

25 AUG 2015

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20<sup>th</sup> August 2015

Dear Mr Leakey

**RWE Generation UK plc, Aberthaw Power Station, Environmental Permit  
RP3133LD**

**RE: Improvement Condition 7**

With reference to the above Improvement Condition please find enclosed the 2014 monitoring report for "Monitoring of vegetation and bulk soil measurements at seven potentially vulnerable Natura 2000 sites in England and Wales and model-based analysis of the data" produced by the Centre for Ecology and Hydrology.

Please contact Amy Lavisher on the above telephone number if you have any questions or if clarification is required.

Yours sincerely



Richard Little  
Station Manager

Enc:  
CEH Fifth Report, August 2015, "Monitoring of vegetation and bulk soil measurements at seven potentially vulnerable Natura 2000 sites in England and Wales and model-based analysis of the data".

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25 AUG 2015

**Monitoring of vegetation and bulk soil  
measurements at seven potentially vulnerable  
Natura 2000 sites in England and Wales and model-  
based analysis of the data.**

**Fifth Report to the  
Power Station and Refinery Operators (Final Draft)**

**August 2015**

**Don Monteith, Simon Smart, Susan Jarvis, Chris Evans  
Rob Rose, Peter Henrys, Heather Carter & Patrick Keenan**

**Centre for Ecology & Hydrology  
Lancaster Environment Centre**



Draft report version 1: submitted 5 <sup>th</sup> June 2015
Draft report version 2: changes agreed following meeting with Steve Griffiths (E.ON) and Paul Sutton (RWEnpower) submitted 7 <sup>th</sup> July 2015
Draft report version 3: further minor changes following comments from Steve Griffiths (E.ON) submitted 14 <sup>th</sup> July 2015
Final draft: further minor changes following comments from Steve Griffiths (E.ON) submitted 14 <sup>th</sup> August 2015

## 1. Introduction

Operators of power stations and refineries in England and Wales who “opted in” to the Large Plant Combustion Directive (LCPD) are required by the UK Environment Agency to undertake “a monitoring programme to assess changes in acidification and eutrophication deposition and ecological effects at appropriate Natura 2000 sites”, as part of the operating permit improvement conditions for plant. A formal response outlining this monitoring programme was submitted to, and accepted by, the Environment Agency in March 2008. The NERC Centre for Ecology and Hydrology were awarded a four year contract to implement the monitoring in 2011.

The monitoring programme is based on protocols for ecological and deposition monitoring at Natura 2000 sites approved by the Environment Agency in September 2010, and is intended to complement a previous modelling assessment review conducted by the Environment Agency in relation to the Integrated Pollution Prevention and Control permitting for UK refineries and coal-fired power stations. Following discussions between the installation operators, the Environment Agency, Natural England and Countryside Council for Wales (CCW) (now Natural Resources Wales (NRW)), seven Natura 2000 sites were selected for inclusion in the network of sites (now known as the Habitats Monitoring Network (HMN)), including at least one site relevant to each of the 13 participating installations. As sulphur deposition was the dominant issue associated with power station and refinery emissions, sites were selected on the basis of the installation's modelled percentage contribution to the minimum site-relevant critical load for sulphur ( $CL_{maxS}$ ), plus the percentage contribution to total sulphur deposition and total acid deposition, while the absolute level of sulphur deposition arising from the installation was also taken into account.

Monitoring has focused on three components relating to the conservation objectives of the selected sites:

1. Prevailing levels of acidifying deposition and any changes in acidification deposition over the period of monitoring.
2. Prevailing levels of eutrophying deposition and any changes in eutrophication deposition over the period of monitoring.
3. Prevailing ecological condition and any changes in the ecological condition over the period of monitoring.

This is the fifth report to the Power Station and Refinery Operators detailing data collected over the course of the programme, and the second to report on vegetation and bulk soil monitoring data. The previous report covering the latter area was the third report, submitted in December 2013, which summarised vegetation and soil data collected during the field campaign in the summer of 2011, and introduced an approach to assessing the environmental suitability of the habitats for a range of indicator plant species according to the application of the statistically-based model Multi-MOVE. In the current report we append comparable data collected in the summer of 2014, assess any evidence for biological or soil chemical differences between the two surveys, and conduct a more detailed examination of habitat suitability using Multi-Move. The Multi-Move assessment includes use of a wider ensemble of models ( $n = 5$ ) than previously ( $n = 3$ ), in order to provide a greater degree of confidence in the interpretation of the data, and some refinement to model parameterisation.

## 2. Site selection

Seven Natura 2000 sites, listed in Table 2.1, were selected following discussions between the installation operators, the Environment Agency, Natural England and CCW, and a series of site-scoping visits by CEH and E.ON staff. These include at least one site relevant to each of the 13 participating installations. As sulphur deposition was considered the key issue associated with power station and refinery emissions, selection was based on the installation's modelled percentage contribution to the minimum site-relevant critical load for sulphur (CLmaxS), plus the percentage contribution to total sulphur deposition and total acid deposition. The absolute level of sulphur deposition arising from the installation was also taken into account.

Wherever possible, ecological monitoring locations were selected on the basis of possession of the most sensitive designated features (i.e. those with the minimum site-relevant critical loads), using the "main habitat" data provided on the Natural England website for the associated SSSIs (Sites of Special Scientific Interest; <http://www.english-nature.org.uk/Special/sssi/search.cfm>). In practice, the most sensitive area was not always sufficiently accessible, nor was it always possible to find a secure area to base the associated Meteorological/deposition station. In these cases compromises were necessary, although, in all cases the selected habitats are considered to be ecologically very similar to the most sensitive habitats.

**Table 2.1 Monitoring sites and associated power station (PS) and refinery (RF) installations. SAC = Special Area of Conservation; SSSI = Site of Special Scientific Interest**

Installation(s)	Nature 2000 location and SSSI designation	Key monitored Natura 2000 habitat
Aberthaw PS	Usk Bat Sites SAC Mynydd Llangatwyg SSSI	Blanket Bogs
Ratcliffe PS, Cottam PS & West Burton PS	Thorne Moor SAC Thorne, Crowle & Goole Moors SSSI	Degraded Raised Bogs & Active Raised Bogs
Rugeley PS	Cannock Chase SAC/SSSI	European dry heaths
Fawley RF	The New Forest SAC/SSSI	European dry heaths
Drax PS, Eggborough PS & Ferrybridge PS	Skipwith Common SAC/SSSI	European dry heaths & Northern Atlantic wet heaths
Fiddler's Ferry PS & Stanlow RF	Manchester Mosses SAC Astley & Bedford Mosses SSSI	Degraded Raised Bogs
Milford RF* & Pembroke RF	Cleddau Rivers SAC Esgryn Bottom SSSI	Active Raised Bogs

\*Milford Haven Refinery closed at the end of 2014

### **3. Measurements and sample analysis**

Monitoring protocols follow those outlined in the original project specification document agreed with the Environment Agency in September 2010 and are described in the following sections.

#### **3.1 Vegetation surveys**

Initial scoping visits in and discussions with local SSSI site managers in 2011 allowed the identification of the most suitable area of each site for subsequent vegetation surveys and associated bulk soil sampling. Soil solution monitoring locations were also identified within these survey areas.

When choosing the appropriate area for vegetation monitoring consideration was given to:

- a) homogeneity of vegetation of the area (preference given to sites where vegetation was both characteristic of the bog or heath habitats of interest and varied least over a potential survey area of 1-2 hectares);
- b) the ease of access (for regular soil solution sampling);
- c) the likelihood of changes in land management over the next four years – preference being given to areas where land management was likely to remain consistent, so that signals relating to changes in air quality would be more likely to be detected;
- d) whether a secure site was available in the vicinity at which to base a meteorological and atmospheric deposition monitoring station.

In accordance with the original protocols, 50 potential survey plot locations were identified for each survey, although access restrictions and difficult terrain made it impossible to cover all 50 plots at each site over a maximum survey period of five days. On the basis of a power analysis carried out on the soil chemistry data collected during the 2011 survey it was concluded that as many plots as possible should be collected during the 2014 survey to enable as robust a measure of mean chemical conditions as possible (see Appendix 1).

Corner points of a quadrilateral vegetation survey area, normally with sides greater than 100 metres in length, but in some cases slightly shorter as a result of limited availability of suitable habitat, were recorded using a Garmin Global Positioning System (GPS). In both 2011 and 2014 random vegetation survey points (numbered 1-50) were then generated within the defined bounds using a Garmin randomised plotting programme. Each point represented the south-west corner of 2 x 2 metre vegetation survey quadrat, aligned with sides perpendicular to the four major compass points. The survey quadrat was subdivided into twenty-five 40 x 40 cm cells (see Figure 3.1) numbered from 1 (north-west corner) to 25 (south-east corner).

A pair of skilled vegetation surveyors visited each site over the course of one week during the summers of 2011 and 2014. Quadrat points were visited sequentially starting with number 1. It was not always possible to survey all 50 quadrats in the time available, the total number covered depending on the complexity of the terrain and the vegetation surveyed. For each cell of each quadrat a record was made of all species present. To avoid potential transcription errors, all data for higher plants were entered directly in the field into Environmental Change Network MS Access-based database forms on a field-ruggedised computer (Figure 3.2). To



avoid potential identification errors in the field, representative sub-samples of each distinct form of bryophyte (mosses and liverworts) and lichen occurring within each cell were also collected as voucher specimens for later analysis by bryologists/lichenologists.

**Figure 3.1.1 A vegetation quadrat in use at Cannock Chase SSSI in 2011**



**Figure 3.1.2 Screen-dump of the Environmental Change Network vegetation template used to record Cannock Chase vegetation data in the field**

ECN VC Data Entry

Site: CAN Plot Position ID: 30 Survey Year: 2011 Name of Surveyor: Alison Pike Save and exit

Plot information Please enter the plot information recording date: 01-Jul-11

Grid ref: Slope (°): Slope form: Aspect (°): Mean veg height (cm): 20 % cell (cm): 0 Self moisture: 0

SK: 307 14248 0 0 Max veg height (cm): 40 % litter (cm): 10 No. cores: 2

Quality codes for plot: Quality test for plot: Square 5 rush a

Species information Please enter the species recording date: 01-Jul-11

Species name/code	Cell	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Agrostis capillaris	123																									
Betula pendula (g)	2507																									
Calluna vulgaris	278																									
Deschampsia flexuosa	478																									
Juncus effusus	730																									
Liber	51																									
Molinia caerulea	876																									
Moss A	9001																									
Moss B	1151																									
Moss C	1152																									
Saccogyna villosa	2271																									
Baetula glaucocoma	1943																									
Sagina apetala apetala	1153																									
Sagina apetala erecta	1152																									
Sagina intermedia	1154																									
Sagina maritima	1155																									
Sagina nodosa	1156																									
Sagina procumbens	1158																									
Sagina saginoides	1159																									
Sagina sp	4291																									
Sagina subulata	1160																									
Sagina normaniana	1157																									
Sagiolechia protuberans	5463																									
Rundelia rhenobentha	5464																									



### 3.2 Bulk soil chemistry

On completion of the vegetation survey of each quadrat in both 2011 and 2014, two 15 cm long soil cores were extracted from the centre of each quadrat. Each core was sealed in an airtight polythene bag to prevent loss of moisture before placing in a chilled cool box. On return to the laboratory at the Centre for Ecology & Hydrology in Lancaster each wet soil core sample was weighed. In most cases core samples contained sufficient soil to enable all analysis to be undertaken on one of the replicate sample only. In the unusual situation where soil cores contained too large a volume of stones to provide an adequate sievable soil sample, the two replicates were combined.

A small wet homogenised sub-sample was then removed, weighed, and analysed for:

- a) pH (in water) using a Fisherbrand Hydrus 400, buffered at pH 4 and pH 7; and,
- b) extractable nitrate and ammonium, using 6% potassium chloride and analysed colorimetrically using a SEAL AQ2 Discrete Analyser .

The remaining sample was oven dried at 105 °C for three hours before re-weighing to determine percentage dry weight. The dried soil was then sieved through a 2 mm sieve and sub-sampled further to provide material for subsequent analysis of Olsen phosphorus and soil base saturation. Olsen phosphorus was determined by the addition of Olsen's reagent and subsequent analysis of phosphorus using colorimetry on a Skalar continuous flow analyser. Extractable base cation concentration was determined by extracting the sample with 4M ammonium acetate and subsequent analysis by ICPOES (PerkinElmer DV7300). Finally, a dried sub-sample of circa 1 g was ball-milled and analysed for carbon and nitrogen content using a CN Analyser.

## 4. Site descriptions and summary of 2011 and 2014 vegetation surveys

This section provides details of the monitoring locations at the seven selected Natura 2000 sites. In the tables of this section the data represent the percentage of 40 cm x 40 cm cells across all quadrats surveyed on the site.

### 4.1 Manchester Mosses SAC - Astley Moss

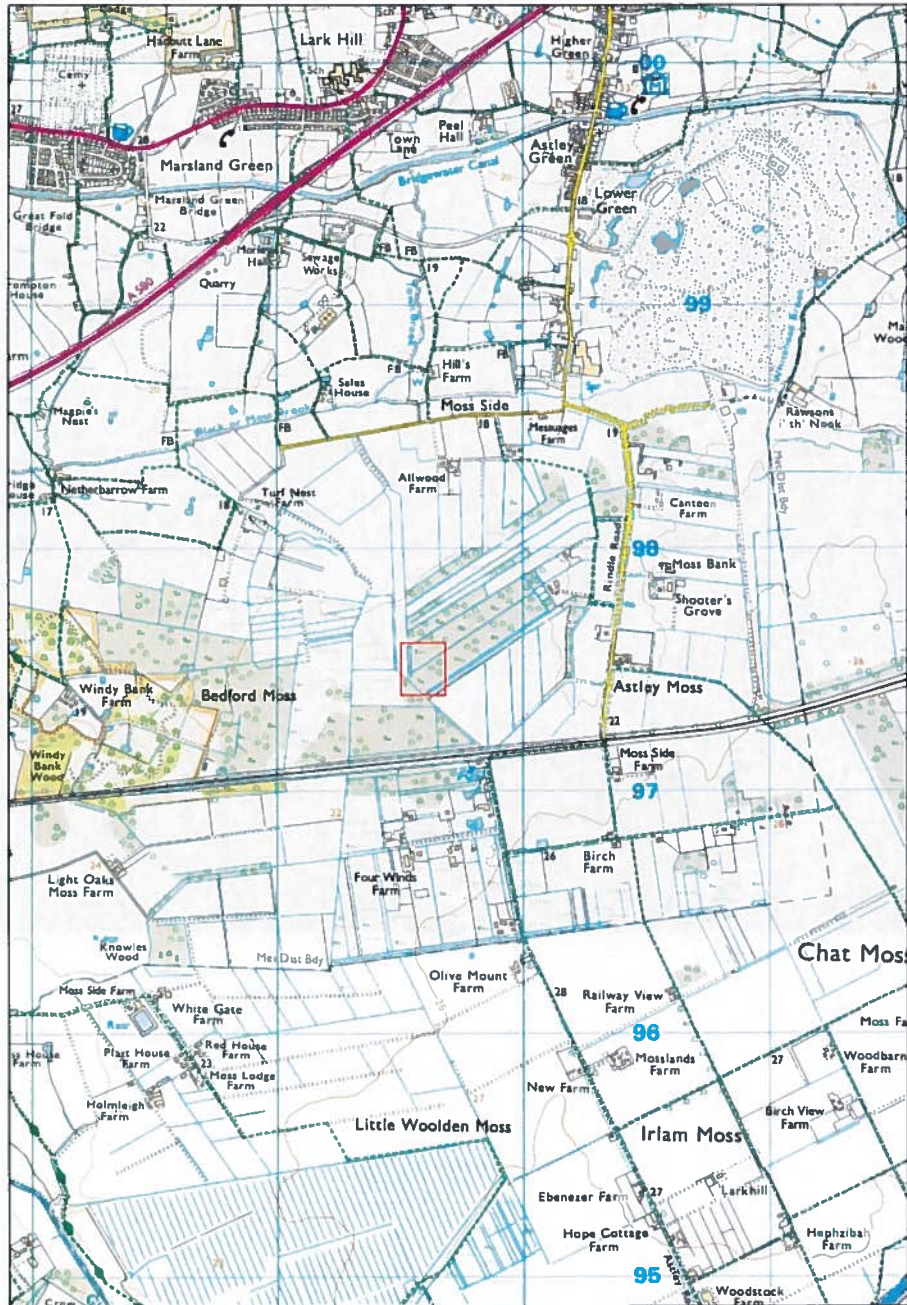
Astley Moss, along with Bedford, Risley and Holcroft Mosses (together known as the Manchester Mosses) are areas of peat bog in Greater Manchester. They represent remnants of a much larger area of raised bog that once occupied a substantial area of south Lancashire north of the River Mersey. Astley Moss was designated a Site of Special Scientific Interest in 1989, while the Manchester Mosses were also designated as a Natura 2000 Special Area of Conservation in 2005. The mosses in this area originated as fen peat that was later colonised by *Sphagnum* that drove a change to an acidic raised bog.



The area has been extensively drained to improve agricultural capacity in recent decades, leading to substantial degeneration of the peatlands. However, a recent restoration programme, overseen by the the Wildlife Trust for Lancashire, Manchester & North Merseyside has resulted in a gradual rise in the water table across much of the site. To minimise the potential influence of the recent hydrological changes, it was decided to focus botanical monitoring to the west of the site, where the water table has been re-established for several years and the bog vegetation has, therefore, had the longest to re-establish.

Summary results of the 2011 vegetation survey carried out between 25<sup>th</sup> and 29<sup>th</sup> July 2011 and the 2014 survey conducted between 14<sup>th</sup> and 18<sup>th</sup> July 2014 are provided in Table 4.1. The key monitored Natura 2000 habitat at the monitoring location is 'degraded raised bogs'.

Figure 4.1.1 Astley Moss and surroundings (red box approximates to main vegetation and soil monitoring area)



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(C)



**Figure 4.1.2 Aerial photograph (Google Earth) of the Astley Moss site, with vegetation survey areas bounded in green. Locations for the Meteorological/Deposition, and soil water monitoring sites indicated by blue and red symbols respectively.**



Table 4.1.

2011 & 2014 vegetation surveys - % occurrence of all taxa recorded in 40 x 40 cm cells

species	2011	2014
<i>Molinia caerulea</i>	87.6	83.4
<i>Eriophorum angustifolium</i>	62.7	26.7
<i>Eriophorum vaginatum</i>	53.1	57.4
<i>Sphagnum auriculatum</i>	13.5	13.0
<i>Sphagnum fimbriatum</i>	4.5	0.8
<i>Sphagnum subnitens</i>	1.0	1.4
<i>Calluna vulgaris</i>	0.9	0.3
<i>Cephalozia bicuspidata</i>	0.9	1.7
<i>Calypogeia fissa</i>	0.8	1.3
<i>Polytrichum commune</i>	0.8	0.9
<i>Sphagnum papillosum</i>	0.7	ND
<i>Sphagnum cuspidatum</i>	0.6	18.4
<i>Betula</i> spp.	0.4	1.0
<i>Calypogeia muelleriana</i>	0.4	ND
<i>Drepanocladus exannulatus</i>	ND	0.2
<i>Lophozia ventricosa</i>	ND	0.3
<i>Sphagnum squarrosum</i>	ND	0.1

ND = Not detected

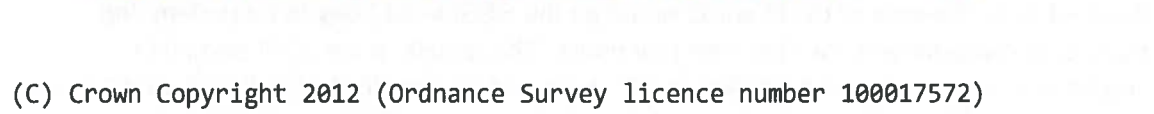
## 4.2 Cannock Chase SAC

The Cannock Chase SSSI is situated between Stafford, Rugeley, Lichfield and Cannock and comprises over 600 hectares of largely dwarf shrub heath. The site was designated as an SAC in 2005. The vegetation is unusual for its blend of west European oceanic species, including *Calluna vulgaris*, arctic-alpine species including *Vaccinium myrtillus*, *V. vitis-idaea*, (and the hybrid of these two species, *V. X intermedium*), *Empetrum nigrum*, and *Erica* species in some areas.

The choice of location of the vegetation plot for this survey followed consultation with Staffordshire County Council regarding current habitat management of the heath towards favourable condition. The area of Brindley Heath, outlined by the polygon in Figure 4.2.2, was deemed to be the area of dwarf shrub heath on the SSSI least likely to be undergoing significant management over the next four years. The results of the 2011 and 2014 vegetation surveys carried out between 27<sup>th</sup> June and 1<sup>st</sup> July 2011 and 7<sup>th</sup> July and 11<sup>th</sup> July 2014 respectively are detailed in Table 4.2. The key monitored Natura 2000 habitat at the monitoring location is 'European dry heaths'.









**Figure 4.2.2** Aerial photograph (Google Earth) of Cannock Chase site, with vegetation survey areas bounded in green. Locations for the Meteorological/Deposition, and soil water monitoring sites indicated by blue and red symbols respectively.





