collected, what will be available in 2015, and how it is intended to be analysed and presented. Since work is still being undertaken on many MoorLIFE sites it is not possible to carry out full analysis of the data. Full statistical analyses looking at differences before and after restoration will be presented in 2015.

Water table

To date, 26 automated dipwells have been installed across MoorLIFE sites, 24 are associated with manual dipwell clusters. The data collected from the manual dipwell campaigns across three sites are described here. Black Hill was set up later than the other sites, and so only data from 2012 is currently available.The data collected from selected automated dipwells on Bleaklow and Rishworth Common are also presented. Much of the analyses are qualitative, with work on statistical testing intended for data collected from once works across all sites have been completed and begun to take effect.

Water table is considered at three spatial scales:

- Cluster scale – how does the water table vary within an individual dipwell cluster of 30 x 30 m?
- Restoration scenario – how does the water table vary between the different restoration scenarios being monitored on Turley, Rishworth and Bleaklow?
- Between MoorLIFE sites – how does water table compare between Turley Holes, Rishworth Common and Bleaklow?

Water table within dipwell clusters

Figures 18 a, b and c below show the mean autumn/winter water table depth collected from individual manual dipwells in the 2011 and 2012 monitoring campaigns on three different types of restoration scenario.

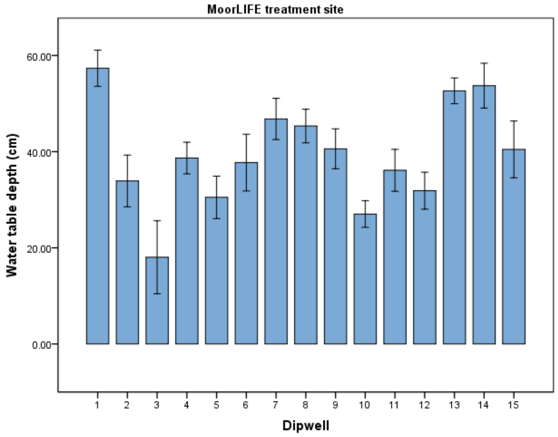
These graphs demonstrate that the water table at the cluster scale is variable, but indicates that the behaviour of water table in dipwells is consistent. Most dipwells have a similar degree of variation.

Water table within sites

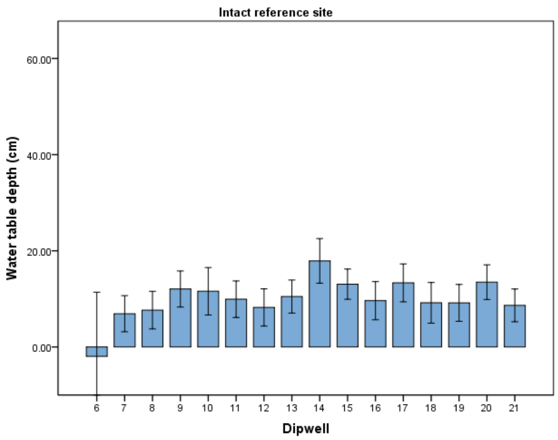
Across a site, water table also appears to vary considerably. Figures 19 (a), (b) and (c) below show the mean water table of dipwell clusters across sites in 2011 and 2012. These graphs show that:

- Water table in intact areas are high, and generally within the top 20cm of peat.
- The two peat pan areas on Rishworth and Turley also show very high water tables, that often measured at or above the soil surface.
- The degraded and highly eroded areas are generally very low, with mean water tables as low as 484mm below the peat surface at one cluster.
- On Bleaklow the late-stage treatment sites of Joseph Patch and Porter had lower water tables than the intact sites, but do not appear to have significantly different water tables to the degraded areas that are currently undergoing conservation works.
- All sites have noticeably higher water tables in 2012 compared to 2011.

(a)



(b)



(c)

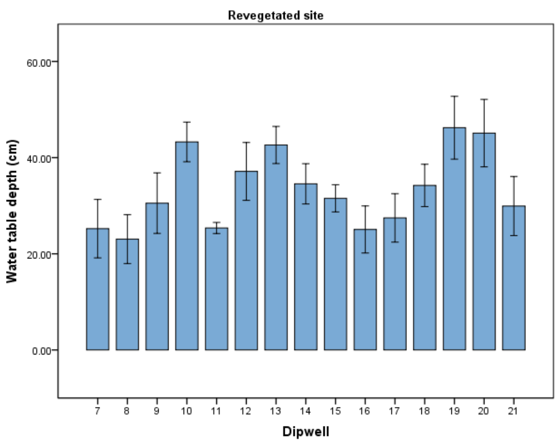
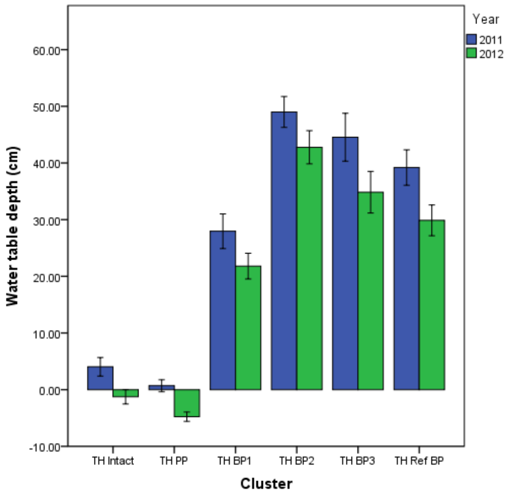
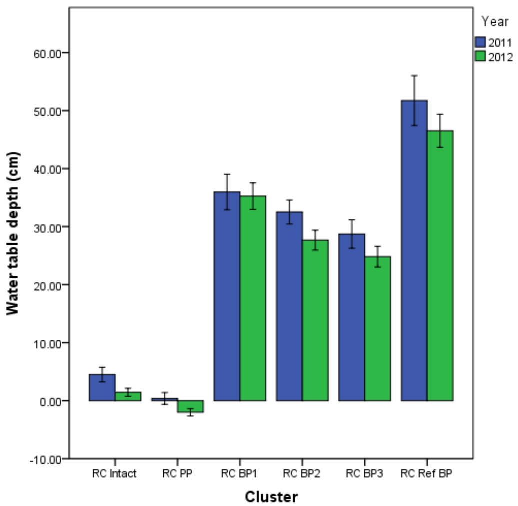


Figure 18 Mean autumn water table depth for individual dipwells in three dipwell clusters. Data was collected in the autumn months of 2011 and 2012 (a) an area of bare peat undergoing treatment in the MoorLIFE project (b) intact reference site (c) a revegetated site that was first treated 10 years previously. Error bars represent 95% confidence limits.

(a)



(b)



(c)

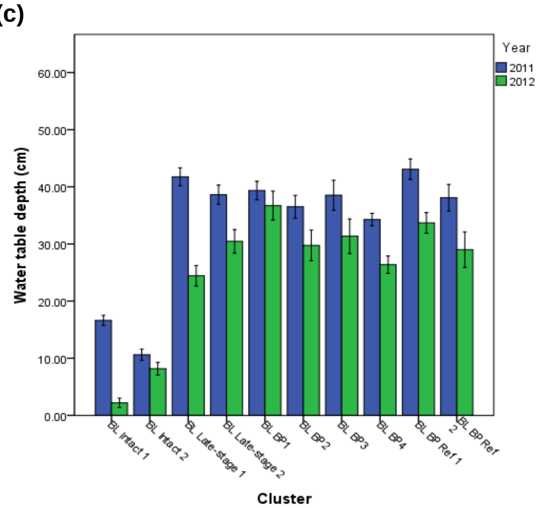


Figure 19 Mean water table depth of the different restoration scenarios on (a) Turley Holes, (b) Rishworth Common, and (c) Bleaklow. Error bars represent 95% confidence limits.

Between-site water table

When water table data from individual dipwells are grouped into restoration scenarios and compared between sites some broad patterns can be identified, Figure 20 shows the data gathered from the four sites in 2012. In particular that of intact sites and peat pans with very high water tables compared to those of degraded sites.

However, mean water tables of different restoration status' between sites are not consistent: for example, there appears to be differences between water tables of degraded sites on Bleaklow, Rishworth and Turley. There also appears to be a large difference in mean water tables between the late-stage restoration sites on Black Hill and Bleaklow.

The bare peat reference site at Rishworth Common has a much lower water table than the treatment sites. This site appears to be much lower than the other degraded sites (reference sites or early treatment sites).

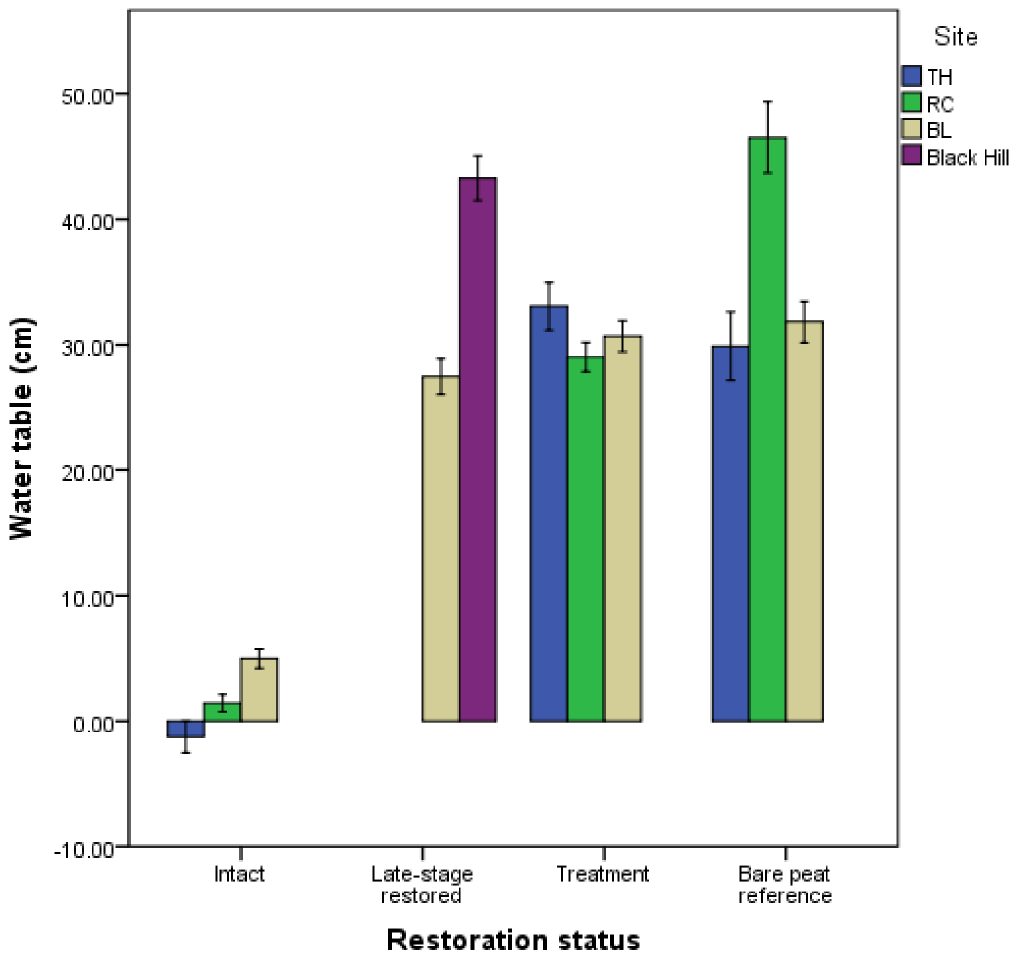


Figure 20 Mean autumn water table depth in 2012 across the four restoration types being monitored over the four MoorLIFE sites. Error bars represent 95% confidence limits.

Water table variability

For each day of water table measurements, the difference between the lowest and highest water table measurement was calculated for each dipwell cluster (i.e the range). The mean range, for each restoration status, is shown in Figure 21 as an example of the variation in water table. The graphs suggest that:

- Intact sites are shown to have the lowest mean variation in water table, and eroding sites have the highest variation.

- Late-stage restoration sites appear to have water tables that vary less than degraded sites.

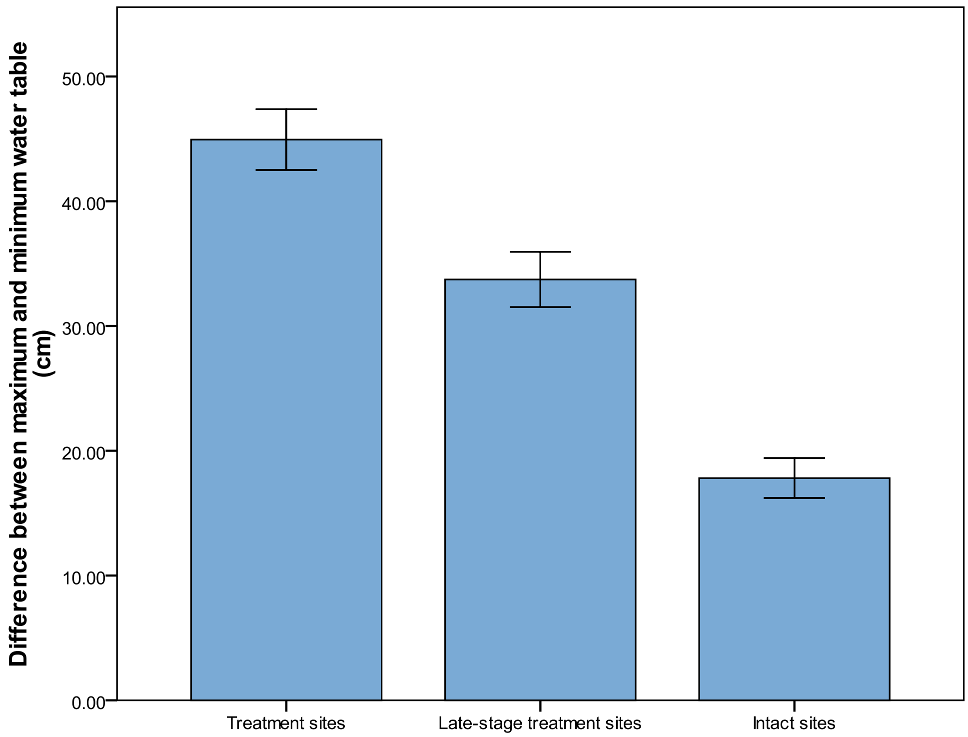


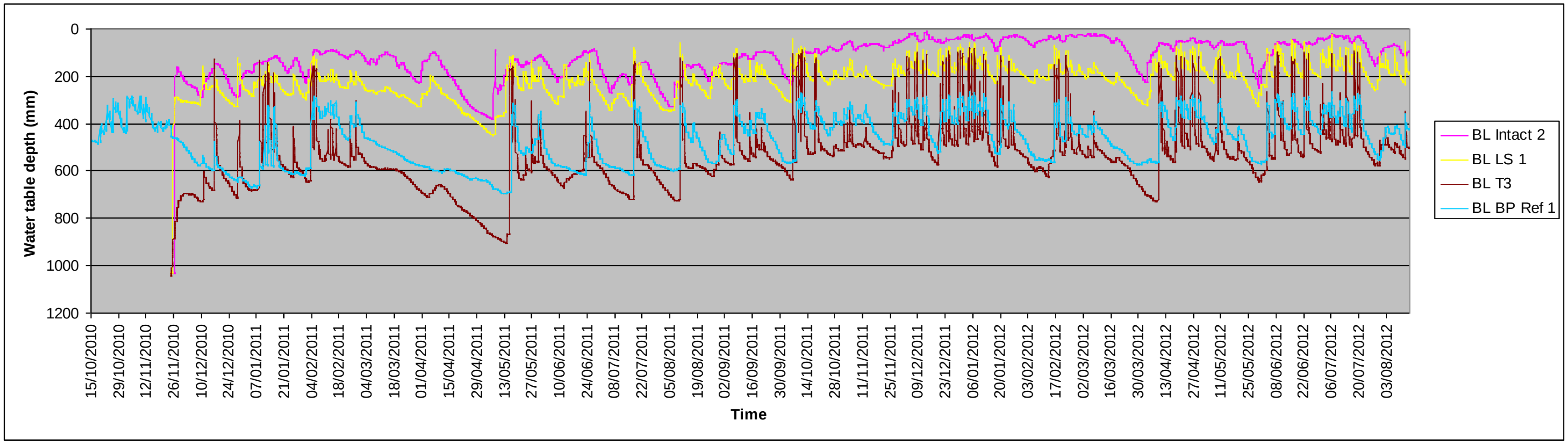
Figure 21 Mean difference between the highest and lowest water table measurements on Bleaklow, indicating that treatment sites vary more than both revegetated, late-stage restoration sites and intact sites.

Temporal behaviour of water tables

The time series of automated water table data for Bleaklow and Rishworth are shown in Figure 22 (a) and (b). The graphs demonstrate the variability of water tables within a site and between different restoration scenarios. The more hydrologically intact areas have water tables that remain near the peat surface and that tend to be more stable than those in more degraded, un-vegetated areas.

The severely degraded areas of blanket bog have water tables that tend to be relatively lower in the peat profile.

(a)



(b)

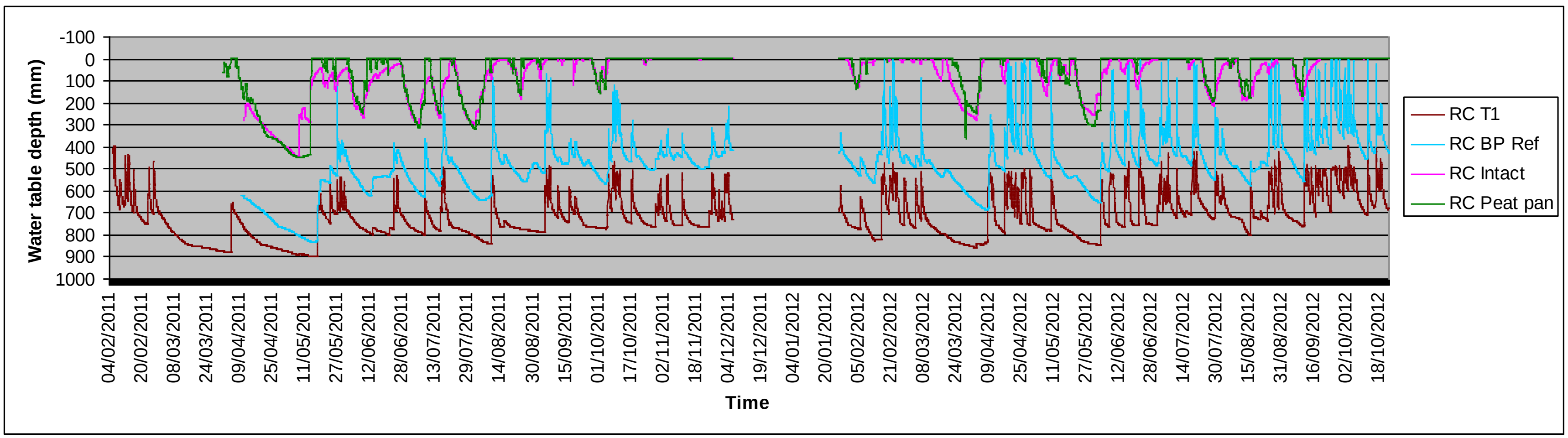


Figure 22 Time series of water table depth measured by automated dipwells on (a) Bleaklow and (b) Rishworth Common. LS refers to late-stage restoration sites, T refers to treatment sites, and BP Ref refers to an untreated area of bare peat being used as a reference site.

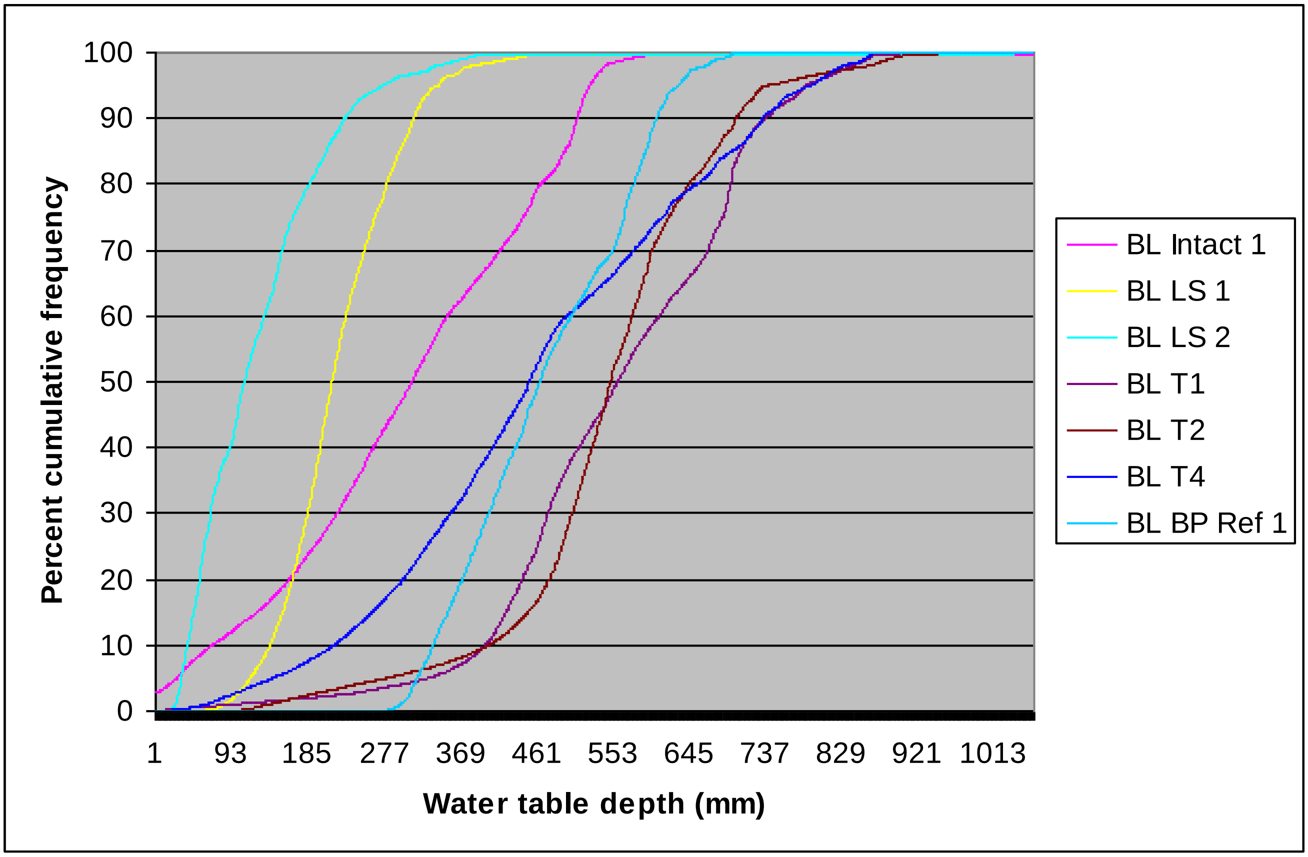


Figure 23 Cumulative frequency curve of water table on Bleaklow, showing the proportion of time water table spends at each depth. Graphs indicate the proportion of time the water table is higher than each water table depth. LS refers to late-stage restoration sites, T refers to treatment sites, and BP Ref refers to an untreated area of bare peat being used as a reference site.