**Table 4.2.**

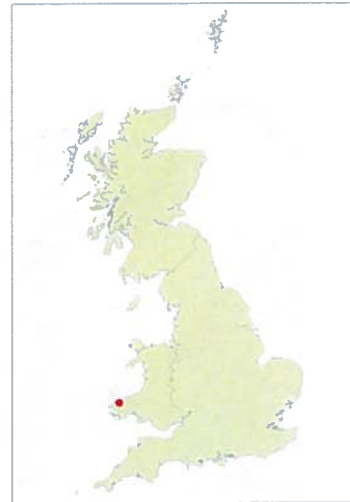
**2011 & 2014 vegetation surveys - % occurrence of all taxa recorded in 40 x 40 cm cells**

species	2011	2014
<i>Deschampsia flexuosa</i>	96.0	95.2
<i>Vaccinium vitis-idaea</i>	94.1	96.2
<i>Hypnum jutlandicum</i>	80.1	60.6
<i>Brachythecium rutabulum</i>	36.3	56.7
<i>Calluna vulgaris</i>	30.7	59.6
<i>Vaccinium myrtillus</i>	7.1	6.2
<i>Pseudoscleropodium purum</i>	6.0	ND
<i>Dicranum scoparium</i>	4.3	4.0
<i>Empetrum nigrum nigrum</i>	4.3	4.2
<i>Pteridium aquilinum</i>	3.9	2.8
<i>Galium saxatile</i>	3.3	8.7
<i>Campylopus paradoxus</i>	2.8	1.5
<i>Rhytidiadelphus squarrosus</i>	2.1	2.2
<i>Agrostis capillaris</i>	1.9	0.5
<i>Holcus lanatus</i>	1.6	ND
<i>Molinia caerulea</i>	1.6	0.6
<i>Rubus fruticosus agg.</i>	1.2	1.3
<i>Campylopus introflexus</i>	1.1	2.0
<i>Carex pilulifera</i>	0.9	ND
<i>Betula spp.</i>	0.7	0.1
<i>Polytrichum formosum</i>	0.5	ND
<i>Cladonia chlorophaea</i>	0.3	0.3
<i>Chamerion angustifolium</i>	0.1	1.2
<i>Juncus effusus</i>	0.1	ND
<i>Trifolium repens</i>	0.1	ND
<i>Campylopus pyriformis</i>	ND	0.4
<i>Galium aparine</i>	ND	0.1
<i>Lophocolea bidentata</i>	ND	0.1
<i>Quercus robur</i>	ND	0.4
<i>Sorbus aucuparia</i>	ND	0.4

ND = Not detected

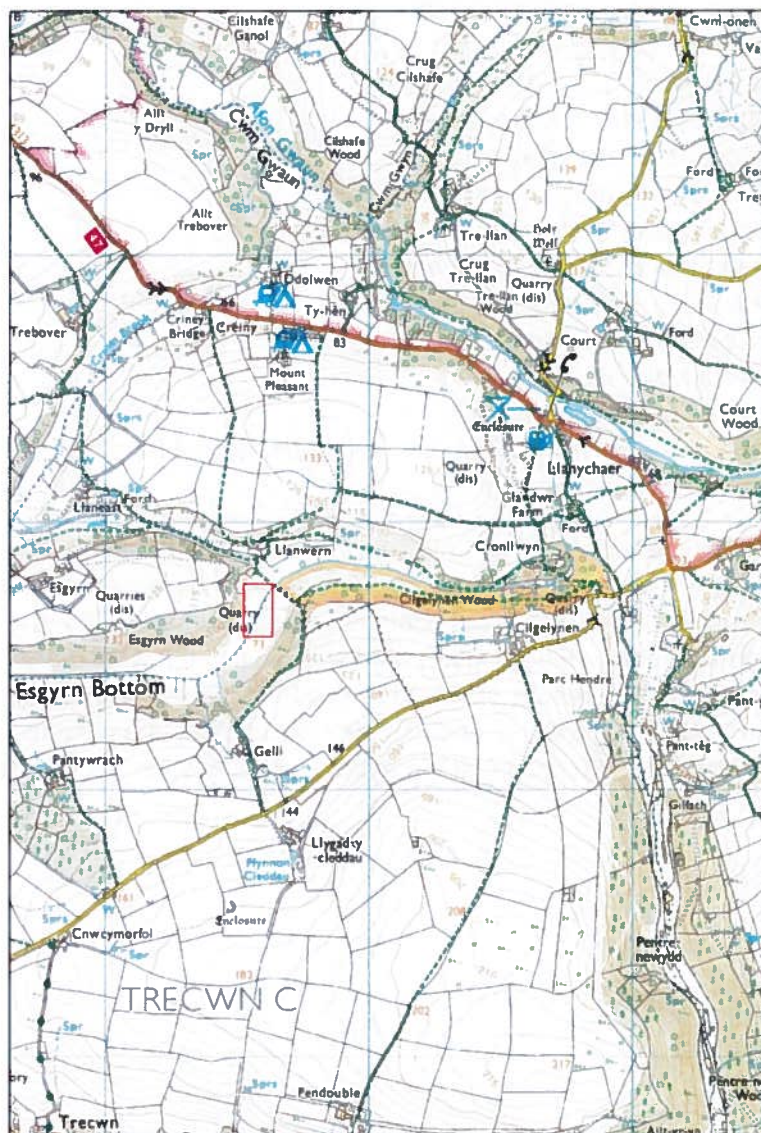
### 4.3 Cleddau Rivers SAC - Esgryn Bottom

The monitoring site at Esgryn Bottom, 3 km south-south-east of Fishguard in south-west Wales and at an altitude of circa 80 m above sea level, is situated on the watershed between Afon Cleddau to the west and Afon Gwaun to the east. Cleddau Rivers was designated an SAC in 2004. The site lies within a melt-water channel system thought to have formed during the Late Pleistocene by sub-glacial stream erosion from melt-water. Much of the valley comprises thick peat deposits of up to 7 m depth that have formed over early Holocene lake-bed deposits thought to date from the early Holocene (9,000 - 10,000 years BP). The relatively small area of peatland has been subject to considerable degradation in the past as a result of peat cutting and drainage. Hydrologically, the site is supplied by both moderate levels of rainfall (in a westerly UK context), and springs that arise from the southern end and drain via the main drainage channel.



The vegetation of the site strongly reflects local hydrological variation, with the main area of 'raised bog' dominated by *Erica tetralix* – and *Sphagnum* mosses, while the drier fringes are dominated by *Molinia* sp. An area of characteristic vegetation of approximately 200 m x 100 m was selected for the vegetation survey (Figure 4.3.2), and soil solution dip wells were installed at the north end of the plot. The results of the 2011 and 2014 vegetation surveys conducted between 4<sup>th</sup> and 8<sup>th</sup> July 2011 and 21<sup>st</sup> and 25<sup>th</sup> July respectively are provided in Table 4.3. The key monitored Natura 2000 habitat at the monitoring location is 'active raised bogs'.

**Figure 4.3.1 Esgryn Bottom and surroundings (red box approximates to main vegetation and soil monitoring area)**



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**Figure 4.3.2 Aerial photograph (Google Earth) of Esgryn Bottom site, with vegetation survey areas bounded in green. Locations for the Meteorological/Deposition, and soil water monitoring sites indicated by blue and red symbols respectively.**



**Table 4.3.**

**2011 & 2014 vegetation surveys - % occurrence of all taxa recorded in 40 x 40 cm cells**

species	2011	2014
<i>Molinia caerulea</i>	92.6	90.9
<i>Calluna vulgaris</i>	88.8	96.3
<i>Erica tetralix</i>	69.8	87.5
<i>Odontoschisma sphagni</i>	48.6	23.9
<i>Narthecium ossifragum</i>	47.0	48.1
<i>Hypnum jutlandicum</i>	45.0	42.4
<i>Eriophorum angustifolium</i>	34.8	38.1
<i>Cladonia portentosa</i>	21.2	22.1
<i>Potentilla erecta</i>	15.0	10.6
<i>Sphagnum</i> sp.	12.0	ND
<i>Leucobryum glaucum</i>	11.2	12.7
<i>Sphagnum capillifolium</i>	10.4	20.1
<i>Brachythecium rutabulum</i>	10.0	ND
<i>Eriophorum vaginatum</i>	7.8	ND
<i>Cladonia furcata</i>	5.2	0.1
<i>Pteridium aquilinum</i>	4.2	ND
<i>Holcus mollis</i>	3.4	ND
<i>Pleurozium schreberi</i>	3.4	ND
<i>Dicranum scoparium</i>	3.0	1.0
<i>Eurhynchium praelongum</i>	3.0	ND
<i>Vaccinium oxycoccus</i>	1.2	2.9
<i>Sphagnum papillosum</i>	0.8	1.3
<i>Calypogeia fissa</i>	0.4	ND
<i>Campylopus paradoxus</i>	0.2	ND
<i>Drosera rotundifolia</i>	0.2	0.5
<i>Kurzia pauciflora</i>	0.2	ND
<i>Quercus petraea</i>	0.2	0.6
<i>Sorbus aucuparia</i>	0.2	ND
<i>Ulex gallii</i>	0.2	3.0
<i>Scirpus cespitosus</i>	ND	23.0
<i>Sphagnum subnitens</i>	ND	2.3

ND = Not detected



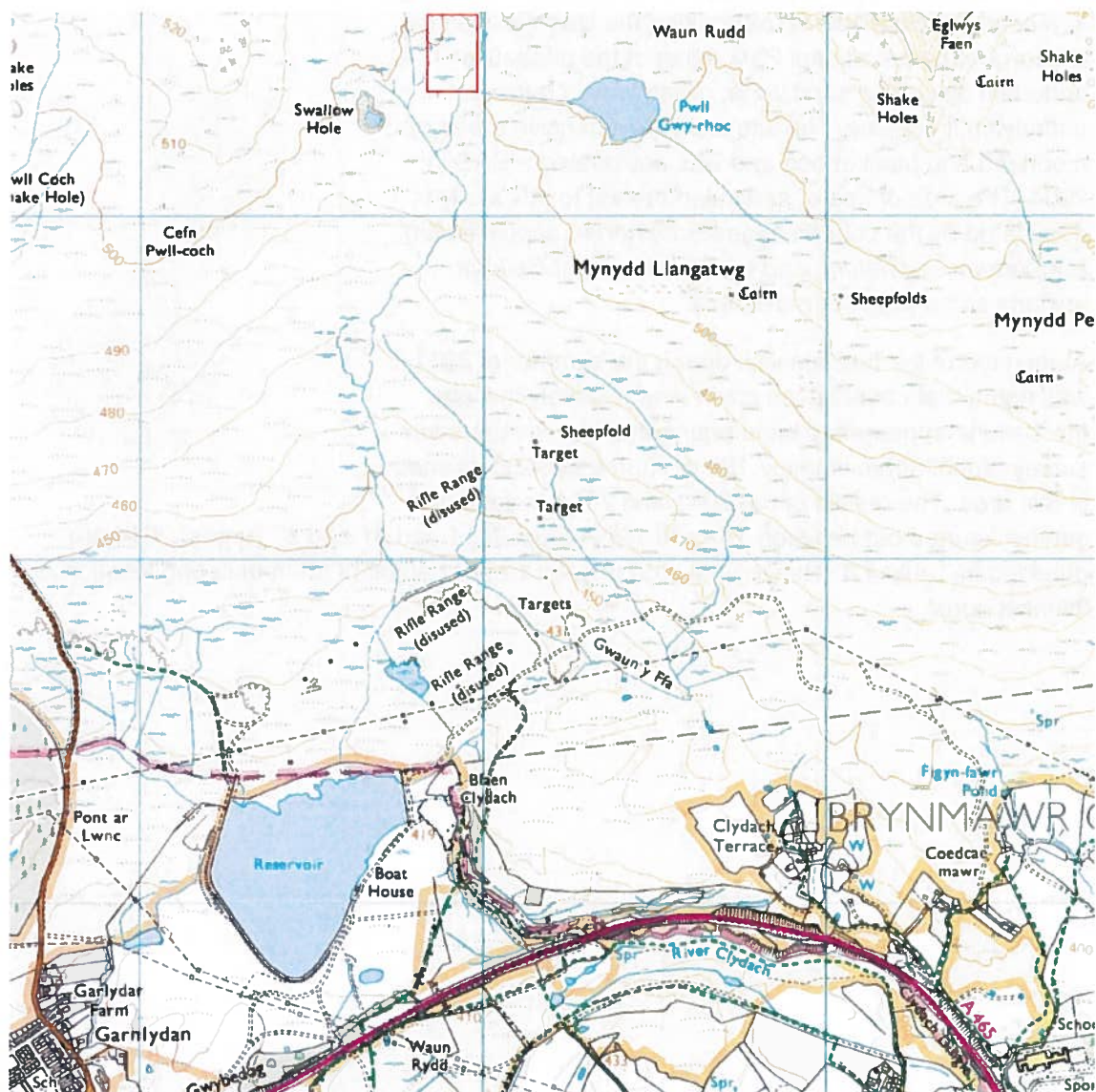
#### 4.4 Usk Bat Sites SAC - Mynydd Llangatwyg

Mynydd Llangatwyg comprises an undulating plateau rising to a height of circa 530 m overlooking the Usk Valley in the Brecon Beacons National Park. Most of the plateau is underlain by coarse sandstone, giving way in parts to underlying limestone. The site includes extensive areas of moorland and blanket bog and was designated a SAC in 2004. The area of bog of particular interest to this study is dominated by the cotton sedges *Eriophorum angustifolium*, *Eriophorum vaginatum*, and to a lesser extent *Calluna vulgaris* and a range of moss taxa.

At the time of the first site visit during the summer of 2011 it was noted that overall plant cover was relatively low and the *Calluna* appeared to be in poor condition. A vegetation survey plot of approximately 150 m square was established in this area. The results of the 2011 and 2014 vegetation surveys carried out between 15<sup>th</sup> and 19<sup>th</sup> August 2011 and 4<sup>th</sup> and 8<sup>th</sup> August 2014 are provided in Table 4.4. The key monitored Natura 2000 habitat at the monitoring location is 'blanket bogs'.



**Figure 4.4.1 Mynydd Llangatwg and surroundings (red box approximates to main vegetation and soil monitoring area)**



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**Figure 4.4.2 Aerial photograph (Google Earth) of Mynydd Llangatwyg site, with vegetation survey areas bounded in green. Locations for the Meteorological/Deposition, and soil water monitoring sites indicated by blue and red symbols respectively.**



**Table 4.4.**

**2011 & 2014 vegetation surveys - % occurrence of all taxa recorded in 40 x 40 cm cells**

species	2011	2014
<i>Eriophorum angustifolium</i>	95.4	82.0
<i>Eriophorum vaginatum</i>	87.8	86.8
<i>Calluna vulgaris</i>	74.0	74.1
<i>Erica tetralix</i>	39.1	43.6
<i>Campylopus</i> sp.	19.5	4.9
<i>Hypnum jutlandicum</i>	18.8	14.0
<i>Gymnocolea inflata</i>	14.1	ND
<i>Cladonia portentosa</i>	12.4	15.2
<i>Sphagnum</i> sp. other <sup>1</sup>	11.1	8.3
<i>Sphagnum capillifolium</i>	9.1	9.1
<i>Molinia caerulea</i>	8.3	16.1
<i>Isopterygium elegans</i>	7.4	4.1
<i>Scirpus cespitosus</i>	7.0	14.9
<i>Odontoschisma sphagni</i>	4.9	ND
<i>Cladonia chlorophaea</i>	3.0	1.1
<i>Calypogeia fissa</i>	2.6	ND
<i>Aulacomnium palustre</i>	2.1	ND
<i>Diplophyllum albicans</i>	1.6	2.4
<i>Polytrichum commune</i>	1.6	2.4
<i>Dicranum scoparium</i>	0.8	6.5
<i>Polytrichum alpestre</i>	0.4	ND
<i>Dicranum majus</i>	0.3	ND
<i>Drosera rotundifolia</i>	0.3	ND
<i>Rhytidiadelphus squarrosus</i>	0.3	ND
<i>Tetraphis pellucida</i>	0.3	ND
<i>Vaccinium myrtillus</i>	0.3	0.3
<i>Cladonia furcata</i>	ND	0.5
<i>Dicranella heteromalla</i>	ND	1.6
<i>Empetrum nigrum nigrum</i>	ND	0.1

ND = Not detected

<sup>1</sup>The *Sphagnum* sp. other category includes *S. cuspidatum* (recorded in 2014 only), and trace amounts of *S. tenellum*, *S. magellanicum* and *S. tenellum* (recorded in 2011 only).

#### 4.5 The New Forest SAC

The New Forest National Park covers over 500 km<sup>2</sup> in Hampshire, southeast England, approximately 20% of which is either heathland or grassland. Overall the New Forest encompasses a very wide range of terrestrial and freshwater habitats and was designated an SAC in 2005. Heathland was determined to be the most sensitive habitat type for the purposes of this study. Following considerable effort to find appropriate land for the co-location of vegetation surveying and meteorological/deposition monitoring, an area was identified at Hill Top, 2 km to the north east of Beaulieu. The vegetation survey plot of circa 150 m x 100 m is on a raised area of grazing land bordered by the Exbury Road to the south and west and Rolleston Road to the north, and is dominated by *Calluna vulgaris*, *Erica tetralix* and *Molinia caerulea*.



The results of the 2011 and 2014 vegetation surveys carried out between the 29<sup>th</sup> August and 2<sup>nd</sup> September 2011 and on the 21<sup>st</sup>, 22<sup>nd</sup>, 26<sup>th</sup> and 27<sup>th</sup> August 2014 respectively are shown below. The key monitored Natura 2000 habitat at the monitoring location is 'European dry heaths'.



**Figure 4.5.1 New Forest, Beaulieu site and surroundings (red box approximates to main vegetation and soil monitoring area)**



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**Figure 4.5.2 Aerial photograph (Google Earth) of New Forest, Beaulieu site, with vegetation survey areas bounded in green. Locations for the Meteorological/Deposition, and soil water monitoring sites indicated by blue and red symbols respectively.**





**Table 4.5**

**2011 & 2014 vegetation surveys - % occurrence of all taxa recorded in 40 x 40 cm cells**

species	2011	2014
<i>Calluna vulgaris</i>	97.9	94.5
<i>Molinia caerulea</i>	97.1	95.6
<i>Erica tetralix</i>	86.9	76.3
<i>Cladonia portentosa</i>	47.8	44.9
<i>Campylopus introflexus</i>	39.0	8.6
<i>Scirpus cespitosus</i>	12.0	10.1
<i>Dicranum scoparium</i>	6.3	0.1
<i>Polygala serpyllifolia</i>	6.2	0.9
<i>Sphagnum</i> sp.	4.7	2.0
<i>Eriophorum angustifolium</i>	4.2	0.5
<i>Leucobryum glaucum</i>	4.1	0.8
<i>Erica cinerea</i>	3.3	4.0
<i>Juncus squarrosus</i>	3.2	0.3
<i>Eurhynchium praelongum</i>	2.4	ND
<i>Hypnum cupressiforme</i>	1.9	0.4
<i>Ulex minor</i>	1.4	0.1
<i>Cladonia floerkeana</i>	1.0	0.5
<i>Agrostis curtisii</i>	0.8	ND
<i>Juncus articulatus</i>	0.7	ND
<i>Salix repens</i> agg.	0.7	0.3
<i>Cladonia furcata</i>	0.2	0.3
<i>Ilex aquifolium</i>	0.2	ND
<i>Drosera rotundifolia</i>	0.1	0.2
<i>Pedicularis sylvatica</i>	0.1	ND
<i>Quercus</i> sp.	0.1	0.1
<i>Cladonia fimbriata</i>	ND	0.1
<i>Cladonia ochrochlora</i>	ND	0.1
<i>Dicranella heteromalla</i>	ND	0.6
<i>Odontoschisma sphagni</i>	ND	0.4

ND = Not detected

#### 4.6 Skipwith Common SAC

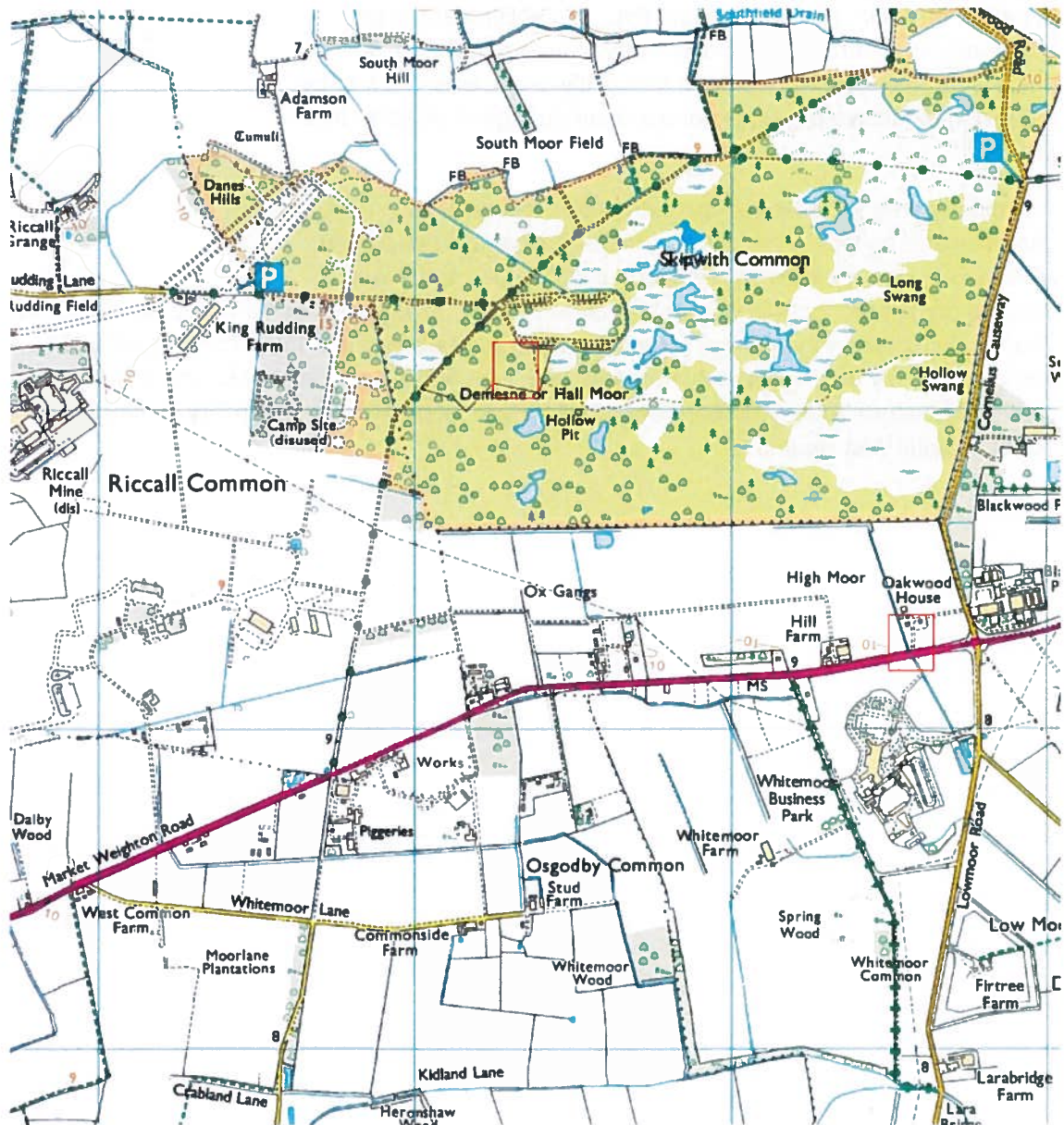
The Skipwith Common National Nature Reserve comprises approximately 270 hectares of open heath, wetlands, woodland and scrub and was designated an SAC in 2005. The Common is largely owned by the Escrick Park Estate and is managed by them in partnership with Natural England (NE). Establishment of the most suitable heathland vegetation survey area followed extensive discussion with local NE wardens to identify areas least likely to be subject to extensive physical management during the years of this project.