The cumulative frequency graph in Figure 23 has been constructed using the data collected from 8 of the 10 automated dipwells on Bleaklow.

The graph shows that:

- While the intact site, SH, fluctuates, it is always within the top 400mm of the peat. Its steep gradient indicates that it is less variable than all the other sites as it covers a smaller range of water table depths.

- Site JP, a late-stage restoration site, has a similar gradient – indicating a relatively low degree of water table fluctuation when compared to the six degraded and unrestored sites. It does, however, occupy a position between that of the degraded sites and the intact. The graph indicates that the water table at JP never reaches the surface.

- PO is also a late-stage restoration site of a similar age to JP. With its shallower gradient, the water table at PO appears to occupy a wider range of depths than JP, but generally, the water table is generally higher than that of the early treatment/unrestored sites.

The mean water table depths as calculated from the automated dipwell data are shown in Figure 24. These means differ from the autumn water table depths as they are calculated from points collected through all seasons and over a two year period.

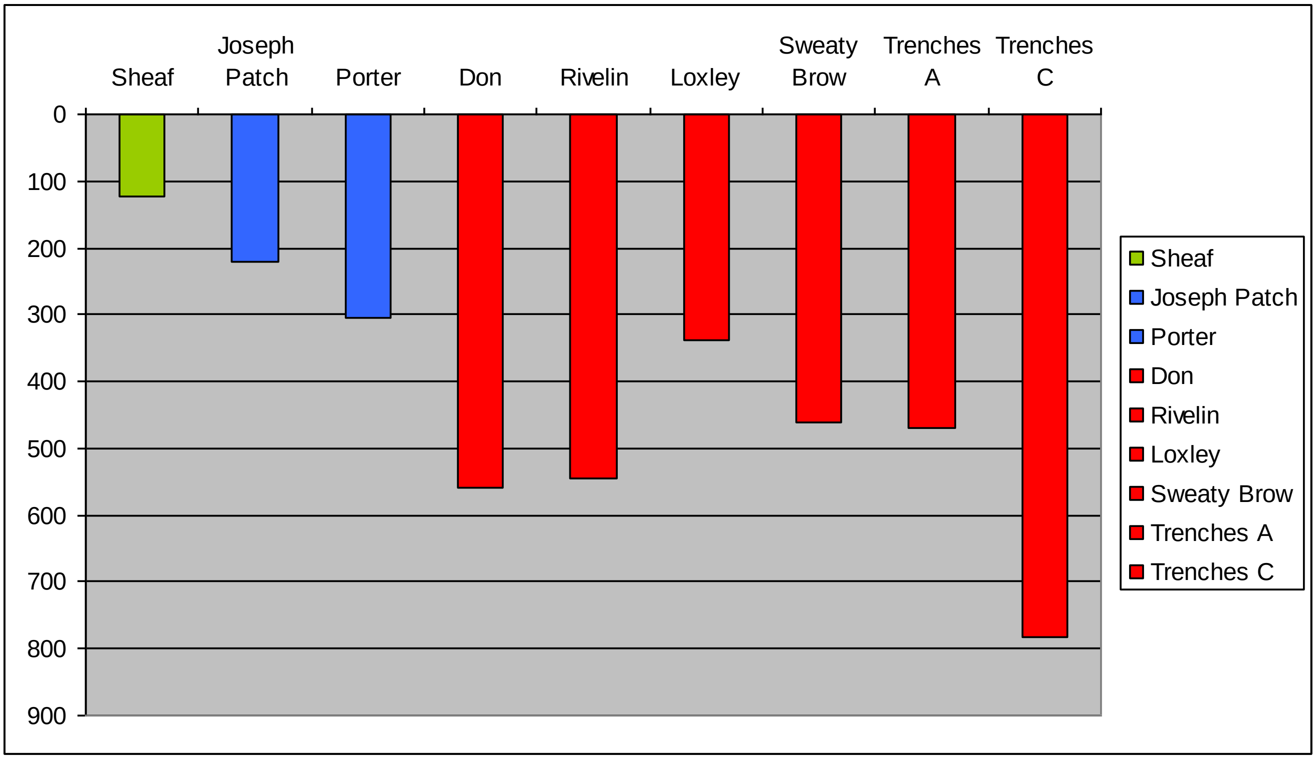


Figure 24 Mean water table calculated from hourly water table measurements taken over a 2 year period on Bleaklow.

This data suggests a pattern of the degraded sites, shown in red, with low mean water tables, intact sites having a high water table, and the late-stage restored sites having an intermediate water table. The variation in the mean water table of degraded sites is again demonstrated, although this has not been statistically tested at this stage.

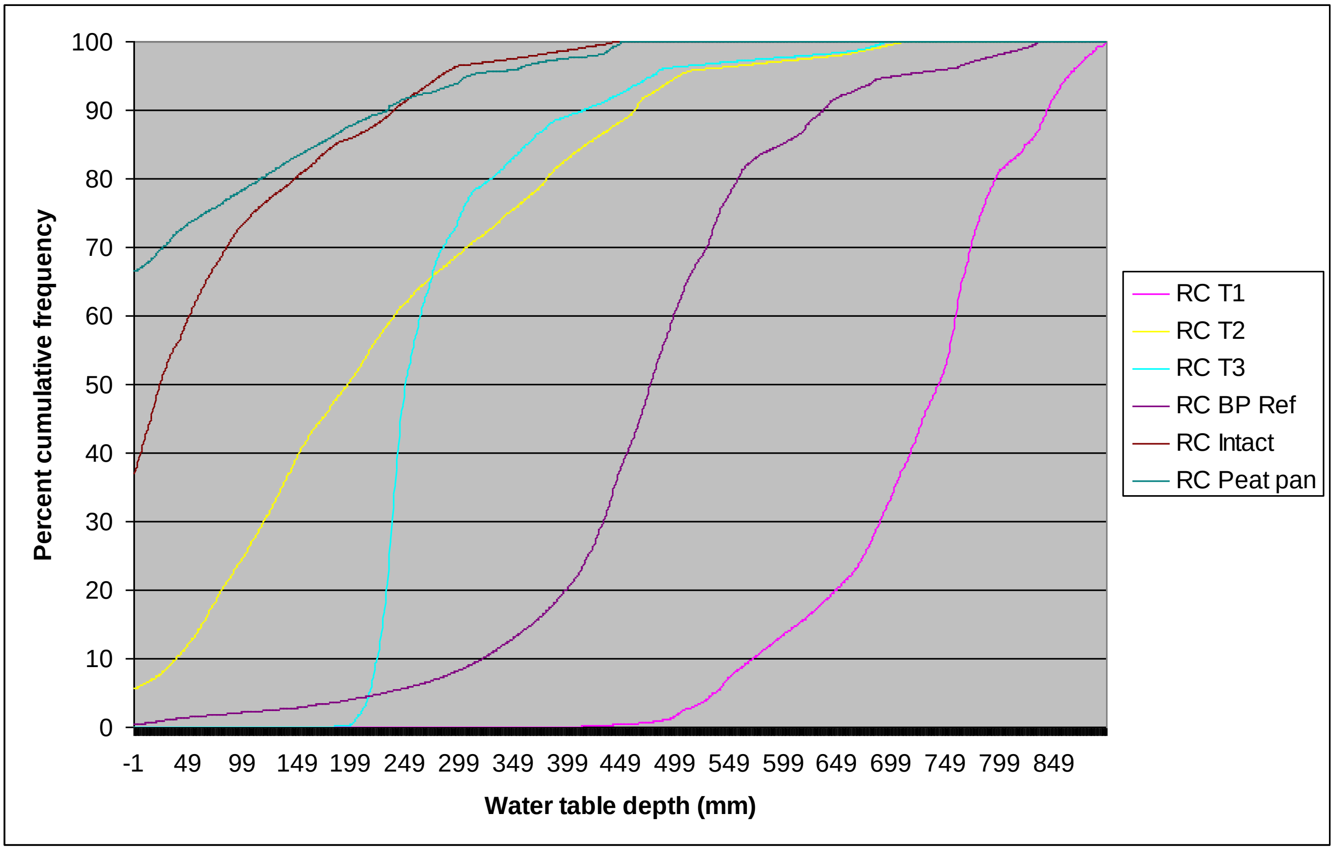


Figure 25 Cumulative frequency curves for water table on Rishworth Common. Graphs indicate the proportion of time the water tale is higher than each water table depth. T refers to treatment sites and BP Ref refers to an untreated area of bare peat being used as a reference site.

Similarly, the cumulative frequency graph (Figure 25) for the six Rishworth water tables shows that:

- Water table depths varies across the site.
- The water table at the peat pan areas and intact areas behave similarly, with water tables in the top 20cm of the peat nearly 90% of the time.
- The areas of bare peat have low water tables, and between these areas, water table appears to vary considerably, and to generally occur lower down in the soil profile.

Water quality

Table 12 shows the number of catchments per site, and the number of samples collected per site so far. Bleaklow has the most samples as we were able to collect samples throughout the year. The other three sites had sampling campaigns concentrating on the autumn/winter months, to coincide with the manual dipwell campaigns. Altogether, 292 water samples have been taken to date.

Table 12 Summary of water samples taken from each MoorLIFE sites

Site	Number of catchments sampled	Number of samples collected up to December 2012	Time period
Bleaklow	4	117	Oct 2011 – Dec 2012
Turley Holes	4	64	Feb-Mar 2012, Sept-Dec 2012
Rishworth Common	6	99	Feb-Mar 2012, Sept-Dec 2012
Black Hill	4	38	Sept-Dec 2012

Bleaklow water quality

The data from over a year of water sampling on Bleaklow have been analysed. Kruskal-Wallis tests indicate that there are significant differences in water quality between different catchments on Bleaklow in terms of DOC concentration ($H=10.37$, $p < 0.05$), POC concentration ($H = 19.78$, $p < 0.001$) and colour in Hazen ($H=17.49$, $p < 0.01$).

On Bleaklow, the water draining the bare peat reference site (BL-BP-Ref) has the highest level of POC, with a median concentration of 5 mg/l. This concentration is significantly higher than the other three sites (BL-BC, $Z = -2.90$, $p < 0.05$); BL-MBC, $Z = -2.815$, $p < 0.05$; BL-Intact, $Z = -3.63$, $p < 0.001$). Most samples (82%) contained detectable levels of POC suggesting that levels of erosion on this site are higher than the other catchments (Figure 26).

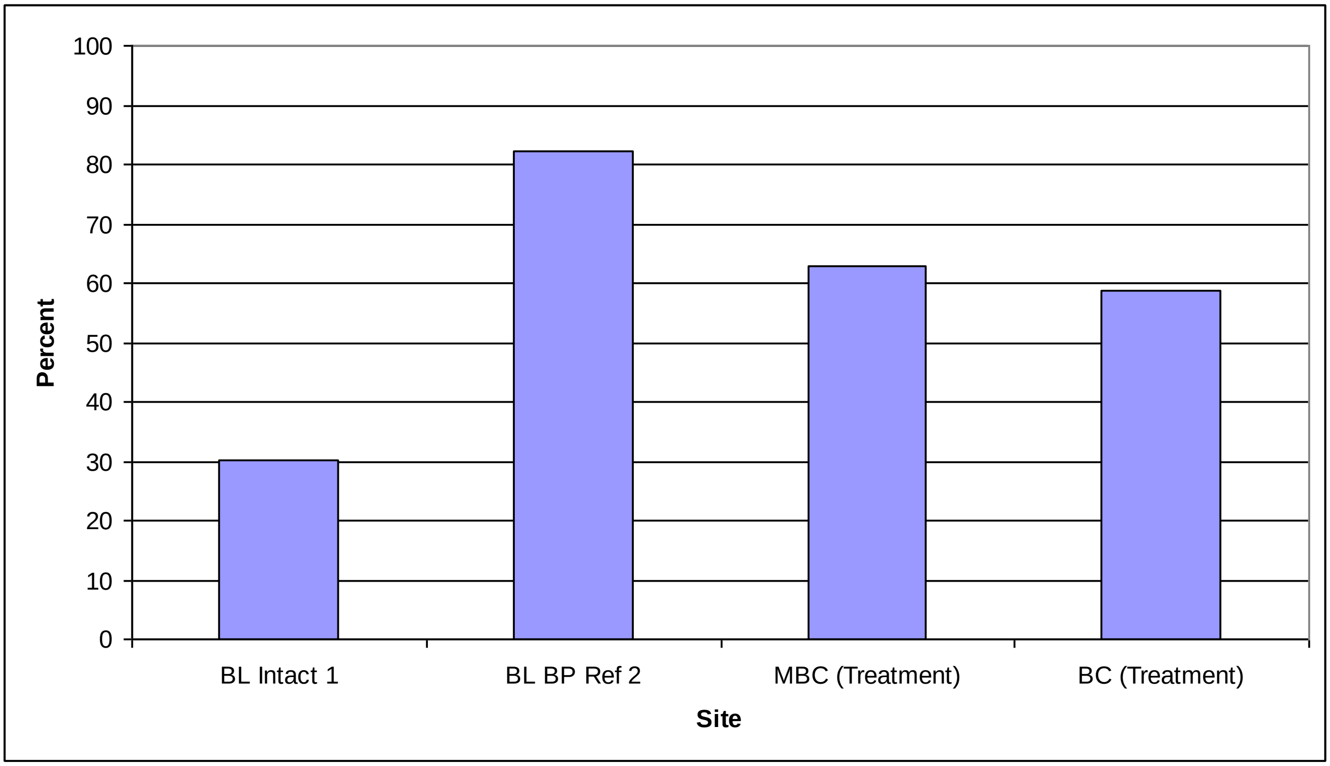
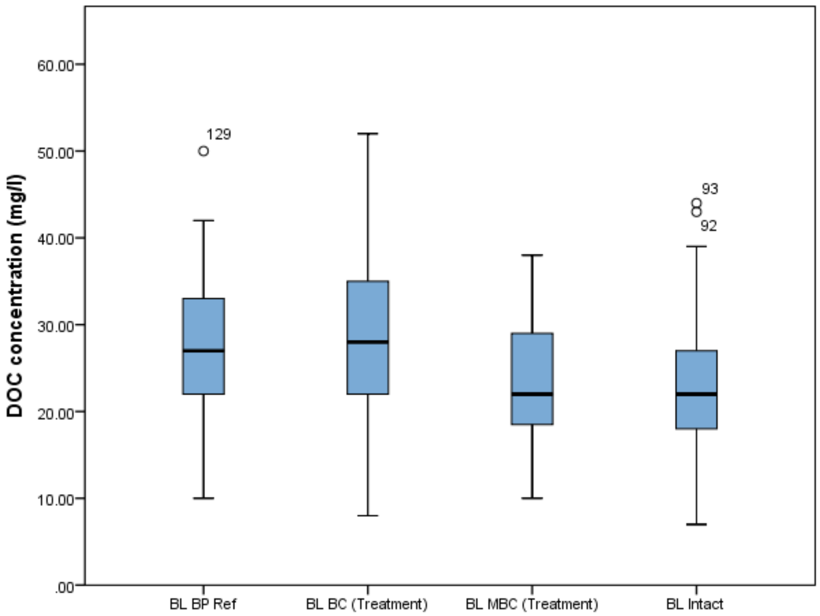


Figure 26 Proportion of water samples containing detectable levels of POC. BL-Intact-1 and BL-BP-Ref-2 are sites being monitored as reference sites for comparison of treatment areas. MBC and BC are two streams draining the Woodhead area of Bleaklow.

In addition, BL-BP-Ref has high levels of DOC (median 27 m/g) and colour (710 Hazen units). BL-BC shows similarly high levels of DOC and colour (28 mg/l and 700 Hazen units respectively). Figure 27 shows DOC concentrations and colour levels of Bleaklow catchments.

(a)



(b)

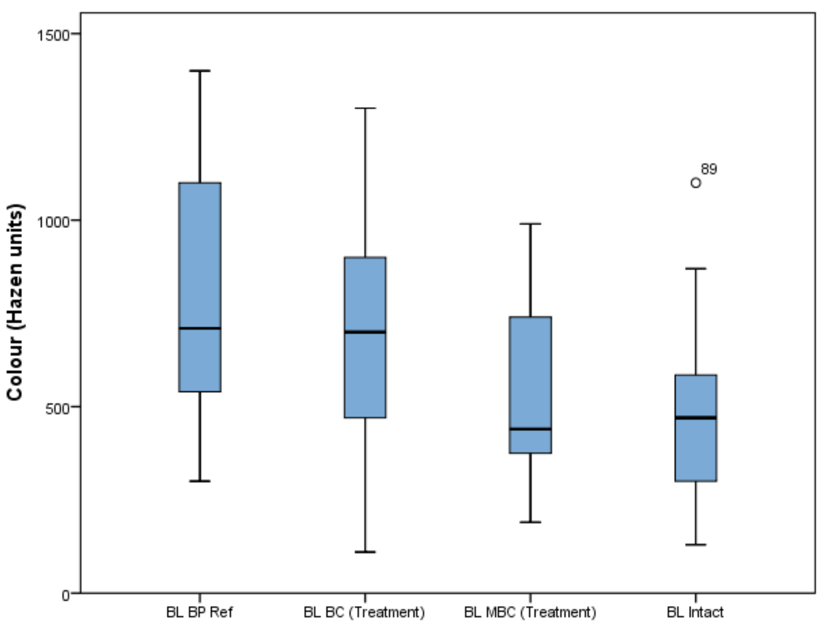


Figure 27 DOC concentration and colour in Hazen units of catchments draining Bleaklow catchments draining MoorLIFE restoration areas and untreated reference sites. Refer to Table 2 for site codes.

BL-BC, having similar DOC and colour levels to BL-BP-Ref, has a level of quality between that of the bare peat reference site and the second treatment catchment, BL-MBC. BL-MBC has significantly lower concentrations of DOC (22 mg/l, $Z = -2.73$, $p < 0.05$) and colour (440 Hazen units, $Z = -2.30$, $p < 0.05$) then BL-BC. But the two treatment catchments contain similar concentrations of POC (both 1 mg/l), and samples collected from the catchments contain detectable levels of POC in more than 50% of samples.

The intact reference site, BL-Intact, does not have statistically different concentrations of DOC or colour to MBC. It does have significantly lower concentrations of POC than each of the other three sites, with a median of 0 mg/l and only 30% samples containing detectable levels.

Seasonal variation of water quality on Bleaklow

Figure 28 shows the variation in DOC from the Bleaklow sites throughout 2011 and 2012. The graph clearly shows the seasonal variation of DOC concentrations. DOC in all four catchments can be seen to increase steadily from January 2012 and reaches a peak in late August 2012. The red hatched area indicates the approximate time of the first lime treatment of the catchment areas of the water sampling points in May 2012.

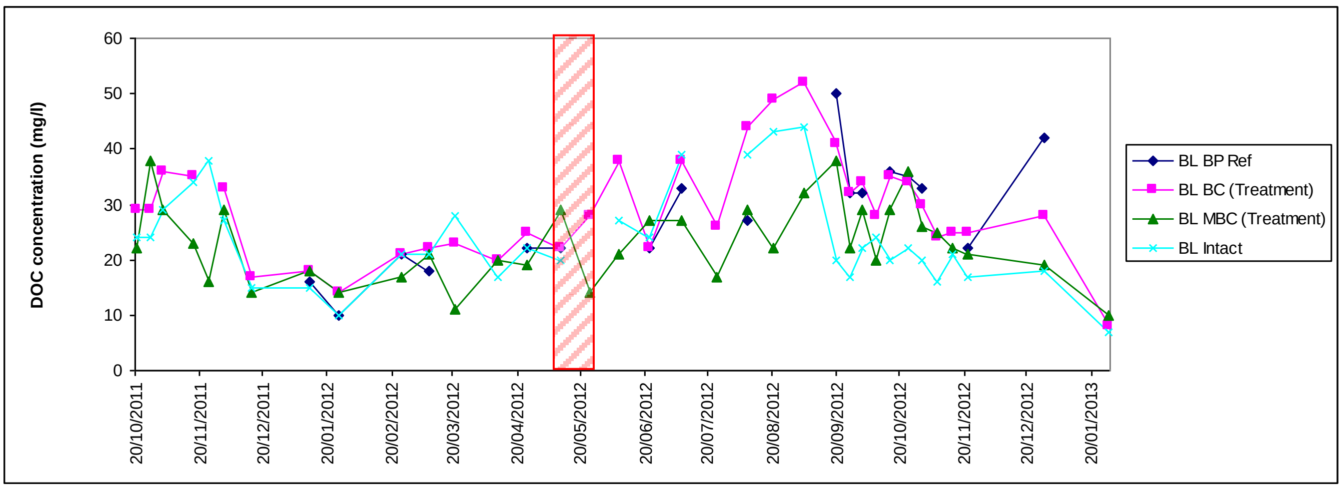


Figure 28 Annual variation in DOC concentrations of Bleaklow catchments draining MoorLIFE restoration areas and untreated reference sites. The red hatched area shows the approximate period of lime application on Bleaklow.

An interesting pattern following the liming treatments is the apparent departure of BL-MBC DOC concentration from the patterns of the other three sites. Where DOC concentrations at BL-BC, BL-Intact and BL-BP-Ref appear to follow a similar size and rate of increase, DOC concentrations in BL-MBC appeared to increase more slowly and to a lower level. DOC in BL-MBC returns to a similar level to the other three sites by October 2012 – approximately 5 months following treatment.

Water samples were also tested for their absorbance at 400nm, 465nm and 665nm. Figure 29 shows the relationship between DOC and absorbance at 400nm, with a strong positive relationship evident. However there is some apparent drift in the relationship for BL-BP-Ref and further investigation is required to determine why this is. Possible reasons are age of samples or possible disturbance prior to sampling.