The survey area selected (of approximately 1 hectare) is characterised by typical heathland species including *Erica tetralix*, *Molinia caerulea*, *Calluna vulgaris*, but also includes some wetter patches dominated by *Eriophorum angustifolium* and a range of moss and liverwort species. The results of the two vegetation surveys conducted between the 1<sup>st</sup> and 5<sup>th</sup> August 2011 and the 28<sup>th</sup> July to 1<sup>st</sup> August 2014 respectively are provided in Table 4.6. The key monitored Natura 2000 habitats at the monitoring location are 'European Dry Heaths' and 'North Atlantic Wet Heaths'.



Figure 4.6.1 Skipwith Common and surroundings (red box approximates to main vegetation and soil monitoring area)



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**Figure 4.6.2 Aerial photograph (Google Earth) of Skipwith Common site, with vegetation survey areas bounded in green. Locations for the Meteorological/Deposition, and soil water monitoring sites indicated by blue and red symbols respectively.**

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**Table 4.6**

**2011 & 2014 vegetation surveys - % occurrence of all taxa recorded in 40 x 40 cm cells**

species	2011	2014
<i>Erica tetralix</i>	72.3	70.8
<i>Molinia caerulea</i>	66.8	57.2
<i>Calluna vulgaris</i>	57.6	23.0
<i>Eriophorum angustifolium</i>	53.8	62.0
<i>Sphagnum recurvum</i>	38.7	52.3
<i>Eurhynchium praelongum</i>	16.3	2.0
<i>Carex binervis</i>	12.9	0.9
<i>Campylopus introflexus</i>	9.8	7.6
<i>Campylopus paradoxus</i>	9.0	0.4
<i>Betula spp.</i>	7.9	9.7
<i>Juncus acutiflorus</i>	4.2	5.6
<i>Cladonia sp.</i>	3.6	0.4
<i>Gymnocolea inflata</i>	2.9	ND
<i>Hypnum jutlandicum</i>	2.2	15.0
<i>Juncus articulatus</i>	1.1	0.1
<i>Sphagnum palustre</i>	0.9	ND
<i>Cephalozia connivens</i>	0.5	0.9
<i>Lophocolea bidentata</i>	0.5	ND
<i>Pinus sylvestris</i>	0.5	0.1
<i>Cephalozia bicuspidata</i>	0.4	0.2
<i>Odontoschisma sphagni</i>	0.3	ND
<i>Pohlia nutans</i>	0.3	ND
<i>Agrostis sp.</i>	0.2	ND
<i>Calypogeia fissa</i>	0.2	2.4
<i>Eriophorum vaginatum</i>	0.2	ND
<i>Cladonia portentosa</i>	0.1	0.8
<i>Polytrichum commune</i>	0.1	0.3
<i>Potentilla erecta</i>	0.1	0.1
<i>Aulacomnium palustre</i>	ND	0.5
<i>Carex nigra</i>	ND	0.8
<i>Galium saxatile</i>	ND	0.1
<i>Juncus effusus</i>	ND	0.8
<i>Quercus robur</i>	ND	0.1

ND = Not detected

#### 4.7 Thorne Moor SAC

The Thorne Moor SSSI lies 8 km to the south of Goole in South Yorkshire. It comprises part of the Humberhead Peatlands National Nature Reserve - the largest area of raised bog wilderness in lowland Britain and was designated an SAC in 2005. A relic of the Humberhead wetlands, the site is characterised by substantial peat deposits that accumulated over millenia until peat became recognised as a major fuel resource in medieval times. More recently peat from the site has been exploited for horticultural use. Extraction for horticulture became mechanised in the 1960s and continued until 2004. Over the last decade Natural England have overseen a process of rewetting with the aim of encouraging *Sphagnum* mosses and Cotton grasses and restoring the Moor as a fully functioning bog.



Selection of the vegetation survey site followed discussions with Natural England staff and staff from Leeds University involved in studies of the carbon budget within the Thorne Moor system. It was not possible to identify any area completely devoid of extraction, so attention focussed on areas where water levels have been raised for several years and are now considered to be in a new stable state. The area selected is situated toward the centre of the reserve and covers circa 180 m<sup>2</sup>. The water table is generally very close to the surface and supports vegetation dominated by the Cotton grasses *Eriophorum vaginatum* and *Eriophorum angustifolium*, with *Calluna vulgaris* and *Erica tetralix* dominating slightly drier raised areas.

The results of the two vegetation surveys carried out between the 8<sup>th</sup> and 12<sup>th</sup> August 2011 and 4<sup>th</sup> and 8<sup>th</sup> August 2014 are shown below. The key monitored Natura 2000 habitats at the monitoring location are 'Degraded raised bogs' and 'Active raised bogs'.



**Box approximates to main vegetation**

ance number 100017572)

**Figure 4.7.2 Aerial photograph (Google Earth) of the Thorne Moor site, with vegetation survey areas bounded in green. Locations for the Meteorological/Deposition, and soil water monitoring sites indicated by blue and red symbols respectively.**



**Table 4.7**

**2011 & 2014 vegetation surveys - % occurrence of all taxa recorded in 40 x 40 cm cells**

species	2011	2014
<i>Calluna vulgaris</i>	71.4	42.1
<i>Erica tetralix</i>	46.9	37.2
<i>Eriophorum vaginatum</i>	46.2	51.1
<i>Eriophorum angustifolium</i>	44.4	69.9
<i>Sphagnum fimbriatum</i>	41.6	43.9
<i>Campylopus pyriformis</i>	20.2	14.4
<i>Polytrichum commune</i>	14.7	8.5
<i>Betula</i> spp.	13.9	7.6
<i>Pteridium aquilinum</i>	13.9	27.6
<i>Cladonia portentosa</i>	11.5	10.3
<i>Drosera rotundifolia</i>	5.7	2.7
<i>Calypogeia muelleriana</i>	2.9	0.4
<i>Eurhynchium praelongum</i>	2.9	ND
<i>Kurzia pauciflora</i>	2.1	ND
<i>Cephalozia connivens</i>	1.1	3.6
<i>Mylia taylorii</i>	0.8	ND
<i>Sphagnum papillosum</i>	0.7	ND
<i>Pohlia nutans</i>	0.6	ND
<i>Dryopteris dilatata</i>	0.5	ND
<i>Lophocolea bidentata</i>	0.5	0.3
<i>Cephalozia bicuspidata</i>	0.2	ND
<i>Vaccinium oxycoccos</i>	0.2	ND
<i>Andromeda polifolia</i>	0.1	ND
<i>Cratoneuron commutatum</i>	0.1	ND
<i>Rubus fruticosus</i>	0.1	ND
<i>Cladonia fimbriata</i>	ND	0.4
<i>Cladonia floerkeana</i>	ND	0.9
<i>Cladonia macilenta</i>	ND	0.1
<i>Drepanocladus revolvens</i>	ND	1.7
<i>Hypnum jutlandicum</i>	ND	6.8
<i>Sphagnum squarrosum</i>	ND	0.7



## 5. Bulk soil chemistry results

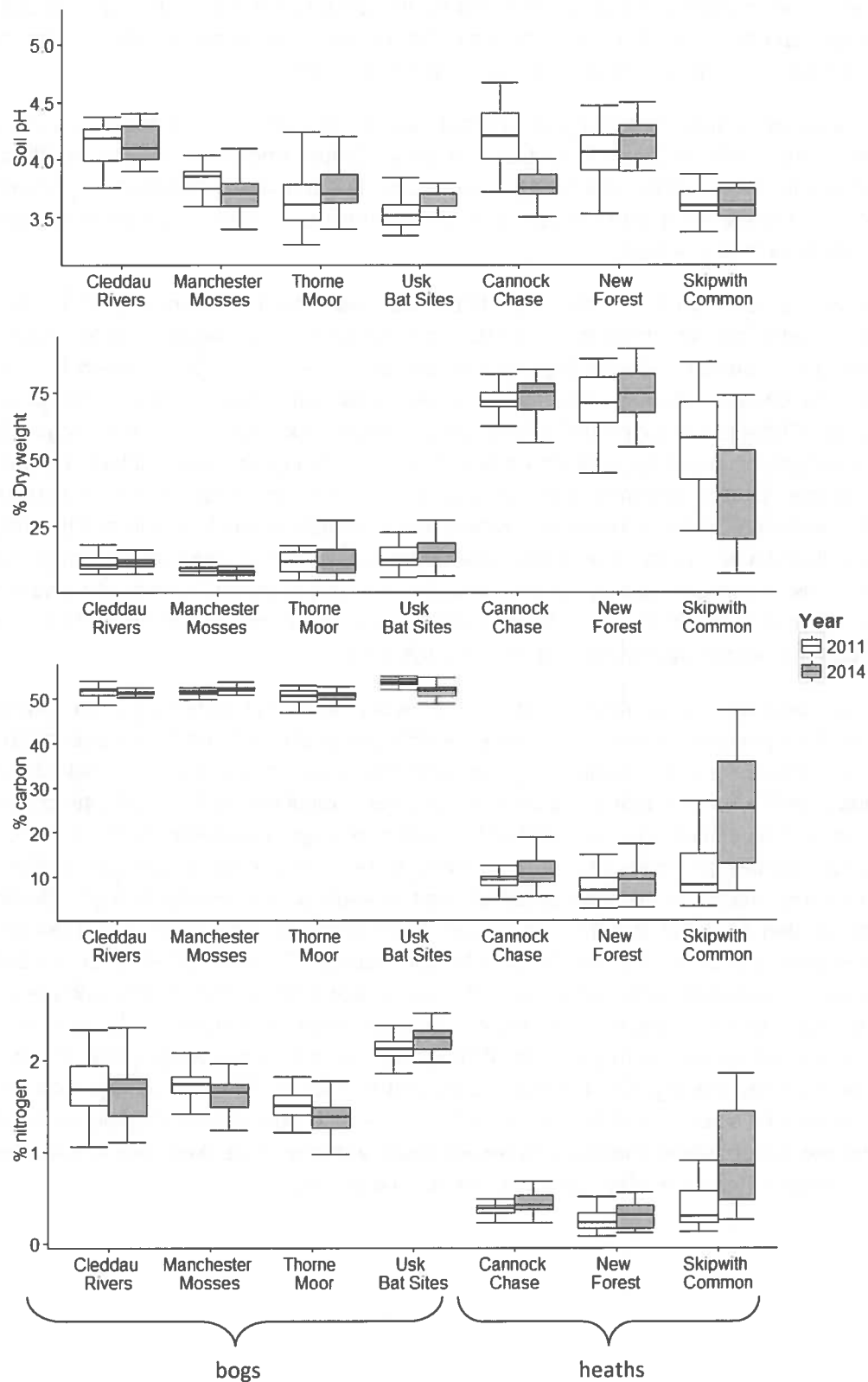
In the following section we present the bulk soil physical and chemical data in the form of boxplots. The boxplots summarise the distribution of data representing individual measurements made on soil samples taken from each quadrat surveyed for vegetation at each site. The median value is represented by the boxed centre line, the top and bottom of the boxes represent the 75th and 25th percentile values respectively and the top and bottom lines represent the maximum and minimum values respectively.

Measurements include percentage dry weight, soil pH (in water); percentage soil carbon and nitrogen, and their ratio in individual samples, Olsen phosphorus concentration, and exchangeable base cation (calcium, magnesium, sodium and potassium) concentration, potassium chloride-extractable nitrate and ammonium (as nitrogen – together representing the mineralisable component).

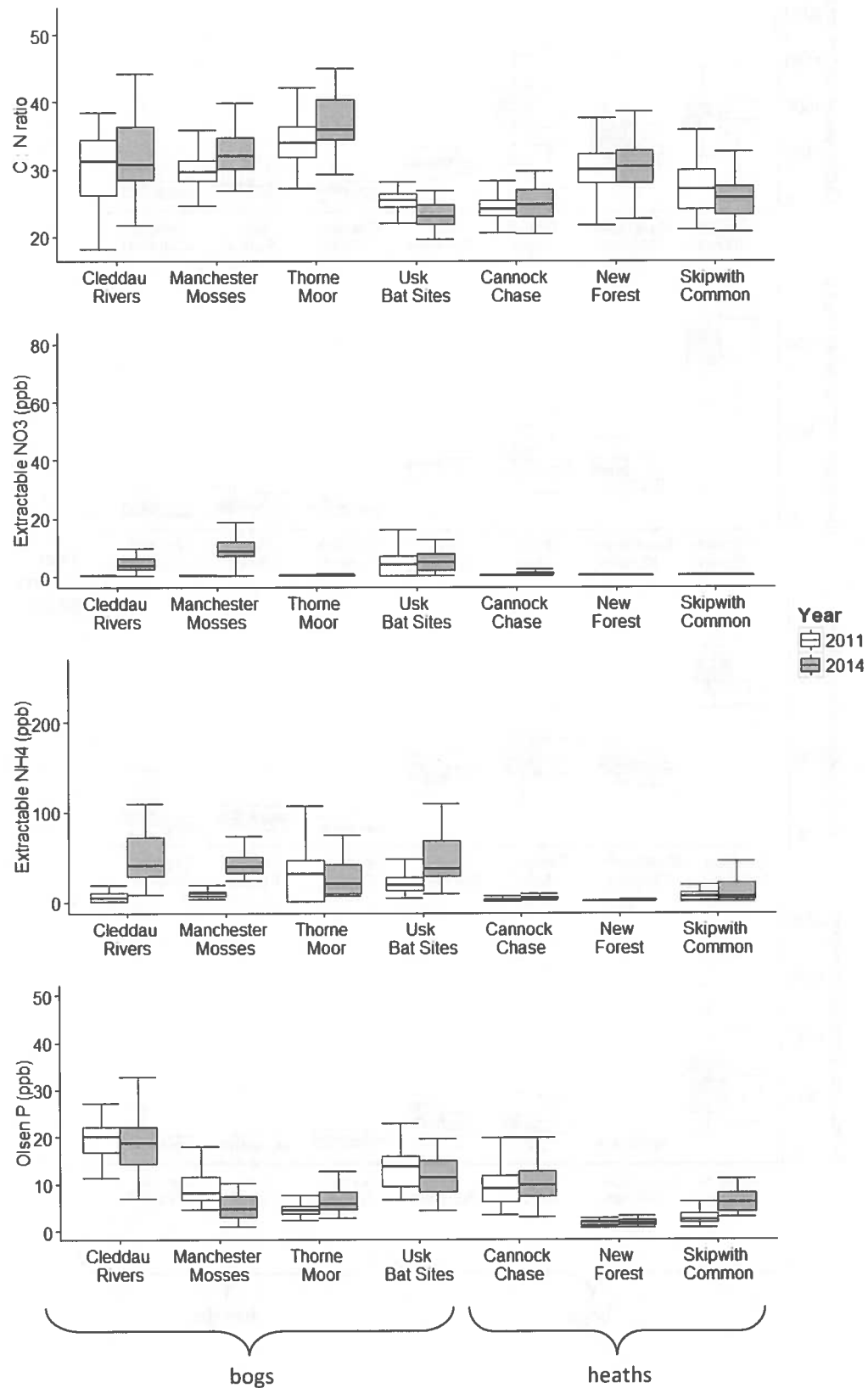
The measurements demonstrate clear differences between the chemistry of the bog and heathland soils that are broadly consistent with differences in organic matter content (as reflected by % carbon). Percentage carbon content of around 50%, as seen for Cleddau Rivers, Manchester Mosses, Thorne Moor and Usk Bat Sites, is typical for peat soils worldwide. Organic matter provides negatively charged surfaces, or ion exchange sites, to which positively charged base cations attach. Hence exchangeable base cation content tends to be higher for the peatland sites (Figure 5.3). Particularly high levels of sodium and magnesium in the Cleddau Rivers soils reflect the coastal location of the site and the influence of sea salts from sea spray. The higher organic matter content of peats also tends to result in higher levels of nitrogen than for mineral soils, but the ratio of carbon to nitrogen also tends to be much higher in the former as a consequence of the much higher carbon content, implying that these are comparatively nutrient-poor ecosystems.

There is considerable variation in soil pH between sites but generally good agreement between the two survey years. The HMN sites with lowest soil pH broadly correspond to those with the highest levels of recently estimated acid deposition (see Figure 6.8). Acid deposition acidifies soils (i.e. lowers their pH) as a result of gradual displacement of soil base cations with hydrogen and aluminium ions. Current soil pH will be strongly influenced by the historical acid deposition regime at these sites and is likely to be undergoing a gradual increase (i.e. becoming less acidic) at the most acidified sites at least, as a consequence of reductions in acid deposition over the last three decades. Such changes have been observed for soils analysed over this period by the UK Countryside Survey (CS) (Norton et al. 2012) although pH increases between consecutive surveys are mostly slight implying slow recovery rates. Despite this long-term national trend there is little evidence for consistent changes in soil pH between the two surveys of this project, although for two of the most acidic sites, Thorne Moor and Usk Bat sites, average soil pH was slightly higher in 2014. Reasons for significantly more acidic (lower pH) soils in 2014 relative to 2011 at Cannock Chase cannot be accounted for by any change in deposition chemistry in recent years and are more likely due to samples with higher average organic matter content in the second survey.

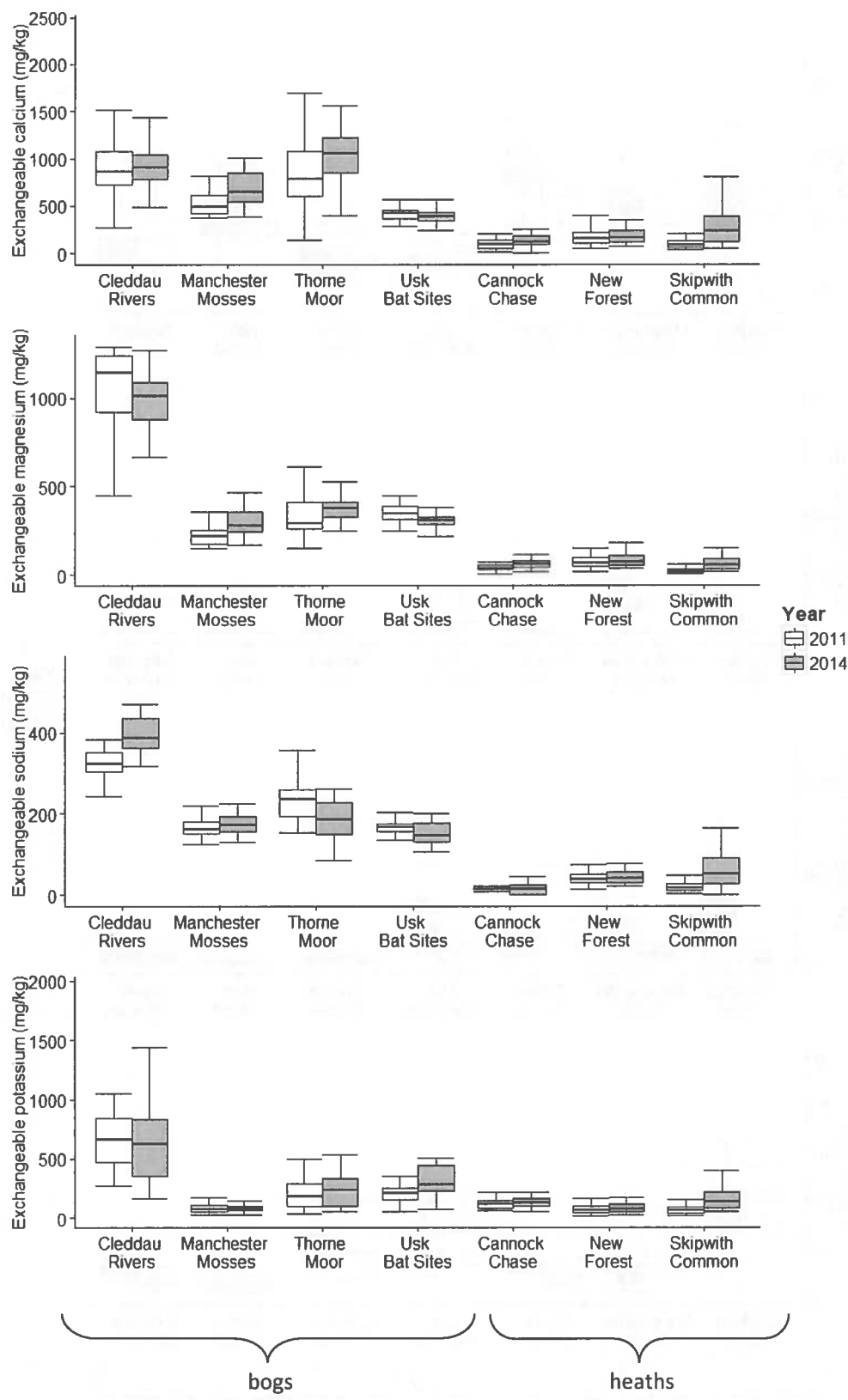
**Figure 5.1** Soil pH, percentage dry weight (i.e. weight of dried soil relative to the weight of the soil in its wet field condition), and percentage carbon and nitrogen of individual soil samples collected from the centre of each vegetation quadrat.