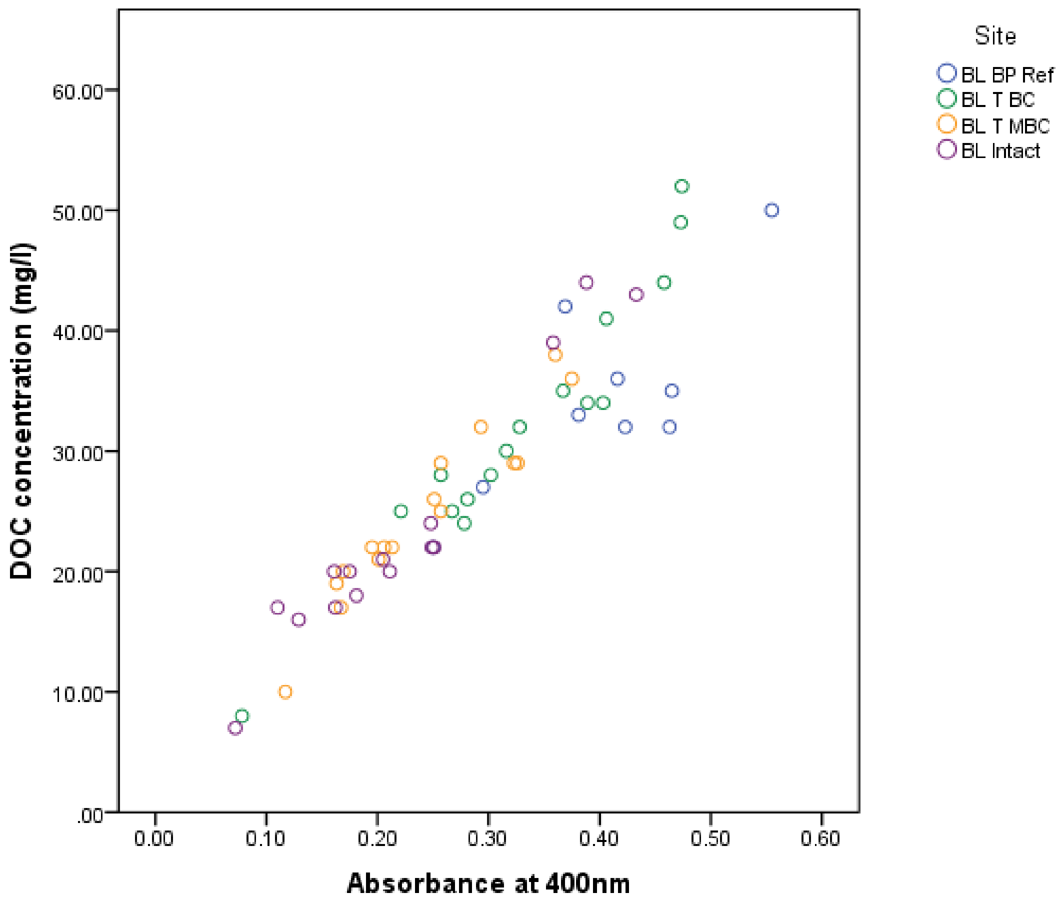


Figure 29 Relationship between DOC concentration and Absorbance at 400nm. Refer to Table 10 for site codes and restoration status.

Rishworth Common

Data from Rishworth Common is from the autumn/winter period of 2012, as such figures represent only autumn concentrations rather than annual. The sampling took place after the autumn flush event that is evident in the Bleaklow data.

A Kruskal-Wallis test indicates strong significant differences in water quality among the sampling points. Significant differences are found in DOC ($H = 34.85$, $p < 0.001$), POC ($H = 12.88$, $p < 0.05$) and colour ($H = 31.70$, $p < 0.001$). The graphs of DOC and colour in Figure 30 (a) and (b) indicates that the main difference is in the intact site and this is supported in the post-hoc testing (Mann-Whitney U tests), the results of which are presented in Tables 4.5, 4.6 and 4.7.

The highest DOC concentrations and colour levels are found at sampling points TC-T1 (32 mg/l, 1045 Hazen units), RC-BP-Ref-1 (37 mg/l, 1000 Hazen units) and RC-BP-Ref-2 (32.5 mg/l, 960 Hazen units). Sites RC-T2 and RC-T3 showed statistically similar levels of DOC (both 29 mg/l) and colour (695 Hazen units and 825 Hazen units respectively.) The intact reference site, RC-Intact, showed relatively low levels of DOC and colour (11 mg/l and 250 Hazen units).

Table 13 Test statistics (Z values) from post-hoc (Mann-Whitney U) testing of DOC concentrations from water samples taken from Rishworth Common. Signficance levels: *0.05, **0.01, ***0.001.

	RC-BP-Ref-2	RC-T1	RC-T2	RC-T3	RC-Intact
RC-BP-Ref-1	-1.694	-0.790	-2.472*	-2.506*	-4.035***
RC-BP-Ref-2		-0.308	-1.390	-1.361	-4.101***
RC-T1			-0.931	-1.300	-4.066***
RC-T2				-0.410	-4.166***
RC-T3					-3.938***

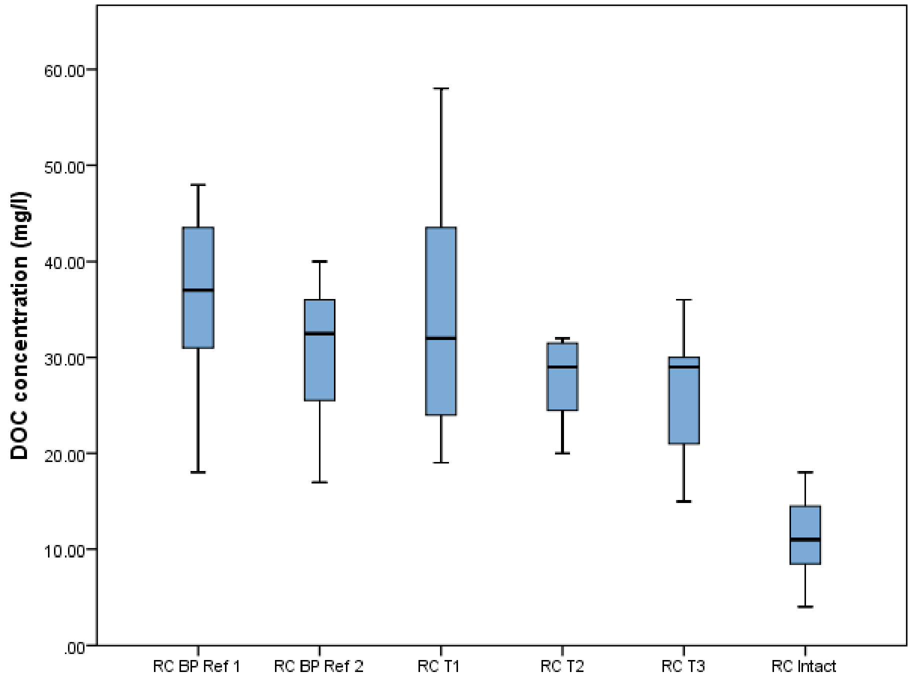
Table 14 Test statistics (Z values) from post-hoc (Mann-Whitney U) testing of water colour (Hazen units) from water samples taken from Rishworth Common. Signficance levels: *0.05, **0.01, ***0.001.

	RC-BP-Ref-2	RC-T1	RC-T2	RC-T3	RC-Intact
RC-BP-Ref-1	-0.309	-0.772	-2.005*	-1.238	-3.637***
RC-BP-Ref-2		-1.187	-2.314*	-1.100	-3.872***
RC-T1			-2.139*	-1.621	-3.991***
RC-T2				-1.387	-3.612***
RC-T3					-3.960***

Table 15 Test statistics (Z values) from post-hoc (Mann-Whitney U) testing of POC concentrations from water samples taken from Rishworth Common. Signficance levels: *0.05, **0.01, ***0.001.

	RC-BP-Ref-2	RC-T1	RC-T2	RC-T3	RC-Intact
RC-BP-Ref-1	-0.699	-0.836	-0.496	-2.026*	-1.500
RC-BP-Ref-2		-0.182	-2.076*	-1.325	-0.651
RC-T1			-1.407	-1.451	-0.787
RC-T2				-3.386***	-2.597*
RC-T3					-0.632

(a)



(b)

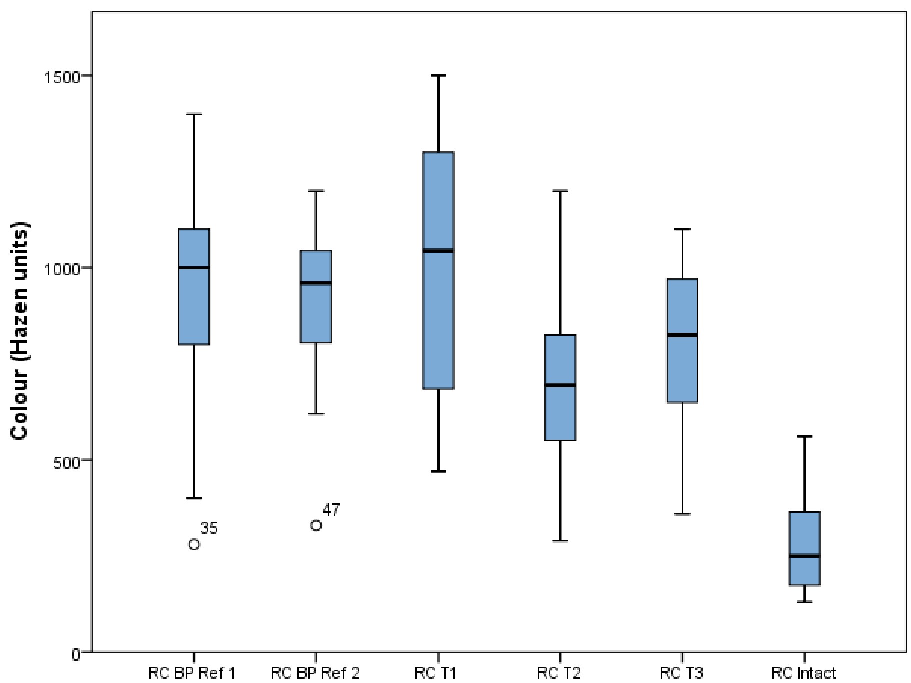


Figure 30 DOC concentration and colour in Hazen units of catchments draining Bleaklow catchments draining MoorLIFE restoration areas and untreated reference sites. Refer to Table 11 for Rishworth site codes.

POC concentrations were highest in RC-BP-Ref 1 and RC-T2, both with medians of 5 mg/l, followed by sites RC-BP-Ref-2 and RC-T1 (both 1.5 mg/l). Sites RC-T3 and RC-Intact had medians of 0 mg/l. The proportion of samples that contained detectable levels of POC also varied across sites and are summarized in Figure 31.

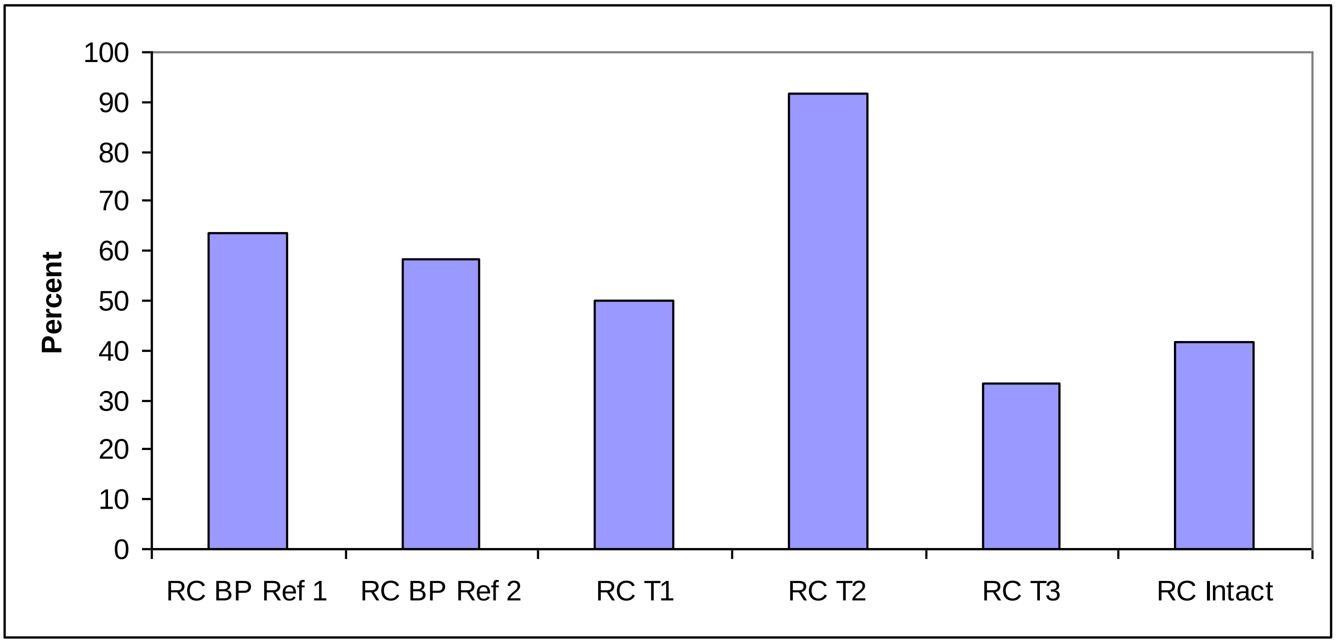


Figure 31 Proportion of samples from Rishworth Common containing detectable levels of POC. BP Ref indicates untreated, bare peat reference sites, T indicates treatment sites. See Table 11 for more information regarding Rishworth site codes.

Examination of the time series for water quality on Rishworth Common shows little variation over the 12 week period (Figure 32), and confirms that data were collected following the autumn flush. The six sites show a range of DOC concentrations that still require further investigation – but again the intact reference site DOC concentration is consistently below that of all the other sites.

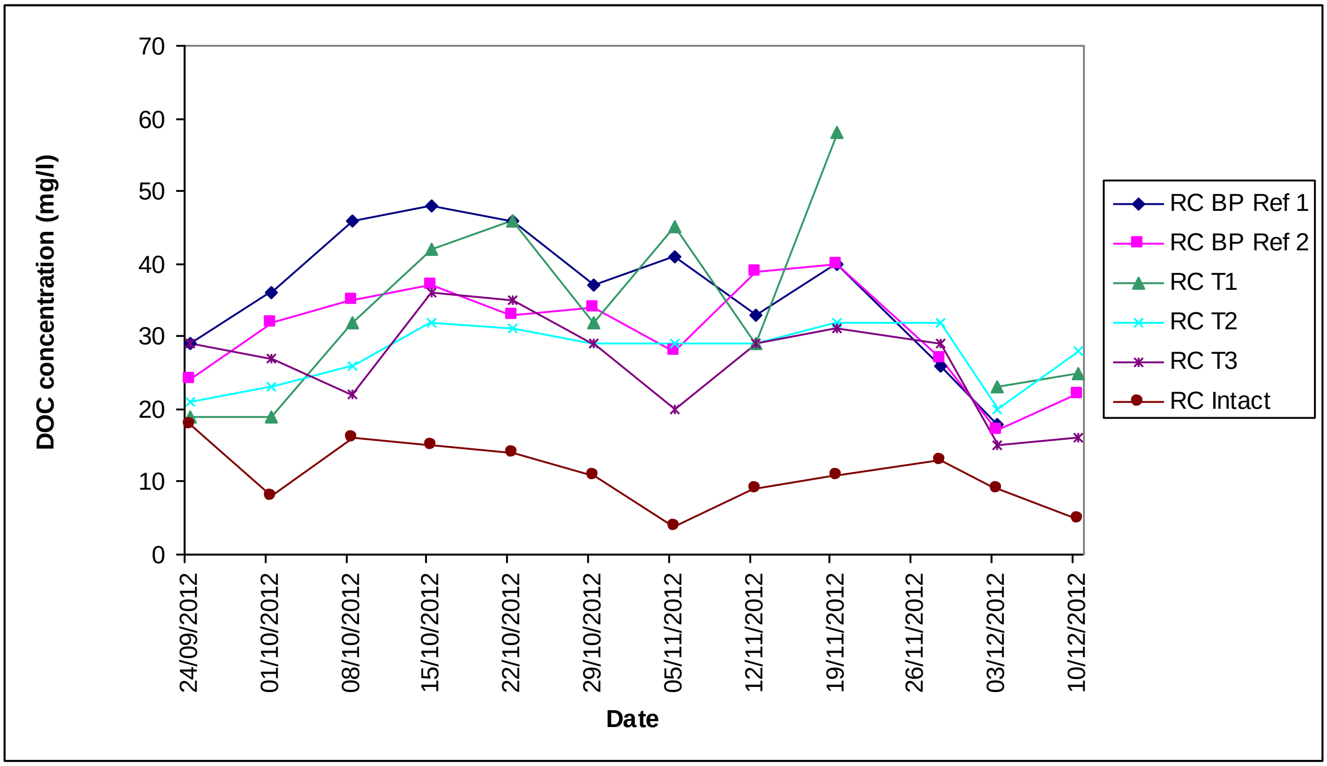


Figure 32 DOC concentrations of water samples taken from Rishworth Common in autumn 2012

The relationship between DOC and absorbance at 400nm again is strong and positive, with less drift than Bleaklow. Spread of data points reflects the range and variation in water quality seen in water samples. The intact reference site appears to exhibit strong clustering and does not overlap with the other sites.

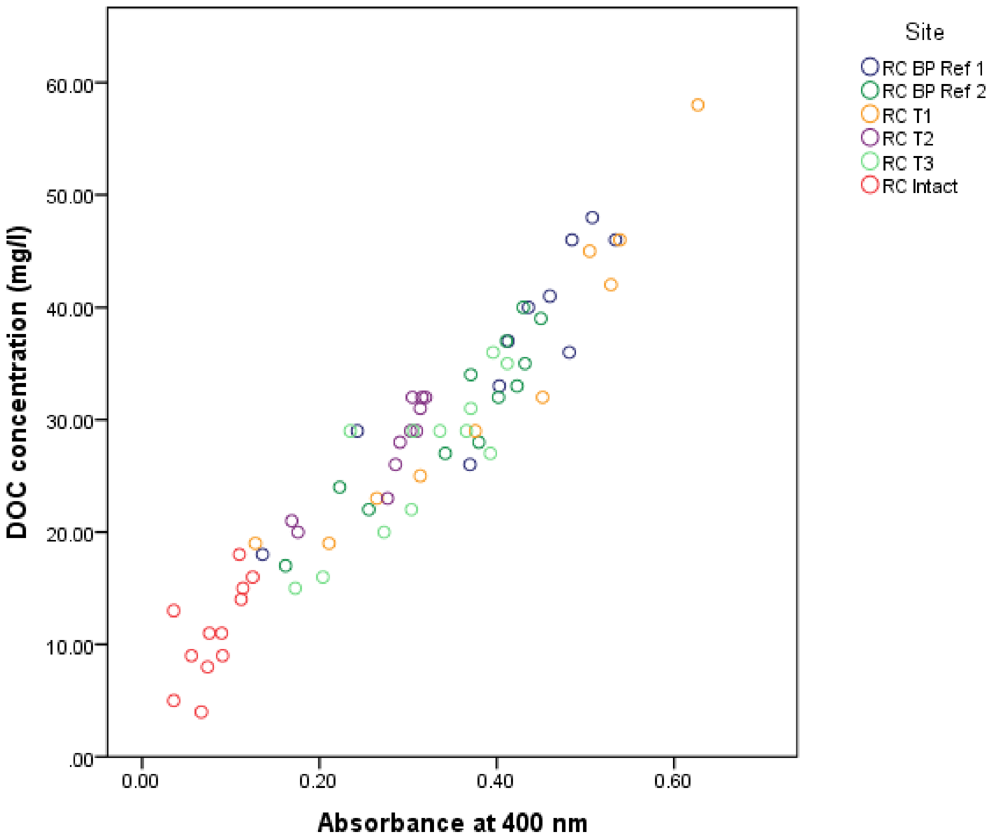


Figure 33 Relationship between absorbance at 400nm and DOC concentration of water samples taken from Rishworth Common

Water quality results summary

The relative conditions of water quality for each sampling point on Bleaklow and Rishworth Common is summarized in Tables 16 and 17.

Table 16 Relative water quality of samples taken from Bleaklow. Water quality is indicated in relation to the other samples taken at the same time. Red indicates where levels are worst, orange indicate lower concentrations, green indicates the best conditions. Refer to Table 10 for details of sampling points.

Sample point	Status	DOC concentration	Colour	POC concentration	% samples containing POC
BL-BP-Ref	Bare peat reference				
BL-BC	Treatment				
BL-MBC	Treatment				
BL-Intact	Intact reference				

Table 17 Relative water quality of samples taken from Rishworth Common in autumn 2012. Water quality is indicated in relation to the other samples taken from the site at the same time. Red indicates where levels are worst, orange indicate lower concentrations, green indicates the best conditions. Refer to Table 11 for details of sampling points.

Sample point	Status	DOC concentration	Colour	POC concentration	% samples containing POC
RC-BP-Ref-1	Bare peat reference				
RC-T1	Treatment				
RC-BP-Ref-2	Bare peat reference				
RC-T2	Treatment				
RC-T3	Treatment				
RC-Intact	Intact reference				

3.4 E3 Discussion

Water tables

The MoorLIFE project represents the first water table monitoring on MFFP sites that has been undertaken prior to, and during conservation works. It will enable a before-and after-treatment comparison of water table condition. The dipwell clusters of automated and manual dipwells have proved effective in characterizing the spatial and temporal behaviour of water tables on MoorLIFE sites. The water table data is extremely noisy and variable. This reinforces the recommendation of Allott et al (2008) to install and measure several dipwells within a small area to give a reliable estimate of water table depth and therefore detect any changes that might occur following restoration works.

Qualitative analysis of the data collected so far by MoorLIFE does indicate that there are important differences in mean water table and the degree to which water tables vary in space and fluctuate over time.

A clear and consistent pattern emerging from the data is the large difference in mean water table and water table variability between intact and gullied areas of blanket bog. Intact areas typically have very high mean water tables with low spatial and temporal variability. In contrast gullied areas have very low mean water tables and a high degree of variability. These findings are consistent with those found in the 2008 Water Table report (Allott et al), which found links between average water tables and erosion status.

The data also shows that areas of degraded blanket bog that are characterized by peat pans have very similar water table patterns to intact areas, with relatively little spatial or temporal variation.

The earlier work on water tables collected preliminary data on a small number of sites and suggested that restoration of bare peat by re-vegetation raises water tables. The monitoring of additional dipwell clusters on late-stage restoration sites by the MoorLIFE project allows further investigation of these patterns of water table on sites treated ten years ago.

The data collected over nearly two years of hourly water table measurements suggests that the annual water table does sit somewhere between that of intact and unvegetated sites. In addition, the water table at two late-stage restoration sites on Bleaklow that are monitored with automated dipwells appear to be situated higher up in the peat profile than most of the unvegetated sites.

The time-series of water table data supports the idea of three different types of behaviour as broadly set out in Allott et al, 2008:

I. Water tables predominantly close to the ground surface (median water table < 150mm) with occasional drawdown events during periods of dry weather.
II. Water tables predominantly fluctuating between depths of 100 and 250 mm with occasional deeper drawdown events during periods of dry weather.
III. Water tables predominantly very low (median water table < 400mm) with occasional wet-up events during rainfall.

Of the time-series presented here, Sites SH and RC-I, the two intact sites appear to fall into the Type I category, as does the peat pan site on Rishworth (RC-PP). The late-stage restoration site, JP falls into Type II, and the other eroded sites, RI and TA on Bleaklow, and RC-BP1 and RC-BP-Ref on Rishworth, fall into Type III. Further analysis of the other auto-dipwell time-series needs to be undertaken to determine if all sites can be categorized in this way.