**Figure 5.2** Soil carbon: nitrogen ratio, extractable nitrate, ammonium and Olsen phosphorus of individual soil samples (in water) collected from the centre of each vegetation quadrat.



**Figure 5.3** Exchangeable base cation (calcium, magnesium, sodium and potassium) content of individual soil samples collected from the centre of each vegetation quadrat.



## 6. Model-based analysis of vegetation data

In this section we:

1. Summarise and compare the vegetation species richness and species compositional data for 2011 and 2014, identifying any differences between years.
2. Assess the typicality of the monitored plant communities by comparing the species composition of the 2011 and 2014 data with reference datasets representing heath and bog throughout Britain.
3. Use measured soil chemistry, local climate data and plant species composition, to populate plant species niche models in order to determine habitat suitability with specific reference to potentially deleterious influences of air pollution. Results are then interpreted and suitability of each site for positive and negative plant indicator species is estimated. Finally we highlight possible ecologically significant differences between years, and potential links to deposition legacy effects and other factors such as site management intervention.

### 6.1 Introduction

A primary requirement of the vegetation survey work was to assess “prevailing ecological condition at agreed Natura 2000 sites and any changes in the ecological condition over the period of monitoring”. It is possible that differences in species richness or composition between the 2011 and 2014 surveys might in part be attributable to ecological conditions driven by management and pollutant deposition legacies. However, significant shifts in vegetation over a period of only three years are likely to be difficult to detect. Differences over such a short period will be influenced by a range of factors including variation in recording effort, transient within-year weather impacts on species population size and the consequences of placing plots in newly randomised locations (Pitcairn *et al.* 2004). Trends in vegetation species composition that can be directly linked with recovery from acidification at Environmental Change Network (ECN) sites are only now becoming clear after 20 years of monitoring at an approximately three year frequency (Rob Rose (CEH) *pers. comm.*). The ECN data show marked variation around the trend that may be due to several of the factors listed above. Similarly, observations from CS have shown a consistent increase in substrate pH between 1978 and 2007 (Norton *et al.* 2012) and an indication of coupled recovery in plant species composition, although this has yet to be fully explored.

While consistent increases or reductions in richness might reflect wider positive or negative ecological change, responses in vegetation to any change in the chemical environment are therefore not necessarily expected over such a short period, particularly if chemical changes have been relatively slight. However, in the following sections we do consider the extent to which any differences we identified were consistent with a directional response. To aid the assessment of the monitoring sites we compare soil chemistry and plant species compositional features with a reference dataset for heaths and bogs throughout the rest of Britain in order to gauge whether or not the HMN sites may be considered typical of these habitats nationally. Finally we repeat the species niche modelling work first described in the Third Report. Soil and vegetation data for 2011 and 2014 are used to produce modelled Habitat Suitability values and results interpreted in a similar manner to that reported previously, thus forming the basis for judgements about the likely favourability of ecological conditions on each site in each year for a range of indicator species used to assess habitat



condition by the conservation agencies. The same suite of indicator species is used. A justification and criteria for selection was provided in the 2011 report.

## 6.2 Methods

### 6.2.1 *Differences in plant community composition and richness between 2011 and 2014*

The total number of species recorded at each site was calculated for both survey years. Effort was made to standardise nomenclature between the two years so that a valid comparison could be made. There were small differences in the numbers of plots recorded at some sites between years and so species frequencies are expressed in this section as percentages throughout.

In order to investigate differences in vegetation community composition between surveys and between sites we used a multivariate statistical method known as non-metric multidimensional scaling (NMDS) ordination (see for example <http://www.tqmp.org/RegularArticles/vo102-1/p026/p026.pdf> for further explanation of the technique). NMDS first determines how different the species composition of each vegetation plot (i.e. quadrat) is from all other plots using one of a number of possible mathematical techniques. In our analysis we used a technique known as "Bray-Curtis dissimilarity" which is commonly used to compare and contrast the species composition of ecological communities. The resulting Bray Curtis distances were then used to arrange the vegetation plots within two dimensional graphs, known as NMDS ordinations. In such an ordination, individual symbols representing each vegetation plot cluster closely together if they contain a very similar set of species, but are spaced at increasing distances apart as their species complements becomes increasingly different. NMDS spaces the points representing each vegetation plot along a horizontal axis (Axis 1) on the basis of the primary difference in species composition between all plots. Then it spaces out vegetation plots, that may be similar with respect to their primary features (i.e. those that have similar Axis 1 positions), on the basis of secondary (or residual) differences on the vertical axis (Axis 2). The major differences in species composition between sites or years are therefore reflected by the relative positions of points along the two axes. Several axes can be included in such an analysis, but normally the most of the important gradients of difference between plots (i.e. those explaining the majority of the difference between plots) can be linked to the first two, or possibly three, axes.

The NMDS approach was used both to compare the similarity of vegetation plots recorded across the HMN and between survey years, and to consider how these compared with bog and heath vegetation at a much larger number of sites across the UK by the 2007 UK CS. The CS comparison enabled the vegetation characteristics of HMN sites, which were originally selected on the basis of their historical proximity to major S and N emission sources and may therefore be expected to have been relatively strongly affected by atmospheric pollutants, to be considered in the context of a much broader range of environmental conditions including relatively unpolluted areas such as the north west of Scotland.

Finally, NMDS was used to investigate the relationship between the spacing of the vegetation plots in a combined HMN CS ordination, and the primary direction of variation in soil chemistry of the plots. In this case a species-environment graph was produced within which arrows (or vectors) representing gradients of change in key soil variables (e.g. pH, carbon:nitrogen ratio

or soil moisture) were superimposed on the vegetation ordination. The direction of the arrow indicates the direction of greatest increase in the variable of interest. The modelling was performed so that the environmental information did not influence the distribution of points which, therefore, remained solely dependent on relative species composition. The method helps to indicate whether the vegetation-based spacing of plots in the ordination is linked to variation between plots in particular soil chemical properties. The relative length of each arrow indicates the relative strength of the relationship between the environmental variable and the ordination axes, so that longer arrows indicate a variable is more strongly correlated with the major differences in vegetation. Finally, the relationship between the position of an individual plot (i.e. each point in the ordination) and an environmental gradient (represented by an arrow) is determined by considering at what point along an arrow a hypothetical line passing perpendicularly through it would connect with that point. Hence, plots lying at the base of an arrow representing soil pH will be both similar to each other in terms of vegetation composition, and indicative of soils of lower pH than plots positioned further up the arrow.

#### 6.2.2 Comparison with average heath and bog plant community data from Britain

To place the communities recorded at the HMN sites in a national context, community composition of individual vegetation plots was compared with that of CS 2007, a standardised vegetation survey conducted across the UK (Norton *et al.*, 2012), again using NMDS. The CS covers a much broader range of habitat types than those studied here so, to maintain comparability, we restricted that dataset to heath and bog sites only. CS bog vegetation plots were further restricted to those for which soil chemistry data were available and percentage carbon was greater than 40%, to ensure these were comparably peaty to the HMN plots. Since bryophytes and lichens were recorded at broad taxonomic levels only by CS, comparisons were restricted to vascular species only. The ordination and vector fitting procedure was then repeated including both CS and HMN sites. Quadrat sizes were the same in both HMN and CS datasets.

The R statistical analysis software package *vegan* was used to create the ordination (function *metaMDS*) and fit vectors (function *envfit*) (Oksanen *et al.*, 2011).

#### 6.2.3 Habitat Suitability modelling

The plant species niche model MultiMOVE was run for all indicator species (Table 6.1) for which model data were available. MultiMOVE predicts the suitability of a habitat for individual species on the basis of plant Ellenberg scores derived for the site (see Third Report). The modelling routines were performed twice: first using climate, canopy height and the composition of the vegetation community excluding the species of interest (i.e. Hs\_V) (to provide the site Ellenberg score), and then using climate, canopy height and soil chemistry data (i.e. Hs\_S). In the latter routine, soil chemistry data were used to predict the site Ellenberg values required by the model (i.e. soil pH, soil moisture and soil carbon to nitrogen ratio) using a set of calibration equations. These conform to those reported in Smart *et al.* (2010) and are provided in Appendix 2.

Identical climate and canopy height data inputs were used in both modes (Table 6.2) so that differences between them could only be due to whether ecological conditions were estimated from neighbouring plant species or from soil measurements. The raw probabilities generated

by MultiMOVE were rescaled to correct for differing species prevalence in the training data using the formula in Albert & Thuiller (2008) (and see Appendix 2).

MultiMOVE was applied to the same positive and negative indicator species list used in the Third Report (Table 6.1). The modelling was repeated for the 2011 soil and vegetation data and newly applied to the 2014 data. The new results shown here for 2011 differ slightly from previously because a new iteration of the MultiMOVE package has been applied. The new version has been updated with more accurate and relevant dataset of long term annual average climate data. Two new statistical modelling techniques (Random Forests and Neural Networks) have also been included. This increases the number of methods in the ensemble to five, thus helping to more clearly indicate the range of uncertainty associated with model fitting by providing a wider suite of predictions based on different statistical approaches.

As in the previous report, MultiMOVE was used to model habitat suitability for a set of indicator species at each site. Suitability was predicted from both measured soil conditions and the species composition for both survey years. As previously outlined, three scenarios are possible:

- a) High values for both sets of indices suggest that conditions on site are favourable for the indicator species.

Differences in values may highlight situations where the soil and vegetation are to some extent uncoupled, for instance:

- b) Soil conditions may be recovering from historically high sulphur deposition but the plant assemblage is responding more slowly. Such lag effects might result in higher habitat suitability scores based on soil data compared to scores based on the vegetation species composition.
- c) Conversely, soil-derived scores may be lower than those based on the current species composition. If recovery is expected, this could suggest that the species present are not hindered by those aspects of unfavourable soil conditions that led to lower soil-based scores, or that interventions, such as site management, are over-compensating for less favourable soil conditions. An alternative scenario is that plant species are lagging behind soil conditions and so would be expected to decline in future. Thus the differences between the two types of score should reduce but toward lower habitat suitability. The latter scenario would only apply with a progressive change toward less favourable conditions rather than recovery. With respect to impacts of deposited pollutants this would seem unlikely in the context of widely reported improvements in air quality over the past three decades (e.g. see RoTAP, 2012).

Due to uncertainty in the relationship between soil conditions and Ellenberg scores, soil-derived scores often differ significantly from vegetation-derived scores, and are generally lower (Smart *et al.*, 2010). This uncertainty will be responsible for some of the difference observed between soil-derived and vegetation-derived habitat suitability. However this fraction will remain constant over time since the models remain fixed. Therefore, if the difference between soil and vegetation derived habitat suitability changes between the 2011 and 2014

survey this indicates the difference is not solely due to the calibration uncertainty and may reflect the processes detailed above.

The aims of the MultiMOVE modelling were therefore to:

- a) Re-run models for the 2011 survey with the new MultiMOVE model (v 2.0.1) containing two additional techniques and updated climate data.
- b) For both years, run the model using ecological conditions estimated from the surrounding plant community (Hs\_V) and from measured soil conditions (Hs\_S). As in the previous report soil pH, soil moisture, % carbon and % nitrogen were the soil variables used.
- c) Compare Hs\_V and Hs\_S both within and between years to identify differences that may be due to lags in response of either soil or vegetation and other factors that could be responsible for these differences (see section 6.1.1)
- d) Evaluate the results in the context of changes in ecological conditions estimated from the plant community (summarised as Ellenberg scores) compared to changes in soil variables over time

**Table 6.1. List of indicator species modelled for each site**

Site	Indicator species modelled
Manchester Mosses	<i>Calluna vulgaris</i> <i>Deschampsia flexuosa</i> <i>Dicranum scoparium</i> <i>Molinia caerulea</i> <i>Pteridium aquilinum</i> <i>Vaccinium myrtillus</i> <i>Vaccinium vitis-idaea</i>
Cannock Chase	<i>Calluna vulgaris</i> <i>Dicranum scoparium</i> <i>Drosera rotundifolia</i> <i>Erica tetralix</i> <i>Eriophorum angustifolium</i> <i>Eriophorum vaginatum</i> <i>Molinia caerulea</i> <i>Narthecium ossifragum</i> <i>Pteridium aquilinum</i> <i>Sphagnum capillifolium</i> <i>Sphagnum papillosum</i> <i>Sphagnum tenellum</i> <i>Vaccinium oxycoccos</i>
Cleddau Rivers	<i>Calluna vulgaris</i> <i>Dicranum scoparium</i> <i>Drosera rotundifolia</i> <i>Erica tetralix</i>



	<i>Eriophorum angustifolium</i> <i>Eriophorum vaginatum</i> <i>Molinia caerulea</i> <i>Polytrichum commune</i> <i>Sphagnum capillifolium</i> <i>Sphagnum magellanicum</i> <i>Sphagnum recurvum</i> <i>Sphagnum tenellum</i> <i>Vaccinium myrtillus</i>
Usk Bat Sites	<i>Agrostis curtisii</i> <i>Calluna vulgaris</i> <i>Dicranum scoparium</i> <i>Drosera rotundifolia</i> <i>Erica cinerea</i> <i>Erica tetralix</i> <i>Eriophorum angustifolium</i> <i>Molinia caerulea</i> <i>Sphagnum tenellum</i>
New Forest	<i>Calluna vulgaris</i> <i>Erica tetralix</i> <i>Eriophorum angustifolium</i> <i>Eriophorum vaginatum</i> <i>Juncus acutiflorus</i> <i>Molinia caerulea</i> <i>Polytrichum commune</i> <i>Sphagnum recurvum</i>
Skipwith Common	<i>Calluna vulgaris</i> <i>Drosera rotundifolia</i> <i>Erica tetralix</i> <i>Eriophorum angustifolium</i> <i>Eriophorum vaginatum</i> <i>Pteridium aquilinum</i> <i>Rubus fruticosus</i> agg. <i>Sphagnum papillosum</i> <i>Vaccinium oxycoccos</i>
Thorne Moor	

**Table 6.2. Climate and cover-weighted canopy height inputs for each site. Climate data are long term annual averages from 1961-1990 based on UK Met Office data for the 5x5 km square containing each site. Cover-weighted canopy height values are based on a cover weighting applied to the average canopy height of each plant species divided into the ordinal categories of Grime et al (1995) as follows: 1, <100mm; 2, 101-299mm; 3, 300-599mm; 4, 600-999mm; 5, 1.0-3.0m; 6, 3.1-6.0m, 7, 6.1-15.0m; 8, >15m.**

SITE	Mean cover-weighted canopy height (see legend for interpretation)	Standard error	Mean annual precipitation (mm)	Temperature (°C)	
				Min January	Max July
CANNOCK CHASE	2.32	0.040	679	0.15	19.77
CLEDDAU RIVERS	3.55	0.046	1331	2.29	18.32
MANCHESTER MOSSES	3.71	0.021	877	1.31	20.12
NEW FOREST	3.60	0.023	841	2.09	21.74
SKIPWITH COMMON	3.42	0.036	592	0.50	20.16
THORNE MOOR	3.64	0.065	569	0.63	20.48
USK BAT SITES	3.56	0.012	1414	0.29	18.3

## 6.3 Results

### 6.3.1 Species richness and presence of Common Standards Monitoring indicators

Table 6.3 shows that the total number of species recorded was similar between 2011 and 2014 at most sites. The species lists for the three bog sites, Cleddau Rivers, Usk Bat Sites and Thorne Moor, were slightly shorter for the 2014 survey. Differences are largely accounted for by a reduction in the total number of bryophytes recorded, and the majority of these were only detected in trace amounts in the 2011 survey. Despite a carefully prescriptive monitoring protocol, these differences are likely to result predominantly from between-surveyor errors. In contrast to the recording of vascular plants, most bryophytes were not identified in the field. Rather, a voucher specimen of each newly detected distinct bryophyte form was coded in the field and returned to CEH for specialist identification. The field surveyors went on to record the presence/absence of all individual plants conforming visually to each voucher specimen collected. Significantly fewer voucher specimens were collected during the 2014 survey, perhaps indicating a sharper awareness of what are often subtle taxonomic differences between bryophyte species in 2011.

Of the Common Standards Monitoring (CSM) indicator species identified for the modelling exercise, eight species were not recorded at any site in 2014 (Table 6.4). Of these species most were rare in 2011, i.e. found in a few quadrats only. Only *Eriophorum vaginatum*, present

in 8 plots in 2011 at Cleddau Rivers, was relatively frequent in 2011 and not recorded in 2014. Being a large, potentially dominant perennial graminoid, it is most unlikely that this species has become extinct at the monitoring site within three years. More likely is that the newly randomised plot locations in 2014 simply failed to coincide with the species which was, in any event, infrequent in 2011.

**Table 6.3. Total number of species recorded per site in the two years**

SITE	2011	2014
Manchester Mosses	14	15
Cannock Chase	25	24
Cleddau Rivers	29	20
Usk Bat Sites	26	20
New Forest	25	24
Skipwith Common	28	26
Thorne Moor	26	20

**Table 6.4. Indicator species used for modelling that were not recorded on sites in 2014 having been recorded in 2011. Positive [+] and negative [-] CSM indicators are highlighted using the same notation as the Third report, summarising the 2011 vegetation monitoring.**

SPECIES	NUMBER OF PLOTS OCCUPIED		SITE
	2011	2014	
<i>Sphagnum papillosum</i> [+]	1	0	Manchester Mosses
<i>Eriophorum vaginatum</i> [+]	8	0	Cleddau Rivers
<i>Pteridium aquilinum</i> [-]	3	0	Cleddau Rivers
<i>Drosera rotundifolia</i> [+]	1	0	Usk Bat Sites
<i>Agrostis curtisii</i>	3	0	New Forest
<i>Eriophorum vaginatum</i> [+]	1	0	Skipwith Common
<i>Andromeda polifolia</i> [+]	1	0	Thorne Moor
<i>Rubus fruticosus</i> agg. [-]	1	0	Thorne Moor
<i>Sphagnum papillosum</i> [+]	3	0	Thorne Moor
<i>Vaccinium oxycoccos</i> [+]	1	0	Thorne Moor

The ordination of HMN plots (Figure 6.1) provided no indication of significant shifts in plant communities at individual sites between the two years. The points in Figure 6.1 representing plots for each site are clearly clustered however, with the dry heath at Cannock Chase and the rewetted Manchester Mosses sites defining each end of axis 1. This indicates that the primary determinant of differences in vegetation between sites is soil moisture or a closely associated parameter. It should also be noted that the bog, Usk Bat Sites and Thorne Moor, and heathland, Skipwith Common and New Forest, communities are broadly similar to each other, i.e. they occupy similar ordination space.

A comparison of HMN vascular plant communities with the CS data is provided in Figures 6.2a-b. The inclusion of soil chemistry vectors in these plots demonstrates that in general HMN sites were characterised by lower soil pH and higher C:N ratio than the CS reference data. The distribution of the HMN bog plots (Figure 6.2b) indicate that the vegetation composition of the sites that are likely to have received high levels of acid deposition historically (and are at the higher end of recent HMN acid deposition estimates), i.e. Thorne Moor and Usk Bat Sites, is unusual relative to the vegetation characteristics of all CS sites (i.e. these HMN plots lie at the edge of the distribution of all CS plots). The position of plots for these sites in the ordination is also associated with low soil pH, i.e. plots are aligned at the base of the pH arrow. In contrast, the vegetation composition of the less impacted Cleddau Rivers plots appears more typical of the wider distribution of CS plots, i.e. these plots lie in the centre of the CS distribution, and appears associated with soils of higher pH.

The output from an NMDS modelling run also includes scores for individual species. These "species scores" indicate to what extent each species is associated with the dominant axes of community variation. In the case of the HMN-CS bog ordination, species with negative Axis 1 and Axis 2 scores are likely to be associated with higher pH soils (see Figure 6.2b). There are two species with negative Axis 1 and Axis 2 scores that are abundant at Cleddau Rivers but absent at Thorne Moor and Usk Bat sites, namely the bog asphodel (*Narthecium ossifragum*) and Common Tormantil (*Potentilla erecta*). It is likely therefore that the presence/absence of these two species have had a strong influence on the relative position of plots from the three sites in the ordination.