However, the noise within the water table data means it is difficult to make a simple assessment of water table conditions in different restoration scenarios. Much of the spatial variation in mean water table is likely to be linked to topographical differences between individual dipwells, and between clusters and sites. At the scale of a dipwell cluster there is surface variability of hummocks and hollows that is typical of peatland habitats. At degraded sites there is the additional effect of erosion gullies, which influence water table locally at the gully edge, and contribute to lower water table at a wider landscape level (Allott et al 2008).

The dipwell clusters that are part of the MoorLIFE project have a range of different topographical settings that should be taken into account in the final analysis of water table condition. Some of the different topographical settings can be seen in Figures 34 to 36.

Figure 34 Dipwell cluster at site BL-BP-Ref – an untreated bare peat area.

Figure 35 Dipwell cluster and gully blocks at site BL-T1 on Bleaklow.

Figure 36 Dipwell cluster at site BL-T3. These dipwells are in islands of peat surrounded by large areas of mineral soil.

No statistical analyses of the water table data has yet been carried out and more work is required to investigate these relationships further. The final MoorLIFE report will undertake appropriate statistical analyses to investigate differences in water table depth and behaviour before and after revegatation works. It is likely that several more years of post-works monitoring will be required to begin to adequately answer this question.

Another important aspect of water table behaviour is the response to rainfall. The data suggests that water tables were significantly higher in 2012 than in 2011, and this is likely to be because of the extremely wet weather conditions. Environment Agency hydrological reports indicate that rainfall in 2012 was above average (EA, 2013). Rainfall data is not collected within MoorLIFE, but there are several other projects where it is monitored. This data will be incorporated into water table data to help understand water table in relation to input from rainfall, so providing added value to the MoorLIFE data.

Raised, stabilized water tables could be important for the succession of nurse crop to more typical blanket bog species. Several studies have associated a rise in water table with the recolonisation of bog-associated plants, notably *Sphagnum* species (Haapalehto, 2010).

While monitoring over time is the key objective of the MoorLIFE monitoring programme, the space-for-time analysis such as the one presented in this mid-term report is also beneficial as it can inform MFF as to when observable results might expect to be seen in the monitoring programme. It can also give an indication of what the impacts of earlier restoration work has had, as well as providing context for the MoorLIFE treatment sites.

Water quality

The data gathered on the carbon content of water courses draining MoorLIFE sites has helped to establish a baseline to which water quality post-works can be compared. Through this process spatial and seasonal patterns of water quality are also being characterized and this is informing our general understanding of carbon loss from South Pennines blanket bog.

Characterisation of the relationships between absorbance and DOC will allow for assessments of DOC concentrations post-restoration, both in 2014 during the final sampling periods within the MoorLIFE project, and beyond.

Tables 4.8 and 4.9 summarise the relative quality in terms of carbon for the sampled catchments on Bleaklow and Rishworth. On both sites, the bare peat reference sites tend to be the worst when all three variables of DOC, colour and POC are considered. The water quality of treatment sites is variable and there are some overlaps with the bare peat reference sites. There appears to be a very general tendancy of bare peat reference sites being worst for POC both in terms of number samples containing detectable levels, and for those samples containing higher concentrations of POC.

The intact reference sites tend to have the lowest levels of POC, and on Rishworth levels of DOC and colour were also significantly lower within intact areas than those within degraded areas. On Bleaklow, DOC and colour within intact areas were not significantly different to those on degraded sites. In general however, intact sites tend to have lower levels of carbon leaving the fluvial system than in degraded areas.

The export of POC from peatland systems is known to be highly episodic (Pawson et al 2008), with storm events and high discharge being associated with high erosion rates, and therefore high sediment content. POC loss from the degraded sites is likely to be much higher than the figures presented here. Fixed-interval sampling usually misses the highest flows, and therefore the highest POC concentrations, but storm sampling is beyond the scope of the MoorLIFE monitoring project. The gully blocks installed on Bleaklow as part of the MoorLIFE capital works programme are being monitored by an additional project (the Woodhead Gully Block Monitoring Project) to investigate the impact on storm flow and water quality in the Longdendale Water Safeguard Zone. This project compliments the existing MoorLIFE monitoring programme, and provides considerable added value through monitoring patterns of water quality during storm events.

The data supports existing knowledge of seasonal variation of DOC (MacDonald, Worrall *et al* 2006). Characterising the seasonal variation in water quality on a MoorLIFE site has been useful in helping to explain levels of DOC in the shorter autumn/winter campaigns on the other three sites. We now know that samples from the three other sites were collected just after the annual autumnal flush of DOC from the peat. Therefore there is good reason to expect that the values returned from these other sites during the 10 week campaign are likely to represent minimum value. In repeat campaigns it will be important to try and take samples in a similar period to make the datasets comparable. Future water sampling periods will be informed by year-round water sampling in other MFF projects. The data from these projects will be continually examined to help assess when the next MoorLIFE water samples should be collected, that is, when the autumn flush has finished.

The low DOC concentrations in one limed site – BL-MBC – is of particular interest in light of studies currently being undertaken on the impacts of peatland restoration on DOC loss. Preliminary studies suggest that lime suppresses release of DOC into streamwater (Andrew Stimson, pers comm.). However, BL-BC does not appear to respond to the liming, despite being treated at the same time. Reasons for this difference in DOC response are unclear and require further investigation.

Water colour, and therefore the visible DOC that causes it, is an important aspect of water quality for water companies, since the water must be treated at Water Treatment Works to make it suitable for drinking. The Drinking Water Inspectorate specifies that water colour must be no higher than 20 Hazen units. Several water treatment works in the South Pennines struggle to cope with high levels of colour, particularly during extreme rainfall events. Water Safeguard Zone action plans report that levels of 100 to 150 Hazen units are a particular challenge to water treatment works. The peatland catchments monitored on the MoorLIFE sites have been shown to be a source of highly coloured water, with medians as high as 1045 Hazen units on Rishworth Common, and 710 Hazen units on Bleaklow. The water draining from relatively intact catchments appear to generate lower levels of colour. This indicates an important ecosystem service that is being provided by the remaining areas of intact blanket bog in the South Pennines, and gives further cause to protect these areas from erosion and vegetation loss.

Work still needs to be done to understand the timings of works and their potential impact on water quality. Brash, lime, seed and fertilizer has been applied across most sites, but at different times, and so there are differences in the timings of the treatments across the monitored sites. These will need to be carefully considered and applied during the assessment of restoration works.

Other considerations that need to be made with the water quality data includes the impact of the extremely wet weather experienced in 2012. The recent exceptional and extreme weather conditions reinforce how important reference sites will be to begin assessing the effects of restoration and the effects of other influencing factors.

Future monitoring work under the E3 Action

With two more years remaining of the MoorLIFE project, considerably more data will be collected. Water table monitoring through manual dipwell campaigns will be undertaken in autumn 2013 and 2014. Water table monitoring with data loggers is ongoing and will run to the end of the project. Water sampling will be undertaken as a 3 month campaign in 2014, following the completion of revegetation works. Erosion pins will be measured over summer 2013 and 2014.

2014 will be a key year for data collection under the MoorLIFE project and the last sampling campaigns for water table, water quality and erosion measurements will take place at this point of the MoorLIFE project. If any differences between pre- and post-treatment hydrological datasets will be observable, this will be in the 2014 datasets. Therefore most of the statistical analyses of the datasets will be undertaken in autumn/winter 2014, ready for reporting in 2015.

Work will continue to explore the data collected, to process the data for Black Hill and Turley Holes, and to further quantify spatial differences in mean water tables and carbon loss / accumulation on MoorLIFE sites.

4 Action E5 – Carbon audit

4.1 E5 Introduction

Moorland conservation works involves work in remote areas, on fragile blanket bog, and over large areas. The MoorLIFE project is working to restore 2000 ha of bare and eroding blanket peat.
The project began with the targets to:

- Treat 615 hectares of bare peat with lime, seed and fertiliser, and another 400 hectares of blanket bog treated partially (maintenance treatments).
- Apply heather brash to 186 hectares of bare peat, plus 75km of geotextiles.
- Plant 150,000 plug plants over 110 hectares
- Hydroseed 710 hectares with heather and other dwarf shrub species
- Apply Sphagnum propagules to 610 hectares.
- Gully block the appropriate gullies within the restoration sites

These works are a major logistical operation involving a large amount of greenhouse gas (GHGs) emissions through direct combustion of fossil fuels. The main activities involve:

- Cutting of heather brash from local moors
- Delivery of restoration materials to lift sites
- Lifting of heather brash from lift site to application areas
- Aerial installation of gully blocks using helicopters
- Aerial application of lime, seed and fertilizer
- Travel of staff and contractors to works sites
- Lifting / removing empty brash bags from site

In projects such as MoorLIFE, use of helicopters is a logistical necessity, allowing the rapid lifting and delivery of hundreds of tonnes of materials from roadside lift sites to remote moorlands that are inaccessible, and easily damaged by other vehicles. In addition, helicopters are used to install stone gully blocks straight into gullies, and are also used to apply lime, seed and fertilizer over hundreds of acres of bare peat. This is a quick and efficient method of restoration that would not be logistically or

practically achievable without their use. It also reduces the amount of trampling that would otherwise be required.
Nevertheless, all these activities involve the burning of fossil fuels and as such is responsible for a considerable amount of carbon into the atmosphere.

The undertaking of a carbon audit as part of the MoorLIFE project was undertaken with the aim of identifying areas where carbon savings might be made. Additional benefits include:

1. more informed decision making on how we manage and supervise contracts and therefore emissions.
2. more accurate carbon accounting – restoration projects have carbon benefits, but a carbon audit will enable improved calculations of what these actually are.
3. data to feed into schemes for payments for ecosystem services.
4. identification of areas of cost saving – it is common for organizations to identify ways to save money as well as carbon (Defra, 2009).

Very few carbon audits have been undertaken on conservation works projects. The only example known to MFF is the Norfolk Broads Authority's carbon audit of their fen land management (Olloqui, 2006; LCIC/UEA 2010). To our knowledge, no moorland restoration project has carried out a full calculation of the carbon footprint. This aspect of the MoorLIFE project would appear to be unique in its undertaking.

4.2 E5 Methods

The Department of Environment and Rural Affairs (Defra) have produced guidelines for UK organisations wishing to undertake voluntary carbon audits of their activities. These guidelines are being used as the framework for the MoorLIFE carbon audit.

Scope and boundaries of the MoorLIFE carbon audit

The Defra guidelines state the importance of identifying the activities in an organization (or project) that are responsible for Greenhouse Gas (GHG) emissions, and from which areas of an organization (or in this case, the project) from which information needs to be gathered.

There are three recognized groups of emissions-releasing activities. As per the Defra guidelines, these are stated as follows:

"Scope 1 – Direct emissions: Activities owned or controlled by your organization that release emissions straight into the atmosphere. They are direct emissions." Examples of these in the context of MoorLIFE are emissions from vehicles, including cars and helicopters.

"Scope 2 – Energy indirect: Emissions being released into the atmosphere associated with consumption of purchased electricity, heat, steam and cooling. These are consequences of an organization's activities, but occur at sources not owned or controlled by the organization." These are indirect emissions and would include the consumption of energy in running the MoorLIFE project office.

"Scope 3 – Other indirect: Emissions that are a consequence of your actions, which occur at sources which are not owned or controlled, and which are not classed as scope 2 emissions."