**Figure 6.1. NMDS ordination of all HMN plots coded by year and site. The ordination is based on the presence or absence of each species in each plot and does not include any information on relative abundance of species. Sites are referred to by three letter codes (MAN = Manchester Mosses, CAN = Cannock Chase, CLR = Cleddau Rivers, USK = Usk Bat Sites, NEW = New Forest, SKI = Skipwith Common, THO = Thorne Moor).**

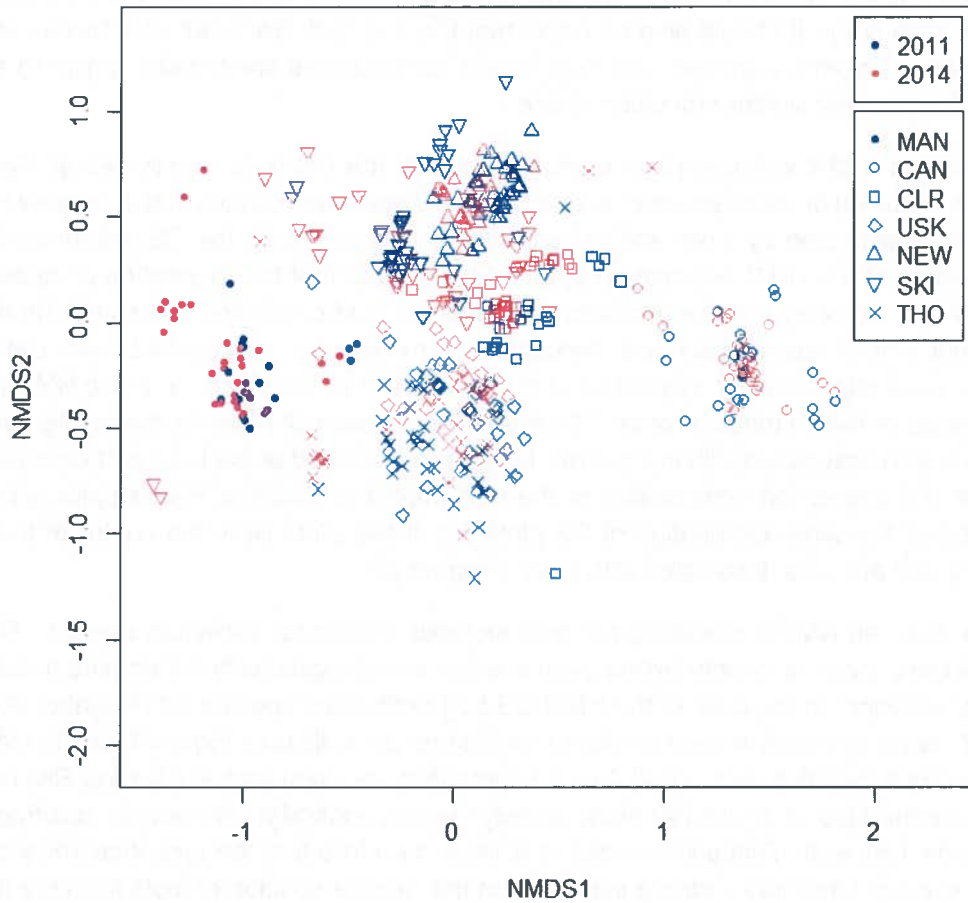
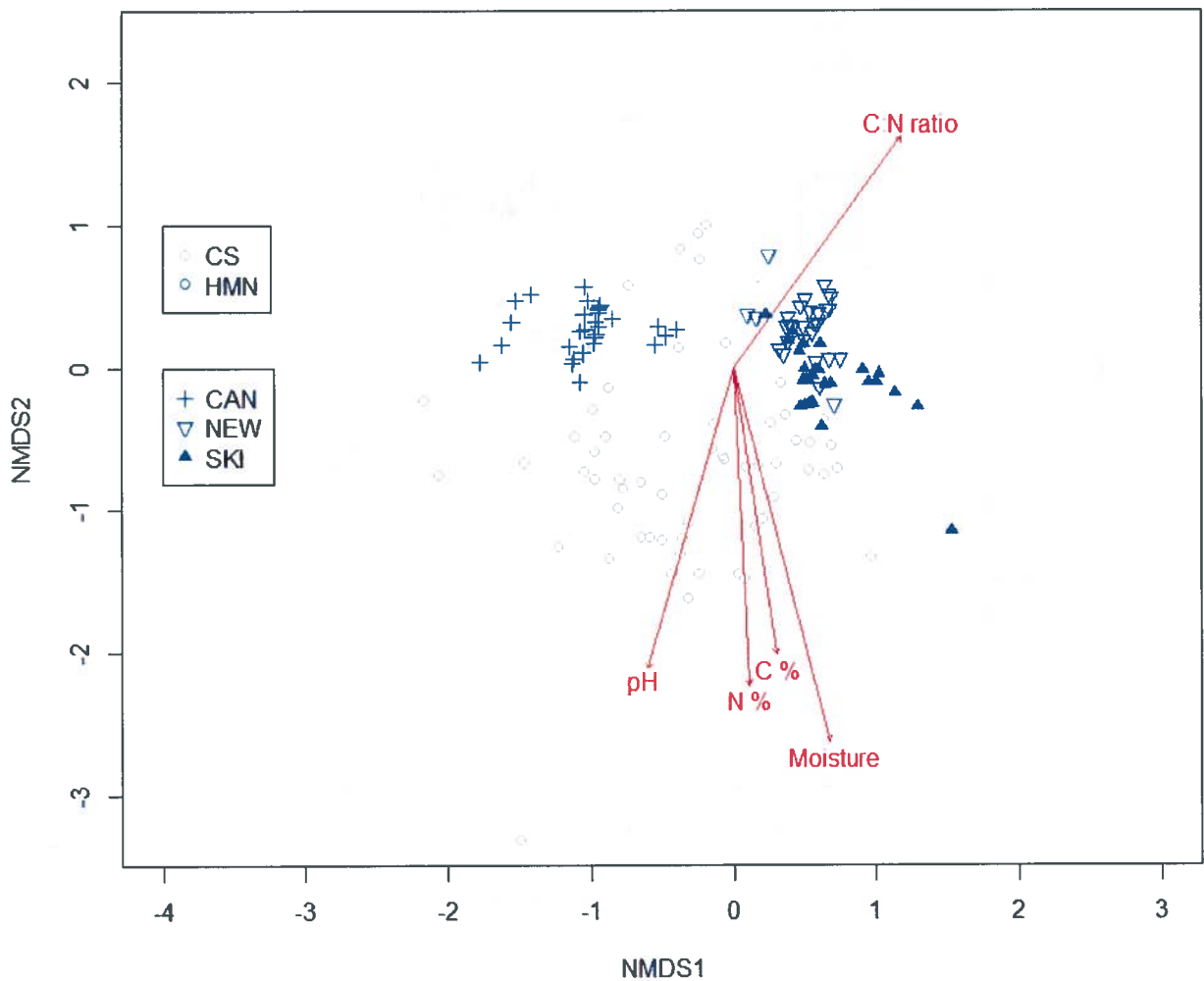
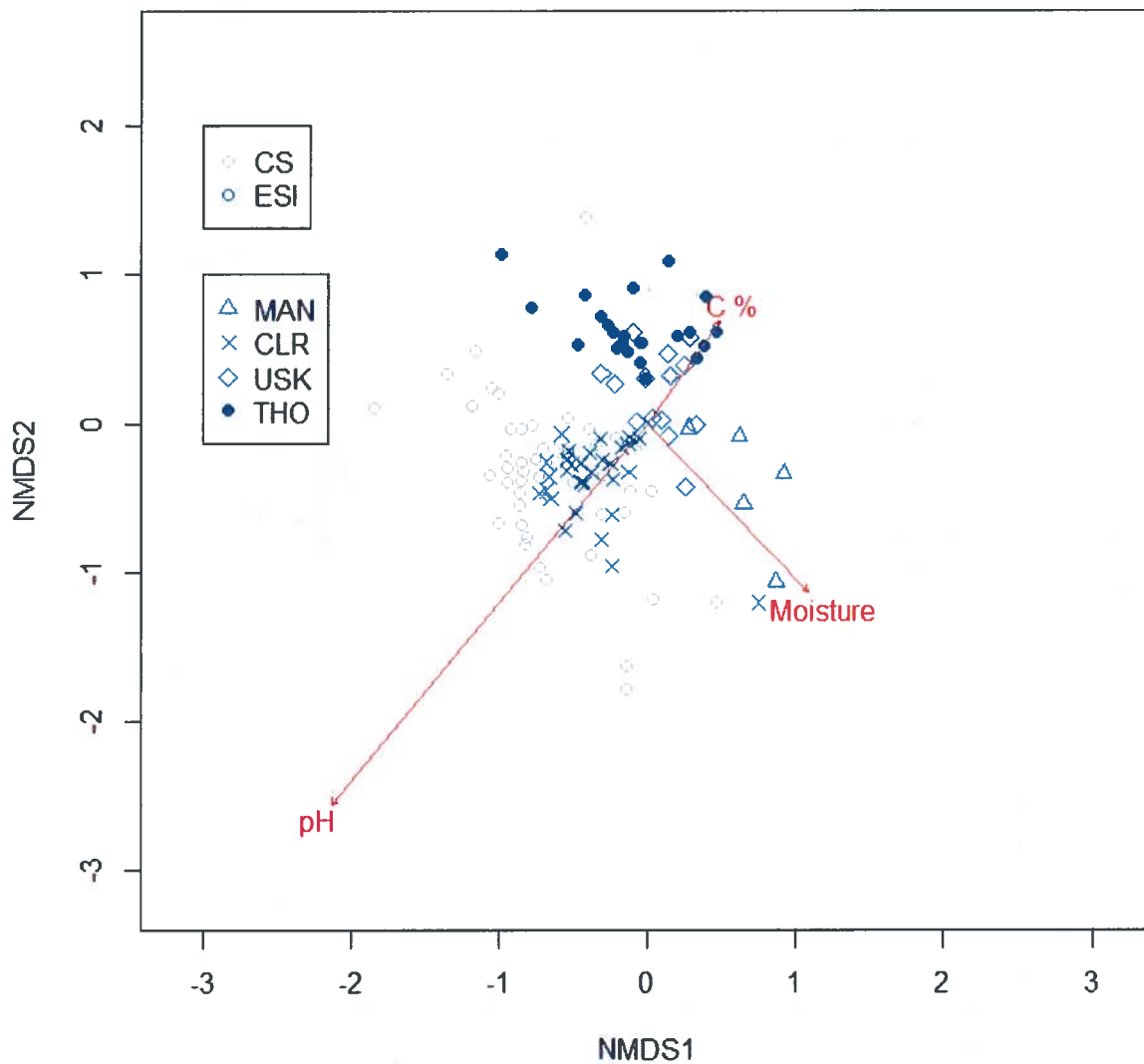


Figure 6.2a. NMDS ordination of the vegetation composition of Habitats Monitoring Network (HMN) and Countryside Survey (CS) healthland plots. Vectors (arrows) represent environmental correlates of community compositional differences between sites. Habitats Monitoring Network sites are designated by codes as in Figure 1. Note that most soil chemical variables are most associated with the second axis of variation in the vegetation (i.e. arrows are predominantly vertical rather than horizontal). This indicates that the vegetation of the HMN sites is characteristic of soils of relatively low pH, that are also relatively dry and contain relatively low % carbon and % nitrogen. The vegetation of Cannock Chase is characteristic of soils with intermediate carbon:nitrogen (C:N) ratios (relative to CS), whereas that for Skipwith Common and New Forest is characteristic of sites with relatively high C:N.

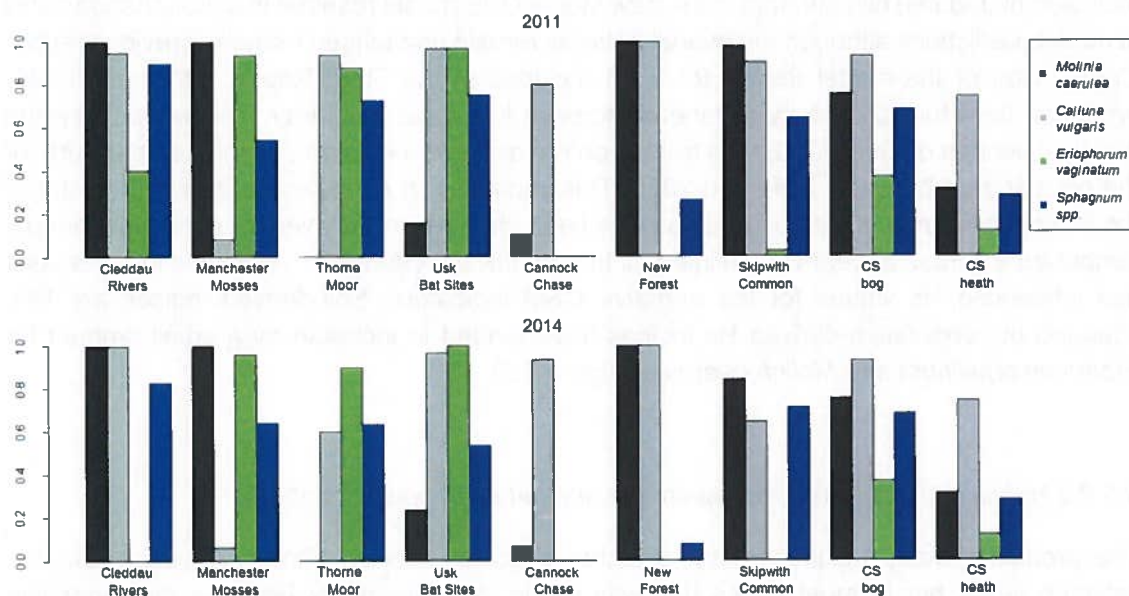


**Figure 6.2b. NMDS ordination of the vegetation composition of Habitats Monitoring Network (HMN) and Countryside Survey (CS) bog plots. Vector (arrows) represent environmental correlates of community compositional differences between sites. Habitats Monitoring Network sites are designated by codes as in Figure 1. This indicates that the vegetation of Thorne Moor (THO), Usk Bat Sites (USK) and Manchester Mosses (MAN) is characteristic of soils of relatively low pH. The vegetation on Manchester Mosses is also characteristic of sites with higher moisture content. The vegetation of Cannock Chase (CAN) is characteristic of soils with higher pH, and lower % carbon content.**



Comparison of CS and HMN data in terms of the frequency of characteristic dominant species of heath and bog showed that CS plots in fact had generally lower frequencies than HMN sites (Figure 6.3). The distributions of species on each HMN site were very similar between surveys, the major difference being the absence of *Eriophorum vaginatum* at Cleddau Rivers in 2014. Of the species shown, all are positive CSM indicators although in degraded bog and heath *E. vaginatum* and *Molina caerulea* can reach high abundance associated with very low species richness (see for example Heal & Diemont 1983; Yeo 1997). There is no evidence that this is the case on HMN sites.

**Figure 6.3. Comparison of between-plot frequencies of characteristic dominants in heath and bog comparing Habitats Monitoring Network sites with Countryside Survey (CS) reference data from 2007.**





### 6.3.2 Habitat Suitability modelling

The following section is based on interpretation of Figures 6.4 – 6.7. Figure 6.4 demonstrates relationships between the frequency of detection of the sensitive lichen *Cladonia* sp. and estimates of nitrogen deposition. The bar plots in Figures 6.5a-g represent MultiMove inferred habitat suitability score for the indicator species recorded at each HMN site in 2011 and 2014. Figure 6.6 displays the variation between plots in community mean traits used to predict Habitat Suitability from vegetation composition for 2011 and 2014 for each of HMN site and compares this to data derived from the CS heath and bog sites. Figures 6.7a and 6.7b show the variation between plots in soil variables used to predict Habitat Suitability from vegetation composition for 2011 and 2014 for each HMN site and compares this to data derived from the CS heath and bog sites.

#### 6.3.2.1 Differences attributable to application of the new Multimove model

Inclusion of updated climate data in the new MultiMOVE model resulted in minor changes only in model predictions although the overall patterns remain unchanged from the previous report. Comparison of the model results for 2011 included in the Third Report with those newly produced here for 2011 show a general increase in habitat suitability. This is because the previous version of MultiMOVE was trained on the average minimum January temperature for the coldest year between 1961 and 2000. This variable is a much less effective predictor of the ecological climate envelope and has now been changed to the average minimum January temperature across all years in the interval. Importantly the change in model and input dataset has influenced Hs values for the negative CSM indicators. Soil-derived indices are little changed but vegetation-derived Hs indices have tended to increase by a small amount for *Pteridium aquilinum* and *Molina caerulea* (Figure 6.5).

#### 6.3.2.2 Habitat Suitability results; within-site and between-species patterns

The predicted Habitat Suitability for selected indicator species showed modest variation between years but in most cases this was within the uncertainty between the modelling approaches (Figure 6.5). The most consistent differences were observed in the heathland sites, especially the New Forest, Skipwith Common and to a lesser extent Cannock Chase.

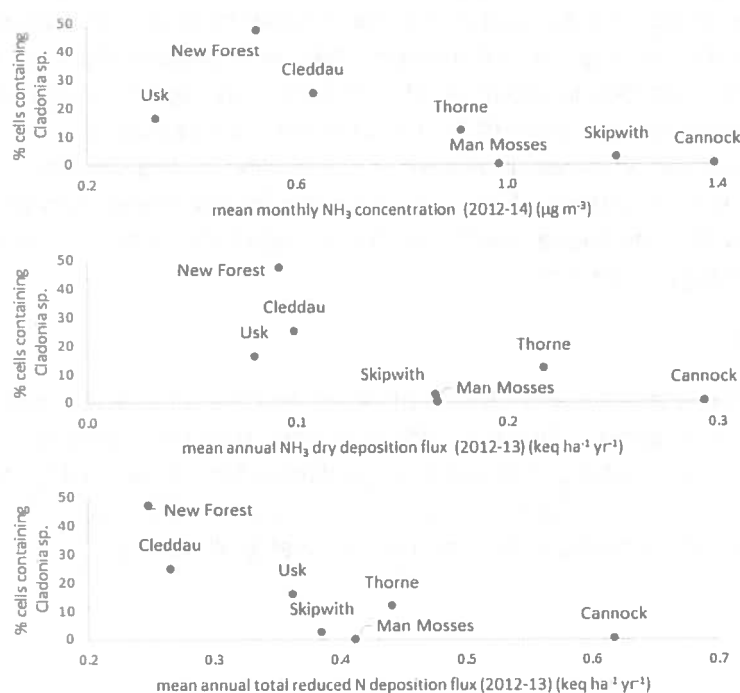
Overall, the mean species-compositional indices used as input to MultiMOVE and derived from the vegetation data, were relatively consistent between surveys (Figure 6.6). Some changes were observed, particularly in Ellenberg R which is intended to reflect variation in alkalinity. Both Skipwith Common and Thorne Moor showed a shift over time towards higher Ellenberg R values, indicative of a plant community associated with higher pH. There was a hint of slightly higher soil pH values at Thorne Moor in the later survey, but this was not statistically significant, while there was no indication of any change in soil pH at Skipwith Common. It is feasible that these positive shifts in Ellenberg R at two of the most acid impacted sites might be indicative of a more lagged response to a longer term gradual increase in soil pH.

Changes in mean Ellenberg R that are not mirrored by soil pH change might also implicate other factors that change the index via changes in species composition. For example small subordinate stress-tolerators with low Ellenberg R values that may have been observed less frequently in the second survey by chance or declined in frequency, either because of change in recorder effort or because of management or weather effects, could have contributed to an artificial increase in Ellenberg R. For example a drier summer could reduce the appearance and frequency of *Vaccinium oxycoccus* and *D.rotundifolia* and increase grass cover which would tend to increase mean Ellenberg R. Over such a short period as three years and when comparing only two surveys, such dynamic within-year factors might be expected to dominate rather than the effects of chronic, long term directional vegetation change (e.g. Pitcairn et al 2004).

### 6.3.3. Lichen cover

With the exception of Cannock Chase, there was little indication from the plot-specific Ellenberg N scores that the vascular vegetation of HMN sites were indicative of greater nutrient nitrogen enrichment than comparable sites nationally (Figure 6.4) and we did not observe any clear relationships between vascular vegetation characteristics and most nitrogen deposition variables measured at HMN sites. However, strong negative relationships were evident between the frequency of occurrence of the dominant lichen genus, *Cladonia* sp., and reduced nitrogen deposition when expressed in terms of mean ammonia concentration, annual dry ammonia deposition flux or total (wet and dry) annual reduced deposition flux (Figure 6.4). We found no similar relationships with total nitrogen flux, gaseous sulphur dioxide concentrations or total acidity fluxes.

**Figure 6.4 Relationships between the frequency of occurrence of the lichen genus *Cladonia* sp. (% of cells where present) and (a) mean monthly ammonia concentration (2012-14 mean), (b) annual dry ammonia deposition flux (2012-13 mean) or (c) total (wet and dry) annual reduced deposition flux (2012-13 mean).**



While there is some indication of a linear relationship between frequency of occurrence and all three metrics, frequency falls to very low levels beyond a mean ammonia concentration of around  $1 \mu\text{g m}^{-3}$  ammonia (Figure 6.4a). This is consistent with the  $1 \mu\text{g m}^{-3}$  CLRTAP Critical Level for effects of ammonia on lichens (APIS website) and with the observation of Sheppard et al. (2011) from experimental work that dry deposited ammonia, relative to all other species of N deposition, is particularly effective in restricting *Cladonia* sp. in heathland.

#### 6.3.4 Summaries of individual sites

##### **Manchester Mosses**

This site is undergoing restoration by rewetting having previously been chronically impacted by drainage. The consequence is species poor vegetation but high Hs scores for all species modelled (Figure 6.5a) which is consistent with rewetting of intact peat layers. The extremely wet conditions at this site make it very unlikely that negative indicators would thrive other than eutrophic algae, and indeed none were recorded in 2011 or 2014. No substantial differences in Hs scores occurred between surveys. Complete absence of the lichen, *Cladonia* sp., across the survey plots at this site is consistent with measured ammonia concentrations in excess of the Critical Level for this pollutant and target organism.

##### **Cannock Chase**

Differences in Hs scores between surveys were generally small and all within the range of uncertainty in model projections (Figure 6.5b). *Pteridium aquilinum* probably still poses a potential threat to the vegetation having Hs scores in both years that are as high or higher than some of the characteristic positive indicators, especially *Vaccinium vitis-idaea* (Figure 6.5b).

The other heathland sites also saw modest but more marked changes in Hs scores for some species between years. We speculate that this is likely to reflect the susceptibility of these sites to more variable changes in soil moisture than perennially wetter bog sites. The lichen, *Cladonia* sp., was recorded in around 0.25% of cells only, again consistent with measured ammonia concentrations in excess of the Critical Level for this pollutant and target organism. Furthermore, Ellenberg N scores (indicative of soil fertility) for the Cannock Chase vegetation plots were high relative to most CS heaths and considerably higher than the two other HMN heath sites, providing additional evidence that nitrogen deposition is having a significant impact on the ecology of this site.

##### **Cleddau Rivers**

No major differences are apparent between years and the all species apart from *Dicranum scoparium* and the negative indicator *Pteridium aquilinum* had soil-derived Hs indices close to or above 0.8 suggesting stable and suitable conditions for characteristic bog species at the site (Figure 6.5c). The lichen *Cladonia* sp. was recorded in around 25% of all cells indicating no major threat to this sensitive organism from air quality at the site.

### Usk Bat Sites

Eleven of the thirteen species modelled had soil and vegetation derived Hs indices above 0.8 and many >0.9. Only soil-derived Hs for *Vaccinium myrtillus* and *Dicranum scoparium* were below 0.5 (Figure 6.5d). There were no major differences in score between surveys and the impression is of an environment that is broadly suitable for the characteristic bog species to occur. The sensitive lichen *Cladonia* sp. was recorded in around 16% of all cells, an intermediate frequency for HMN sites as a whole. Parts of the survey area, however, appeared in a physically degraded condition with significant areas of exposed peat. Bryophyte cover was generally patchy, suggesting that, while key bog forming species were present at the site, the overall vegetation structure may still reflect a legacy of substantial atmospheric contamination.

There is strong evidence from studies of peatlands in the southern Pennines that *Sphagnum*, and associated peat forming species, were lost during the course of the 20<sup>th</sup> century as a direct result of ambient concentrations of sulphur dioxide which can be toxic to these species at high doses (Tallis, 1987; Fergusson et al., 1978). Caporn et al., (2006) noted that while recent *Sphagnum* reintroduction experiments had enabled re-establishment of some species, the atmospheric pollutant legacy, particularly as it affected the chemistry of bog pools might account for continued low abundance of these mosses relative to less polluted areas. This is potentially very important for the re-establishment of a healthy functioning bog, as the sparsity of bryophyte cover clearly limits the potential to resume the peat forming process and leaves peat surfaces exposed to erosional processes which may be exacerbated by grazing.

A study of plant remains and pollutants in peat cores taken from Mynydd Llangatwg by Chambers et al (2007) suggests the site experienced comparable vegetation changes to those in the southern Pennines as a direct consequence of atmospheric pollution. Plant macrofossil remains in these cores indicate a dramatic loss of *Sphagnum* cover around the turn of the 20<sup>th</sup> century (consistent with the early detection of spherical carbonaceous particles derived from the high temperature combustion of fossil fuels) and replacement by *Calluna* and particularly *Molinia* – a grass, the expansion of which has been linked to increased nitrogen deposition. Clearly, the occurrence of a range of *Sphagnum* species during the two HMN surveys demonstrate that conditions, at least across parts, of the survey area are now again conducive to the survival of important bog forming species, but local variability in bryophyte cover may indicate the site is still undergoing the early phase of recovery, and/or that significant areas remain in a sub-optimal condition for re-establishment. Our focus on the presence/absence of CSM indicator species in this report does not take into the account the possible significance of local variation in habitat.

### New Forest

Of all the HMN sites the New Forest heathland showed the greatest differences between soil-derived and vegetation derived indices (Figure 6.5e). These differences were most marked for shallow-rooted peatland species including *Sphagnum tenellum* and *Drosera rotundifolia* and less marked for species that can tolerate drier peats and mineral soils such as *Calluna vulgaris* and *Erica cinerea*. Substrate conditions on the site are heterogenous. Marked grazing and trampling by cattle and ponies has led to a mosaic of open patches where exposed mineral

soil is interspersed with patches of dwarf shrub and wetter peat (Rob Rose pers.comm.). The differences between soil and vegetation Hs scores are likely to have arisen because the 2 x 2m plots are large enough to capture a range of species and soil conditions but soil samples will be more variable because they sample relatively much smaller areas. This is particularly so for soil moisture and % carbon. In fact variation in these two properties is especially noticeable among the heathlands compared to the bogs (Figure 6.7a). Moreover, it is on heathland sites with thinner peat caps that soil analysis of the full 15cm sample is more likely to yield average C:N, soil moisture and pH values that are less representative of the surface peats in which the characteristic bog species present are mostly rooted.

The Hs scores at the New Forest therefore suggest that soil conditions are rather less favourable for the peatland species encountered, especially those suited to the wettest conditions. This appears to be primarily related to grazing pressure and the patchy distribution of thicker peat. The lichen, *Cladonia* sp., was more abundant here than at any other site (occurring in almost 50% of all cells) thus indicating relatively little current threat from air quality to this sensitive species.

### **Skipwith Common**

This is another heathland site and here, as with the other two heathland sites, soil-derived Hs values were lower than vegetation-derived indices across all but one of the modelled species (Figure 6.5f). Soil moisture and % carbon varied more at this site than all other HMN sites, reflecting elements of both wet and dry heath occurring within the survey area. Soil-derived Hs scores at Skipwith Common increased markedly between surveys for all species except *Calluna vulgaris*. Percentage nitrogen, % carbon and soil moisture increased in parallel and will have influenced the Hs scores. Higher rainfall preceding the survey in 2014 may have been influential. If re-randomised plot locations happened to sample wetter peats than this would also explain the between-survey difference.

In summary, while Hs scores based on the vegetation convey high suitability, soil-derived variables suggest lower suitability. Scores varied between years presumably as a result of weather and sampling-related effects. The sensitive lichen *Cladonia* sp. occurred at a low frequency of around 2%, suggesting that current air quality, particularly with respect to ammonia concentration, may not be sufficient for widespread representation at the site.

### **Thorne Moor**

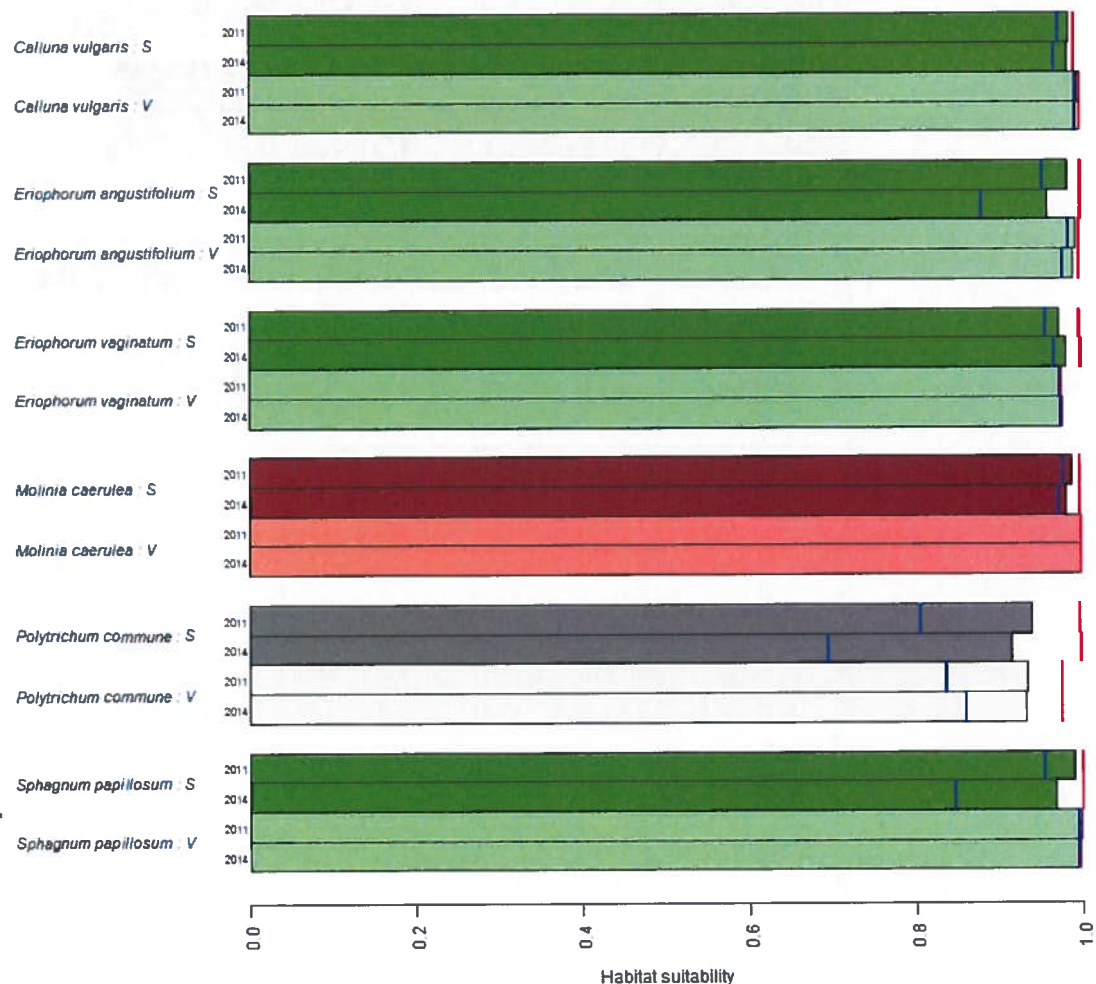
Eight out of the ten species modelled had Hs scores above 0.8 in both years and for both soil and vegetation-derived variables (Figure 6.5g). The impression is therefore of an environment where conditions are generally suitable for the characteristic bog species present. The sensitive lichen *Cladonia* sp. occurred at an intermediate frequency (for all HMN sites) of around 11%.

The site is subject to significant oscillations in the water table as a consequence of hydrological management which is likely to restrict areas suitable for the permanent re-establishment of bog forming mosses. Only the two negative indicators, *Pteridium aquilinum* and *Rubus fruticosus* agg., had soil-derived Hs scores below 0.5 with very little difference apparent between surveys (Figure 6.5g).

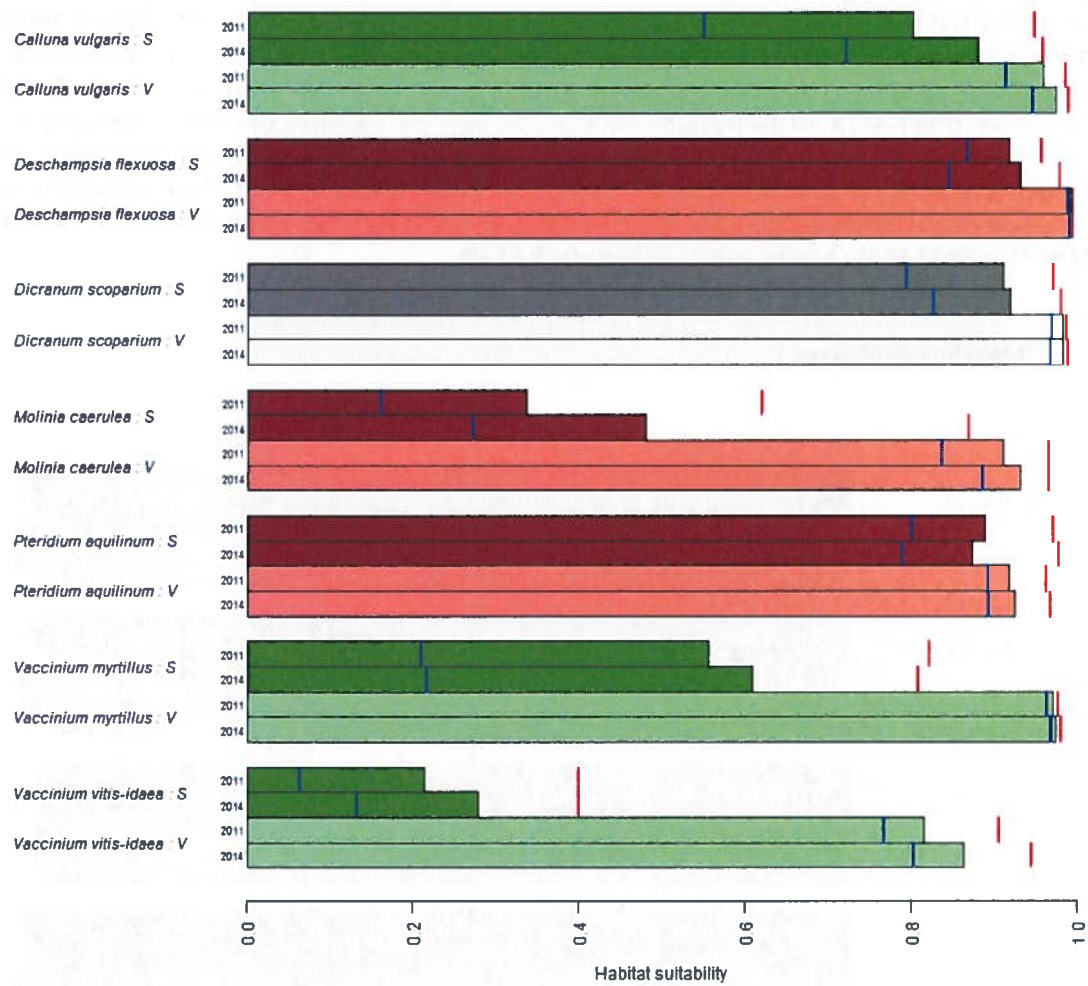


Figure 6.5. Bar plots of Habitat Suitability scores for indicator species recorded at each site in each year, solved using either association with neighbouring plant species (V) or from soil chemistry (S). The same canopy height and climate variables were used in both V and S model runs. Habitat Suitability is averaged over predictions from models using five different methods, the highest and lowest estimates of Habitat Suitability from the five models are represented by the red and blue lines respectively. This gives an indication of uncertainty in the estimate of Habitat Suitability due to the different methods applied. The colours of the bars indicate the type of indicator: green bars for positive indicators, red bars for negative indicators and grey bars for species whose CSM status varies depending upon their abundance in the vegetation (e.g. *Sphagnum recurvum*), potential nitrogen deposition indicators (e.g. *Polytrichum commune*) and scarce species of importance on specific sites (e.g. *Agrostis curtisii*). Asterisks indicate species that were absent at the site in one or both survey years.