Scope 1 and Scope 2 emissions are the recommended emissions types to audit, and Scope 3 are discretionary. Scope 3 emissions can be especially important because there is a risk, should the organization or business responsible for those emissions undertake a carbon audit, of double counting. However, it is acknowledged that it can be difficult to identify whether emissions fall into scope 1 or scope 3.

The MoorLIFE project outsources, but closely controls, the activities that are undertaken during the restoration works. Therefore many of the moorland restoration activites fall within Scope 3. As they are such a significant part of the works, they must be included in this carbon audit.

Figure 37 shows the sources of GHG emissions within the MoorLIFE project and the scopes which each falls into.

Olloqui (2006) describes the process of undertaking a carbon audit at the project level. At this level of carbon auditing (as opposed to national or regional carbon emission measurements) where the level of detail of data needs to be very high, and involves the need to identify individual micro-level activities. The complex nature of the MoorLIFE conservation works involves several substantial logistical operation, employing multiple contractors and using a large team of workers to safely deliver the work to a high standard. This has led to the scope of the carbon audit being kept to the significant restoration activities detailed above.

The focus of this carbon audit is to calculate the direct GHG emissions from the use of fossil fuels required to carry out the capital restoration works. Scope 1 emissions relating to other MoorLIFE activities, such as monitoring and communications, are not currently included, although this could be reviewed once the appropriate models and frameworks are in place. Office based emissions such as electricity consumption which fall under Scope 2 are also being omitted from this first carbon audit. The effort to calculate the GHG emissions of every activity under MoorLIFE could compromise the ability to calculate accurate and precise emissions of the capital works.

The allocation of individual contracts to MoorLIFE action codes allows a convenient and systematic way of identifying which activities to collect data for. The scope of this carbon audit therefore is to are defined as those activities carried out for, and invoiced to, the following MoorLIFE Actions:

- C1 – Stabilising bare peat and halting erosion through planting nurse grasses
- C2 – Increasing stability and resilience by introducing structural blanket bog species
- C3 – Gully blocking to stop peat erosion and restore hydrological integrity.

These actions represent the most important carbon emitting activities, and so should give a representative figure as to the carbon footprint of a project of this type.

As discussed in the introduction, blanket bog is an important store of carbon, and in its degraded state is a considerable source of carbon emissions. The MoorLIFE project aims to protect remaining areas of active blanket bog through stabilization and revegetation of exposed and eroding peat. This will result in protection of remaining carbon stores and the reduction of carbon losses. Part of this carbon audit will involve looking at GHG emissions of capital works in the context of the carbon benefit resulting from such restoration works. This is discussed under the section heading ‘Further work under Action E5’.

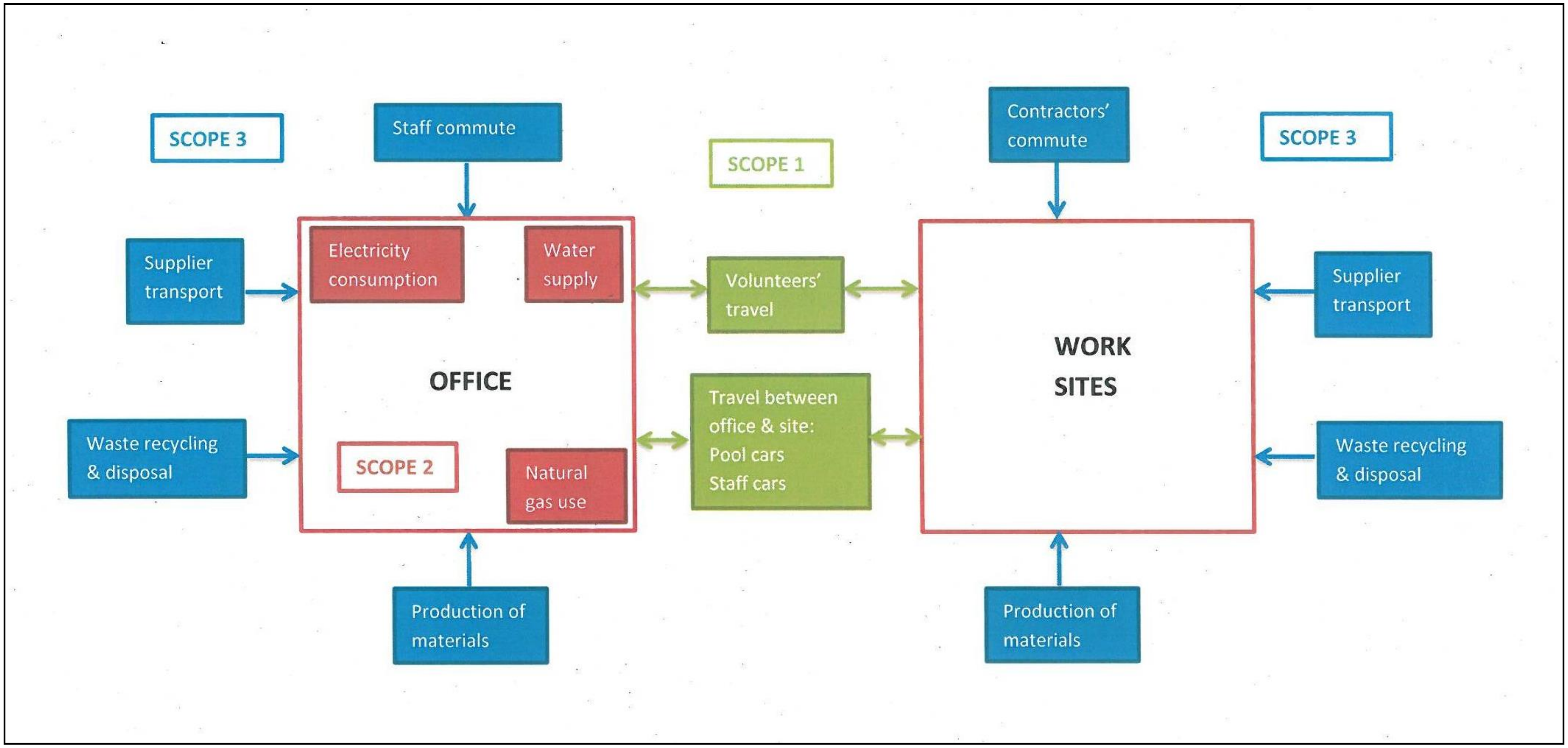


Figure 37 Categorisation of types of GHG emissions into the scopes as defined in the Defra (2009) guidelines.

Period of audit

It is important to define the period of audit. For many businesses and organizations undertaking carbon accounting, a period of a year is used as a representation of typical yearly GHG emissions.

The MoorLIFE project is a five year programme of capital works. The level of work undertaken in each year will not be the same. The different phases of capital works on one site can be spread over a number of years. Therefore the carbon audit is being undertaken across the entire five year period of the MoorLIFE project, to produce a total GHG emissions figure in 2015. This can then be converted to a more comparable, useful figure as detailed below.

Reporting

The Defra guidelines state that GHG emissions should be reported as a gross figure in tonnes of CO_2e, followed by a net figure. A net figure would require accounting for emission reductions brought about by the MoorLIFE restoration works (see Further work under Action E5).

Defra then recommends calculating an intensity ratio. In the business sector, this allows performance to be assessed over time, and allows comparison across different business sectors and products. In the context of the MoorLIFE project, we will be able to calculate tonnes of CO_2e per hectare of restored blanket bog. We will be able to use these figures to calculate differences in emissions in each year of the project, as well as for different techniques, sites, and catchments.

Tools for carbon auditing

The Defra / Department of Energy and Climate Change GHG Conversion Factors tool was identified early on in the process of establishing the protocols for a carbon audit. These are a series of automated Excel spreadsheets which calculate emissions data upon the input of the relevant activity information – such as units of fuel used. Olloqui (2006) undertook a review of the various carbon calculator tools available to organizations to undertake carbon audits. This review confirmed the Defra/DECC tool as being ideal for use in auditing land management activities.

Advantages of the Defra / DECC tool include:

- Use of UK conversion factors that are particular to UK which is especially useful for emissions from transport.
- There is a high level of detail and allows calculation of emissions through its adaptability for different fuel types, payloading etc.
- The spreadsheet is updated annually and is continually refined.
- The tool includes the capacity to calculate Scope 2 emissions, which will enable the expansion of the MoorLIFE carbon audit should this be feasible at a later date.
- The inclusion of the conversion factors allows their incorporation into our own spreadsheets in which activity data is recorded.

Data collection

The first part of the audit process is to gather information on the activities undertaken under MoorLIFE.

All activites that are invoiced to the MoorLIFE project under Actions C1, C2 and C3 are recorded, together with the relevant information required to calculate their GHG emissions. This information varies depending on the type of activity (e.g. cutting of heather brash, or application of lime) and the type of vehicle used. In addition to contracts, the cost of pool cars and staff mileage claims are also included. Any journeys attributed to the main 3 restoration actions are included in the audit.

Where possible, official documents such as invoices and purchase orders are used to gather data, for example the number of bags of brash ordered. However, often the data required, such as miles travelled by contractors to a brash spreading job, or the type of delivery vehicle is not typically included on invoices. This information is gathered through checks with Conservation Works Officers who were present and/or supervising the contract. Google maps is used to calculate the distances travelled between sites.
This carbon audit is very particular to this project. In order to make the figures comparable to other conservation or commercial activities we hope to be able calculate and present GHG emissions in a number of ways. For example it will be possible to state the average GHG emissions per hectare of bare peat treated, or per x metres of gullies blocked.

The data collection is largely complete for Years 1, 2 and 3 of the project and work will continue for Years 4 and 5.

The carbon audit has highlighted areas where a more detailed recording of activities undertaken during restoration works would enhance MFFP’s ability to undertake regular carbon audits. This is not an uncommon finding for organizations undertaking carbon audits for the first time, and there are many examples of processes by which activity data is recorded is continually improved upon (Defra 2009).

The process of gathering data for the carbon audit is having additional benefits in other areas such as in the environmental monitoring programme. An example of this is a detailed collection of when works took place in relation to monitoring activities, such as water sampling.

Further work under Action E5

At the time of writing this report, the task of recording GHG emitting activities in Years 1 and 2 is complete, and Year 3 is nearing completion. The data is accurate and is of a high level of detail. Further reviews of the processes of gathering the data are required to ensure that they are as efficient and as robust as possible. Templates have now been set up to enable more rapid recording. The models required to calculate GHG emissions and appropriate intensity ratios are in development.

Analysis of the data is soon to begin on the first three years of data to ensure the processes are in place ready for reporting in 2015. Presentation of findings to the MoorLIFE team and other project teams within Moors for the Future will enable Conservation Works teams to identify areas where carbon savings could be made. It will also help to guide the carbon audit in terms of presentation and reporting, and encourage discussion of whether the scope of the audit should be widened.

Work will begin on exploring tools and methods to enable calculation of the carbon benefit of the MoorLIFE project. Some of the carbon benefits of the MoorLIFE programme are being directly monitored through carbon content of water and erosion rates at treated and untreated sites. However there are no direct measurements of GHG flux measurements. Proxies can be used through monitoring of the vegetation and water table. Tools are currently being developed by Natural England, who have established GHG Emission Site Types (GESTs) (Birnie and Smyth, 2013; Reed *et al* 2013), and could be utilized in the Pilot Phase UK Peatland Code. This is the trial of a system by which businesses could pay the costs of restoration in return for the carbon benefits, part of which involves the monitoring of carbon proxies to assess the carbon emission reductions of restoration projects.

5. Acknowledgements

With thanks to the MFFP employees and volunteers who have worked to collect vegetation and water table data over the course of the MoorLIFE Project.

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