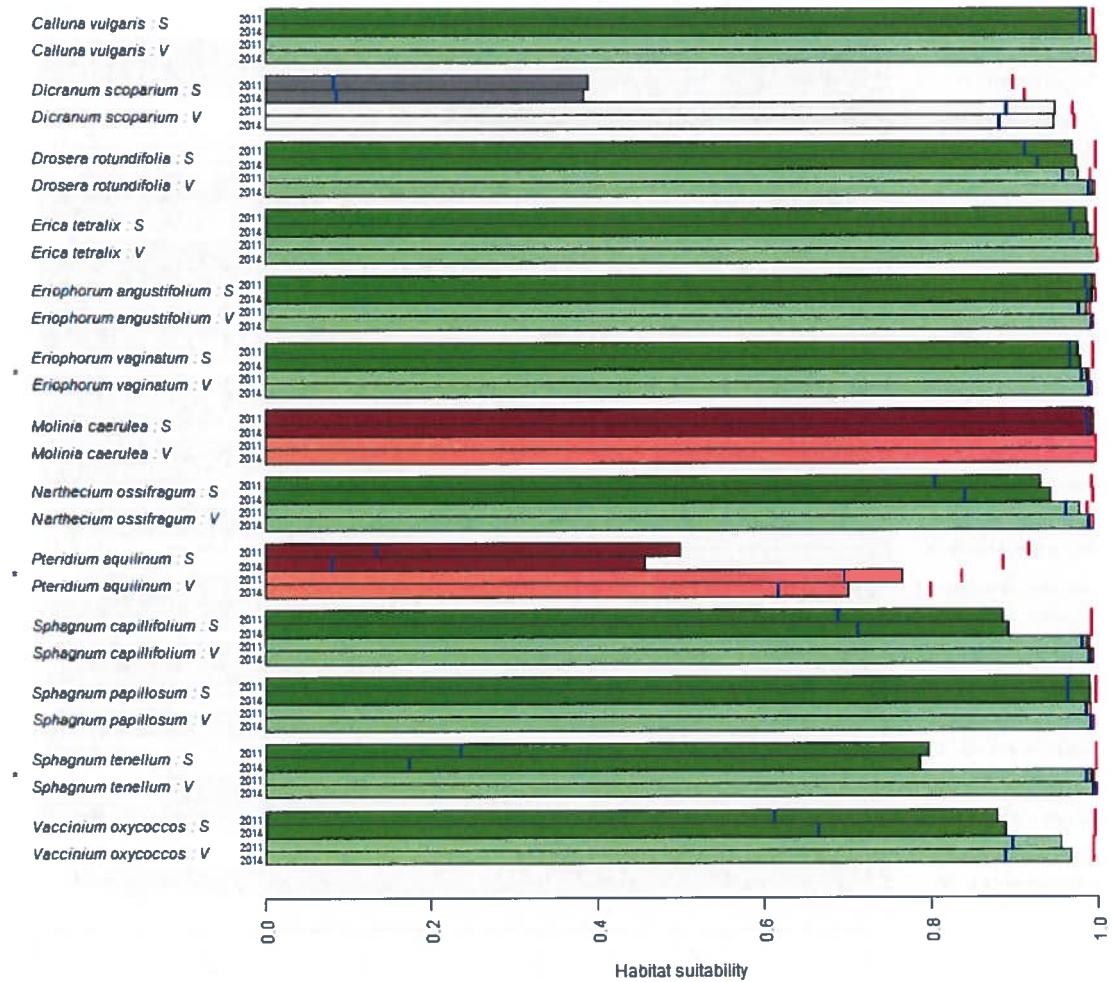
a) Manchester Mosses



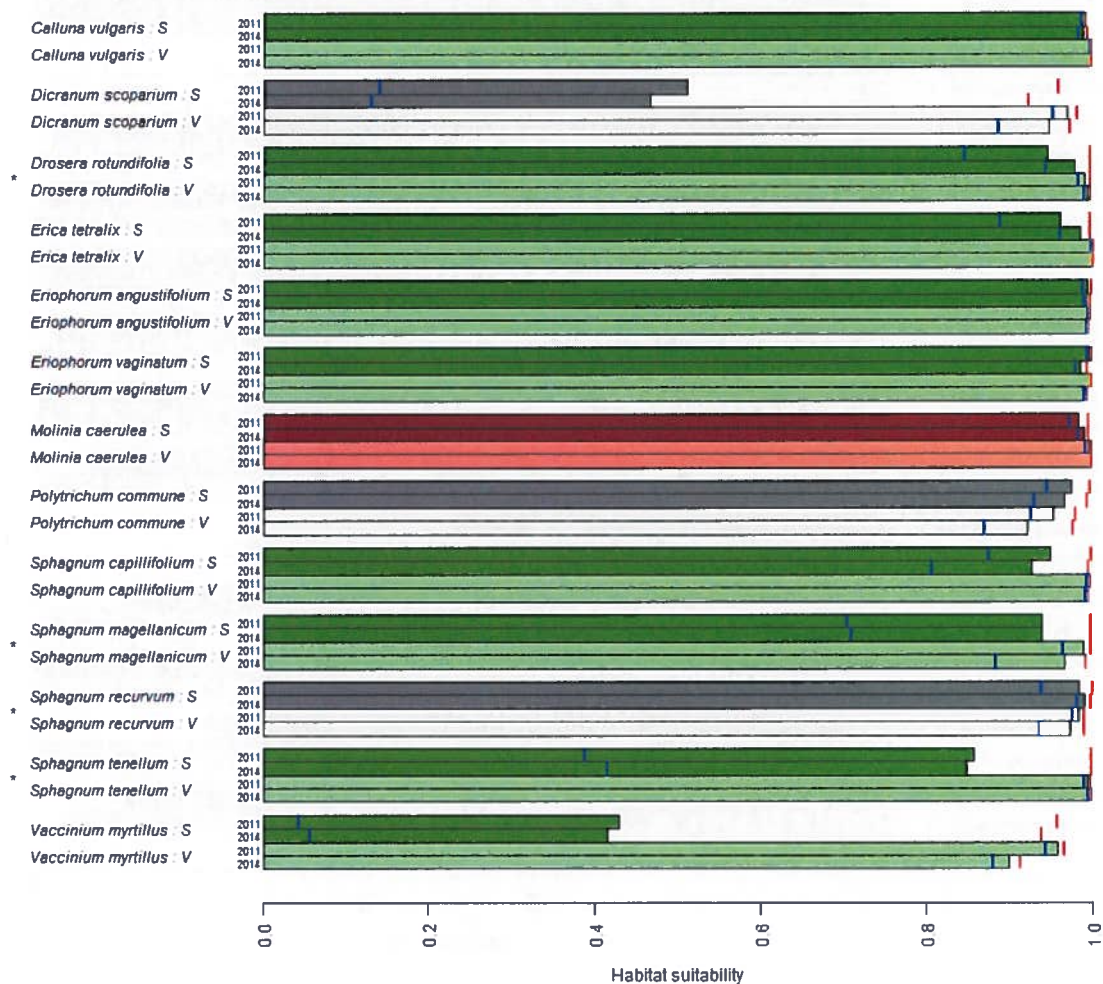
## b) Cannock Chase



### c) Cleddau Rivers

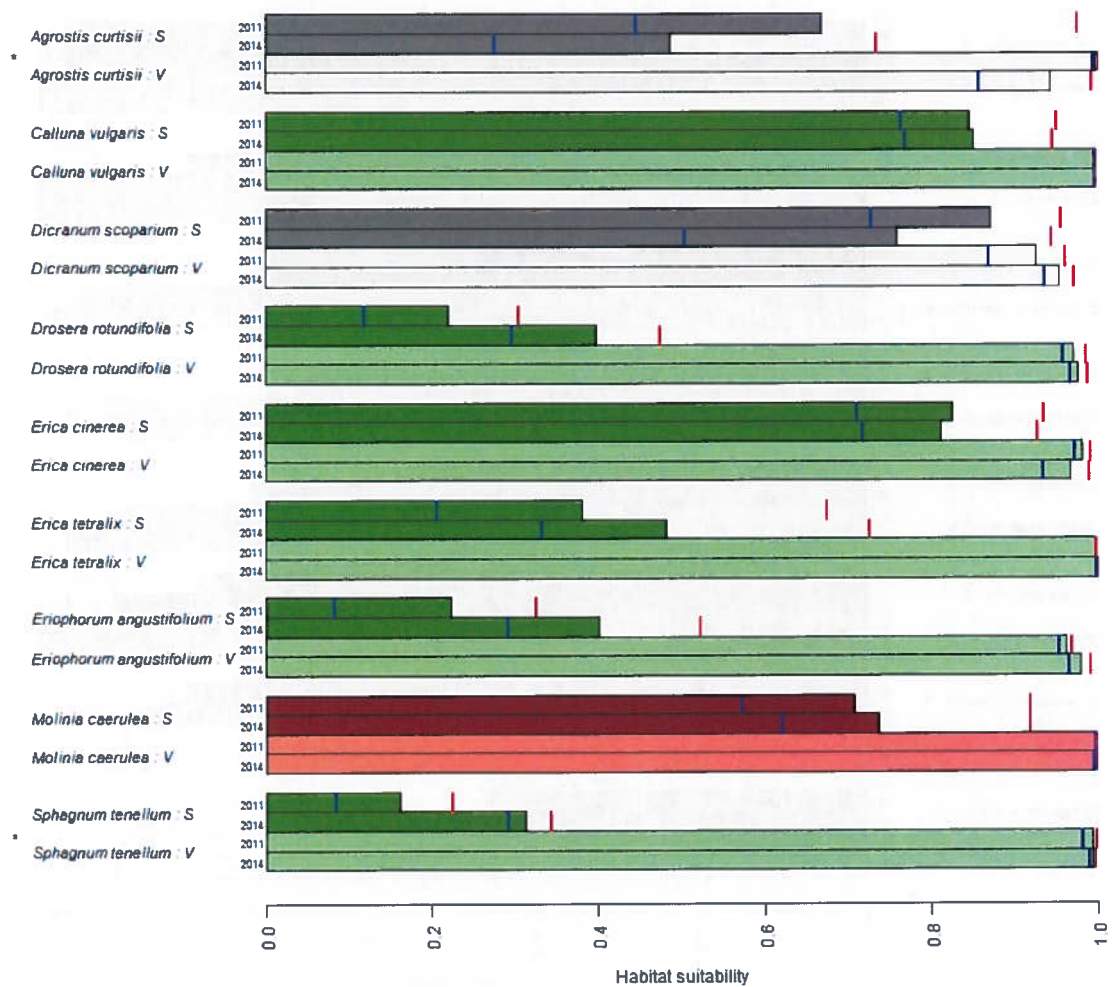


#### d) Usk Bat Sites



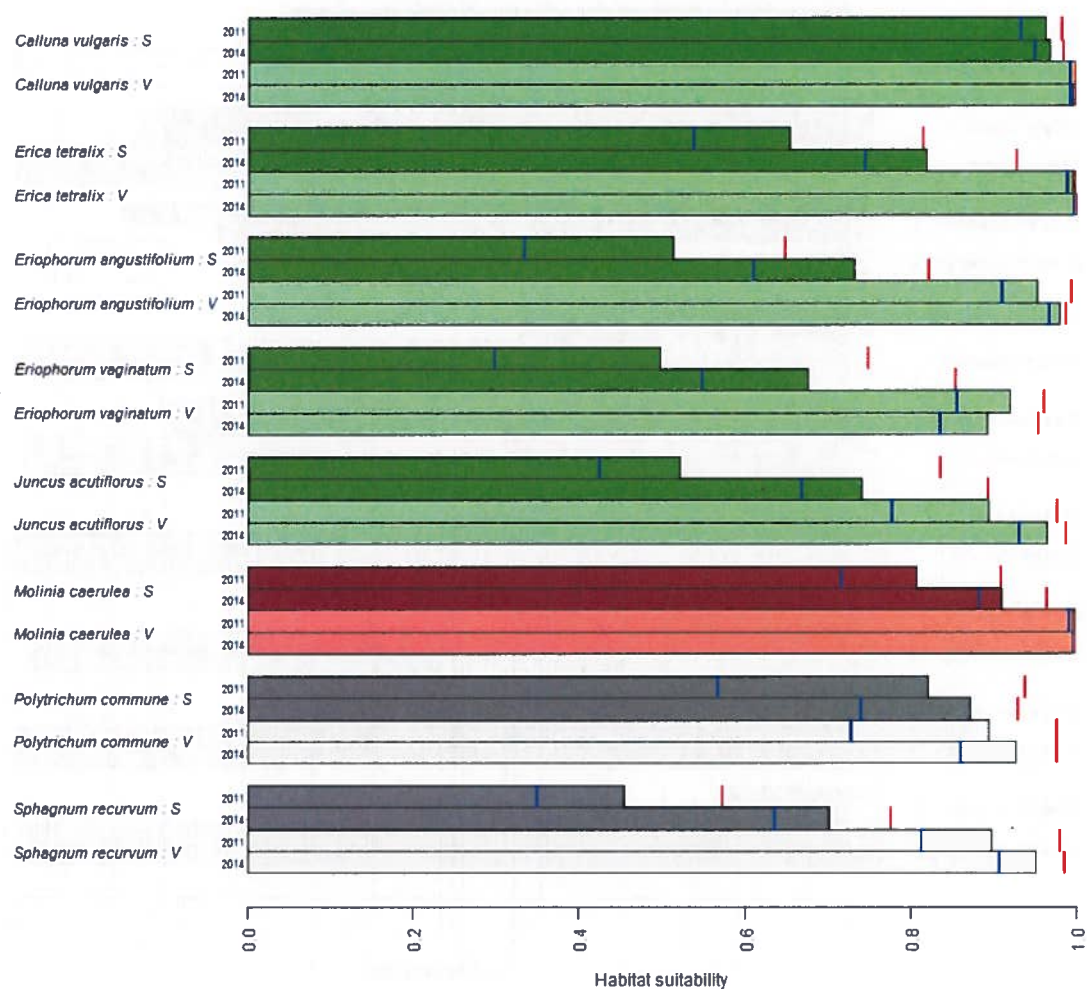


### e) New Forest

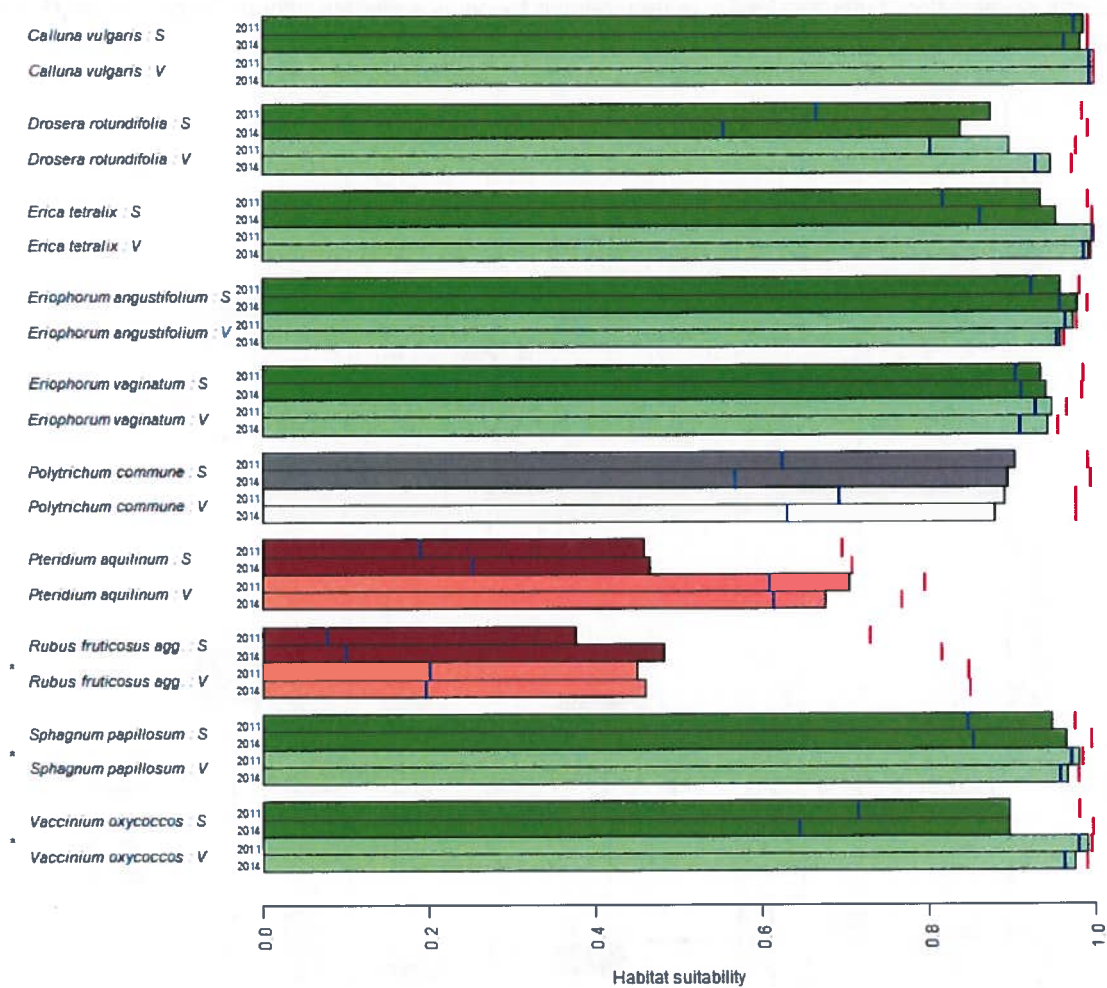




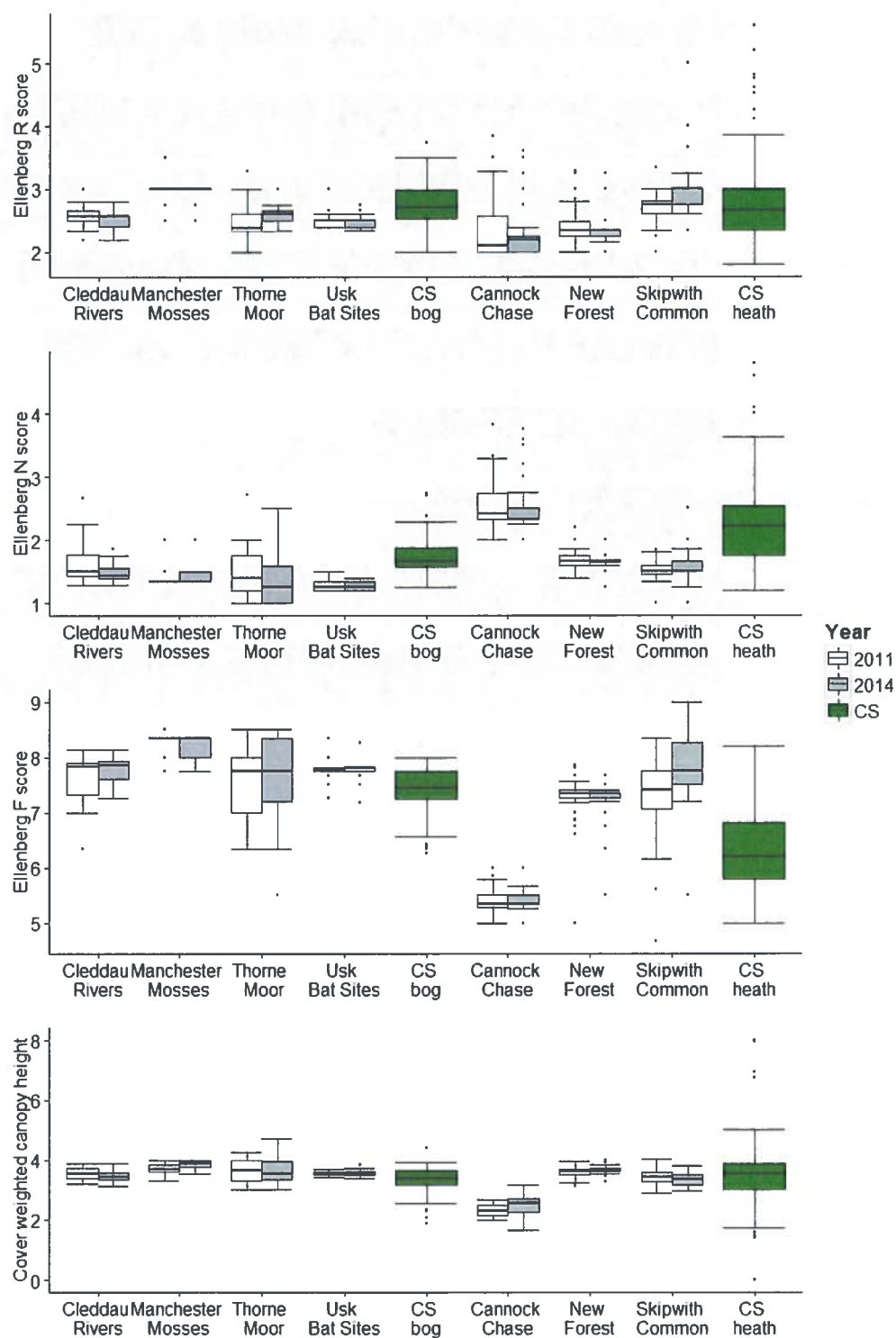
# f) Skipwith Common



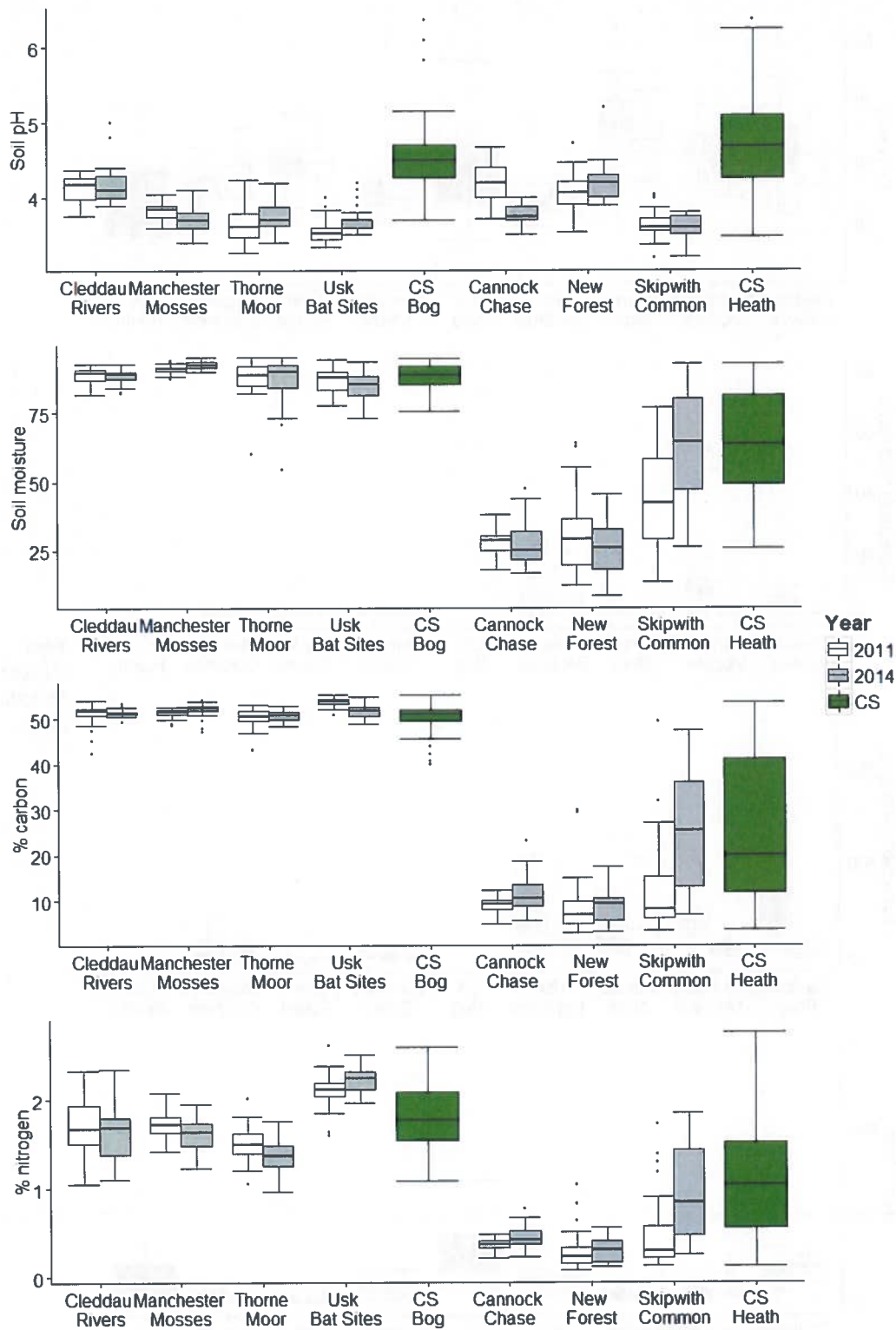
**g) Thorne Moor**



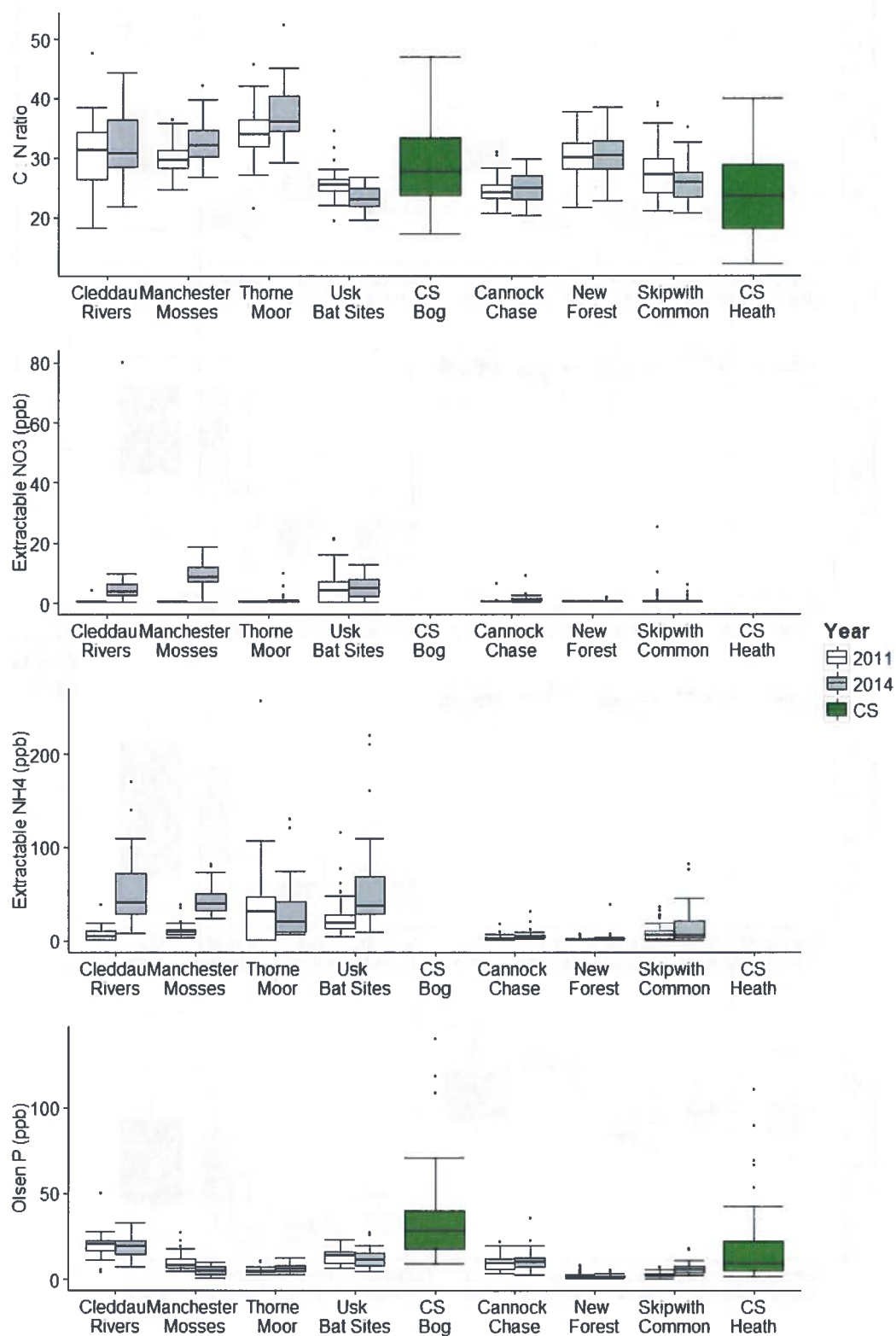
**Figure 6.6.** Variation in community mean traits used to predict Habitat Suitability from vegetation composition between years for each site. Ellenberg N reflects variation in fertility, with plants associated with higher fertility having a higher score, Ellenberg F reflects variation in moisture and Ellenberg R reflects pH variation. Light availability is represented by cover weighted canopy height on the Grime scale (1-8).



**Figure 6.7a.** Variation in soil variables used to predict Habitat Suitability from vegetation composition between years for each site. Habitats Monitoring Network data are plotted alongside distributions for the CS reference dataset.



**Figure 6.7b.** Variation in soil variables used to predict Habitat Suitability from vegetation composition between years for each site. Habitats Monitoring Network data are plotted alongside distributions for the CS reference dataset. CS data not available for extractable nitrate ( $\text{NO}_3$ ) and ammonium ( $\text{NH}_4$ ).





## 6.4 Discussion

Overall, the analyses of species richness and community composition revealed few marked differences in vegetation composition between 2011 and 2014. While there was a slight reduction in species richness reduced between surveys on three sites, it was not possible to ascertain whether this was due to real directional change or sampling variability.

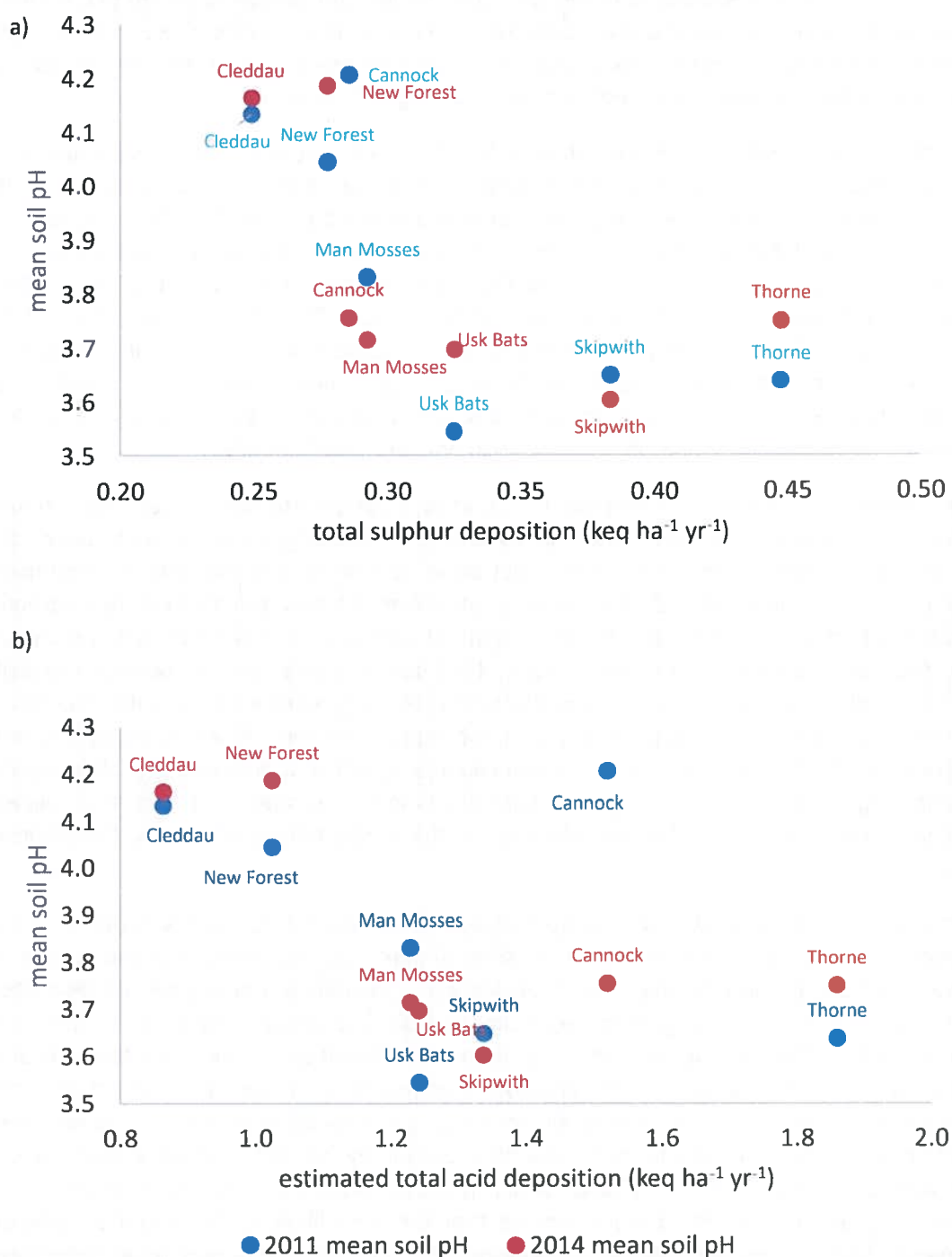
Comparison of plots with the CS data showed that HMN sites were broadly comparable with heath and bog sampled from throughout Britain. Since the HMN data points were mostly contained within the perimeters of the cloud of points defined by the CS reference data we can conclude that the HMN sites are not major outliers in terms of wider national variation in plant species composition (Figure 6.2). It is also clear, however, that the vegetation of HMN sites is characteristic of relatively low soil pH relative to most CS plots (Figures 6.2 and 6.6). Indeed the markedly lower soil pH on HMN sites is consistent with the negative effects of sulphur deposition loading compared to the average range of heaths and bogs in Britain. This accords with the selection approach for the HMN which targeted sites with a high modelled exceedance of the sulphur component of the acid critical load (CL<sub>maxS</sub>)<sup>1</sup>.

Direct comparison between the HMN and CS surveys is complicated by the fact that different surveyors conducted the surveys and slightly different recording schemes were used; the HMN data are based on random points constrained to sample a reasonably homogenous habitat unit on each site while CS plots are a random sample from often much more inherently variable mapped areas of bog and heath throughout upland and lowland Britain. Ideally we would draw on reference data close to each HMN site without historical exposure to high deposition. Unfortunately this was not possible given the geographical extent of the deposition profile combined with the low density of heath and bog in southern Britain. Comparison with low-exposure sites from northern Britain is complicated by collinear differences in climate, site area and biogeography, hence ecological differences in for example C:N ratio and species composition could not be confidently attributed to the partial effects of pollutant deposition legacy.

We observed a clear negative relationship between mean soil pH (for both surveys) and the estimated acid deposition load to the seven sites (Figure 6.8) measured over the course of the monitoring programme to date. This provides strong evidence that soil pH of these sites remains compromised by long term exposure to acid deposition. While environmental conditions at the HMN sites appear, in general, to be sufficient to support most key indicator species of particular value to conservation management, it seems likely that most assemblages are impoverished floristically to some extent relative to less impacted sites. Recent findings emerging both from the Countryside Survey (Norton et al 2012) and the UK Environmental Change Network (Rose et al., in prep), provides widespread evidence of gradual increases in site Ellenberg R scores that are very likely to be linked to gradual increases in soil pH over the past two to three decades in response to very large reductions in acid deposition across significant parts of the UK. It would seem highly likely, therefore, that the HMN site soils are in the early stages of recovery from acidification, and vegetation communities will change gradually in response to any continuing chemical improvements.

Footnote: <sup>1</sup>Protocol for deposition monitoring at Natura 2000 sites in response to power station and refinery operating permit improvement conditions, Issue 1, 20 September 2010

**Figure 6.8 Relationships between the mean of all soil pH samples for the 2011 and 2014 surveys and (a) estimated mean annual sulphur deposition and (b) estimated mean annual total acid deposition, based on the 2012-2013 monitoring data reported in the Fourth Report (2014).**



We found little clear evidence for suppressive effects of nitrogen deposition as a nutrient on the presence/absence of the indicator species of interest, and little indication from the Ellenberg N site scores, with the possible exception of Cannock Chase, that the vegetation

communities of the HMN sites are indicative of a more eutrophied condition than bog and heath sites nationally. However, strong negative relationships with various indices of reduced nitrogen deposition and the occurrence of *Cladonia* sp. are entirely consistent with the known toxicity of reduced N with respect to lichens, and suggest that current ambient levels of reduced N are likely to be inhibiting the prevalence of this key air quality indicator species cover at Manchester Mosses, Cannock Chase and Skipwith Common at least.

While some HMN sites showed changes in habitat suitability for indicator species between 2011 and 2014 we consider that these changes are more likely to reflect sampling effects due to the re-randomisation of plot locations and seasonal weather impacts close to and preceding the surveys. We also suspect that the spatial variability of the better drained heathland soils with patchy thinner peats increases the variability of soil-derived Hs scores and tends to reduce Hs scores compared to those derived from the plant species composition. The most obvious within-site and cross-species changes in habitat suitability were restricted to the three heathland sites; Cannock Chase (Figure 6.5b), Skipwith Common (Figure 6.5f) and New Forest (Figure 6.5e). Unlike the bog sites, the soils are drier and therefore soil moisture is likely to vary much more with rainfall than substrates in a state of reasonably continuous saturation. The largest magnitude changes in Hs were at Skipwith Common where change in soil moisture was larger than for any other site (Figure 6.7b). Differences in rainfall, or a random but influential shift in plot locations in 2014, could both be responsible and in turn have driven the soil-derived cross-species change in Hs (Figure 6.5f). Interestingly soil pH did not show any evidence of change at Skipwith Common.

## 6.5 Conclusions

### 6.5.1 Updated assessment of soil and vegetation status

We have interpreted the vegetation and coupled soil chemistry data for the 2011 and 2014 surveys and undertaken a comparative assessment against reference data from a wider unbiased, representative national sample of vegetation from the same ecosystem types. The vegetation of HMN sites is broadly comparable with that of bog and heath sites nationally. It is clear that soils at the majority of sites are relatively acidic, that soil pH is linked to current (and most probably historical) levels of acid deposition measured at HMN sites, and vegetation communities are indicative of relatively acidic bogs and heaths that occur nationally. On the basis of observations from CS and ECN it is likely that soil pH is slowly recovering from peak acidification in response to large reductions in acid deposition in recent years.

We also observed a strong negative relationship between lichen cover and current levels of reduced nitrogen. This suggests that this sensitive air quality indicator remains compromised by air quality, and particularly ammonia concentration, at several HMN sites.

We found no persuasive evidence of significant ecological differences within each of the HMN sites between surveys that could be attributed to pollutant deposition legacy effects. The absence of clear evidence for changes in vegetation may reflect the limited power of two vegetation surveys relatively close together in time to elucidate chronic long term trajectories of past and potential future change. Whatever differences were observed between the two surveys cannot be reliably or usefully attributed to drivers. The overall message is that ecological conditions across the sites are similar enough between years to suggest short term stability but we cannot rule out low magnitude long-term directional change without biogeochemical modelling or a longer time series of observations.

The results of the new 2011 and 2014 analyses for each site have been used to update the summary table from the previous report (Table 6.5).

**Table 6.5. The summary table of key observations detailed in this report.**

Site	Summary	Current Interpretation based on the consistency and magnitude of Hs scores and other observations
Manchester Mosses	Hs_S and Hv_V scores were generally high for the positive indicator species and reasonably consistent.	Ecological conditions appear currently favourable for the CSM indicator species assessed. However, <i>Cladonia</i> sp. currently absent, potentially indicating current limitation of reduced N on lichen viability.
Cannock Chase	Hs_S and Hs_V scores were inconsistent with Hs_S scores generally low. High Hs_V scores were seen for both positive and negative indicator species	Strong conclusions re. CSM indicators on the ecological condition cannot be drawn without further understanding of the deposition history and management regime. <i>Cladonia</i> sp. scarce, indicating potential current limitation of reduced N on lichen viability.

Cleddau Rivers	Hs_S and Hv_V scores were high and consistent for a range of positive indicator species	Ecological conditions appear currently favourable for the CSM indicator species assessed.
Usk Bat Sites	Hs_S and Hv_V scores were generally high for positive indicator species and reasonably consistent	Ecological conditions appear currently favourable for the CSM indicator species assessed, despite evidence for historic local physical degradation.
New Forest	High variability between Hs_S and Hs_V across a range of species. Hs_V values were medium to high whilst Hs_S values were consistently low.	Strong conclusions on the ecological condition cannot be drawn without further understanding of the deposition history and management regime.
Skipwith Common	Hs_S and Hs_V scores were inconsistent with Hs_S scores generally low. High Hs_V scores were seen for both positive and negative indicator species	Strong conclusions on the ecological condition cannot be drawn without further understanding of the deposition history and management regime. <i>Cladonia</i> sp. scarce, indicating potential current limitation of reduced N on lichen viability.
Thorne Moor	High Hs_S and Hs_V values seen for most positive indicator species with variable consistency. In several cases, Hs_S values were higher, suggesting the vegetation is lagging the soil recovery. Low Hs_S and Hs_V values were seen for the negative indicator species.	Ecological conditions appear favourable for the bog species assessed. Interpretation would benefit from consideration of the deposition history and management regime.

### 6.5.2 Limitations

It is important to recognise that the robustness of the conclusions is limited by the data provided within the project scope. As noted in Table 6.5, further clues as to the factors determining the current status of the HMN sites could be gleaned from further discussion with site managers. However, such lines of enquiry tend to contribute mostly anecdotal evidence rather than new quantitative monitoring data that might usefully extend the time series backwards. Biogeochemical modelling could provide an indication of the extent to which these systems are likely to have acidified historically, where sites currently lie on a recovery trajectory, and to what extent soil acidity might be expected to continue to decline (or pH increase) in response to projected deposition scenarios. From a survey perspective, epiphytic lichen and bryophyte surveys of woodland, the primary habitat for these deposition sensitive species, in or near each site would help indicate whether species at these sites are recovering from well-documented national declines as a result of atmospheric pollution.



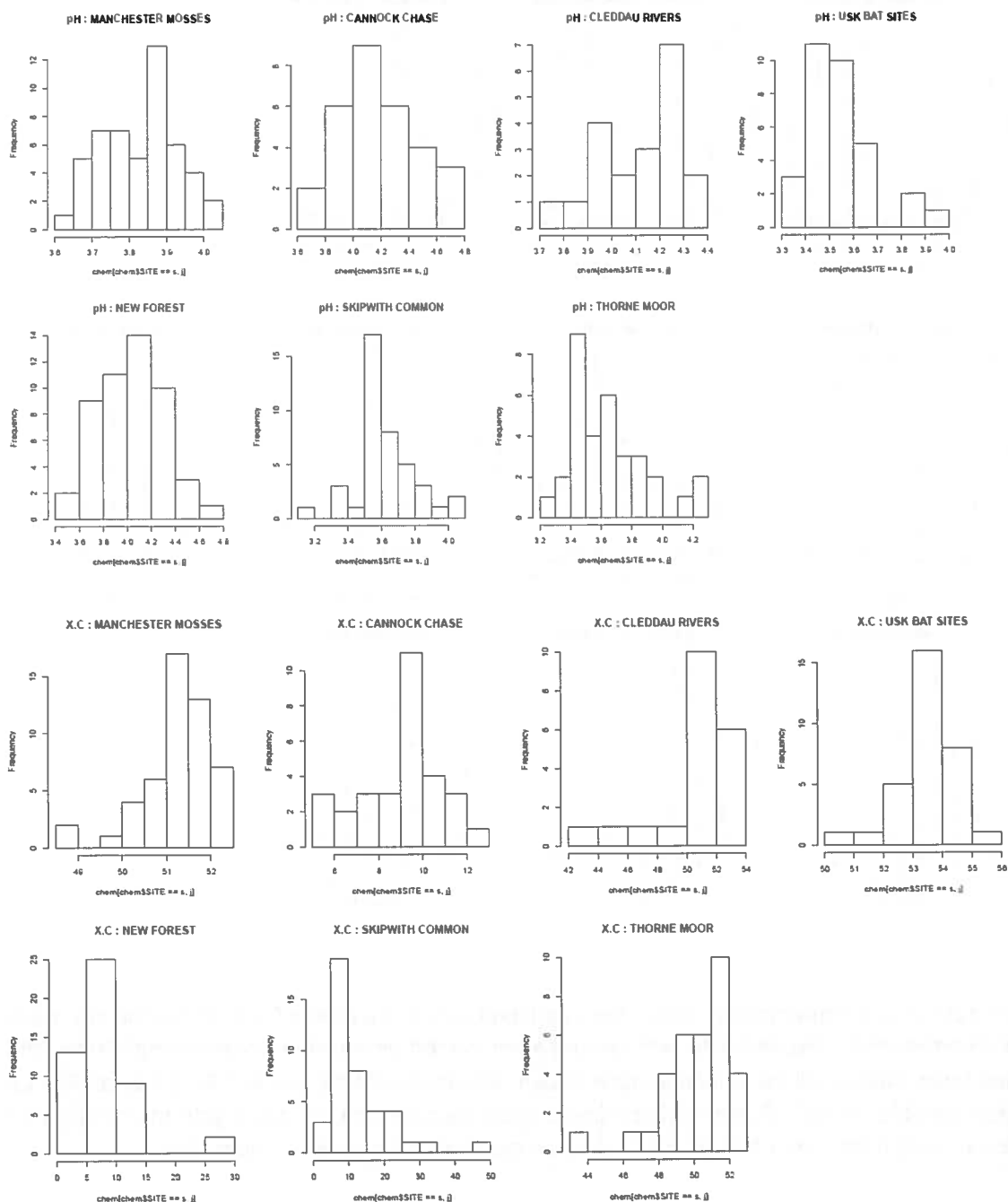
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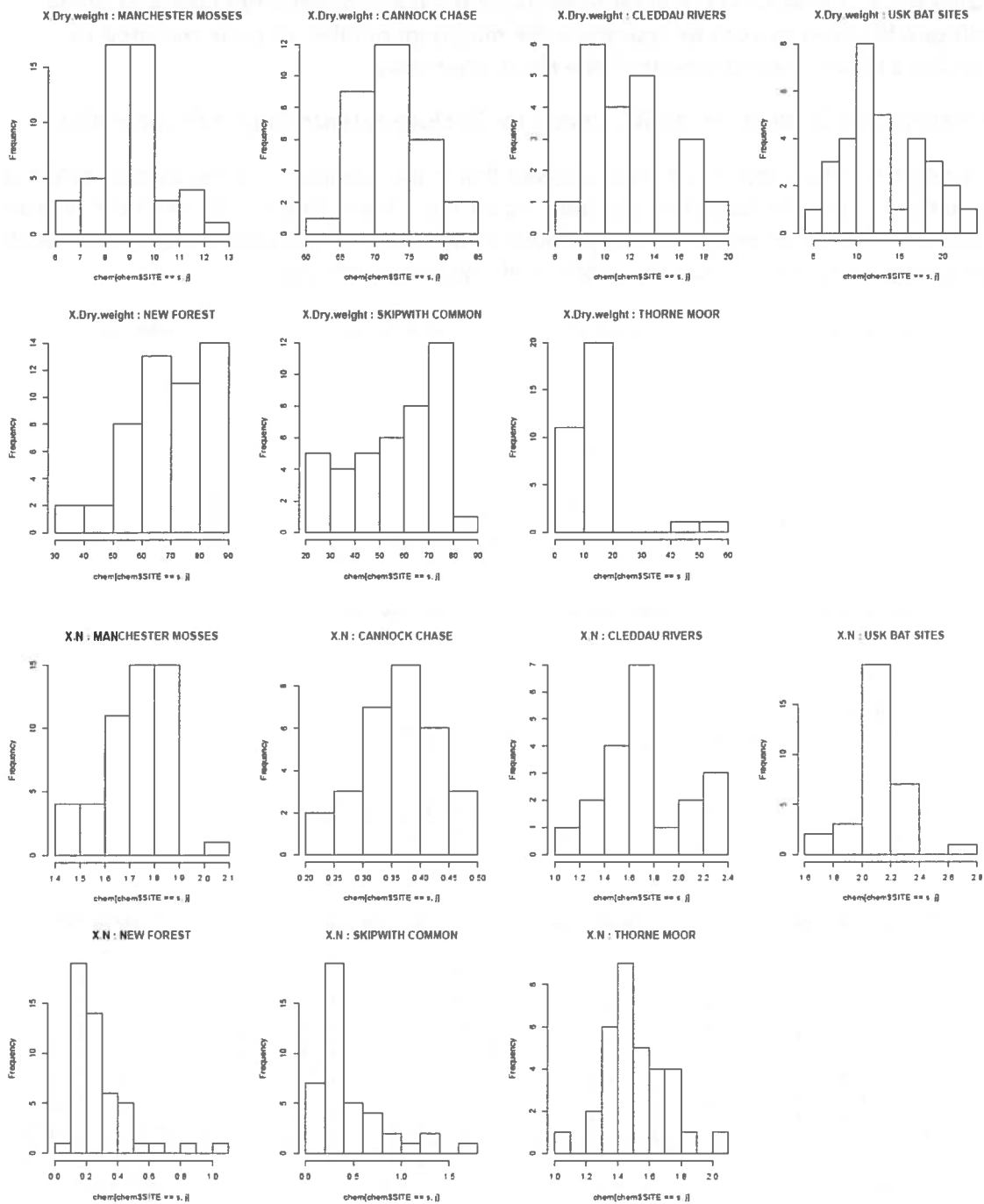
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## Appendix 1. Assessment of within-site variation in soil chemistry measured at the Habitats Monitoring sites to determine the minimum number of plots required to provide a robust measurement of site mean chemistry.

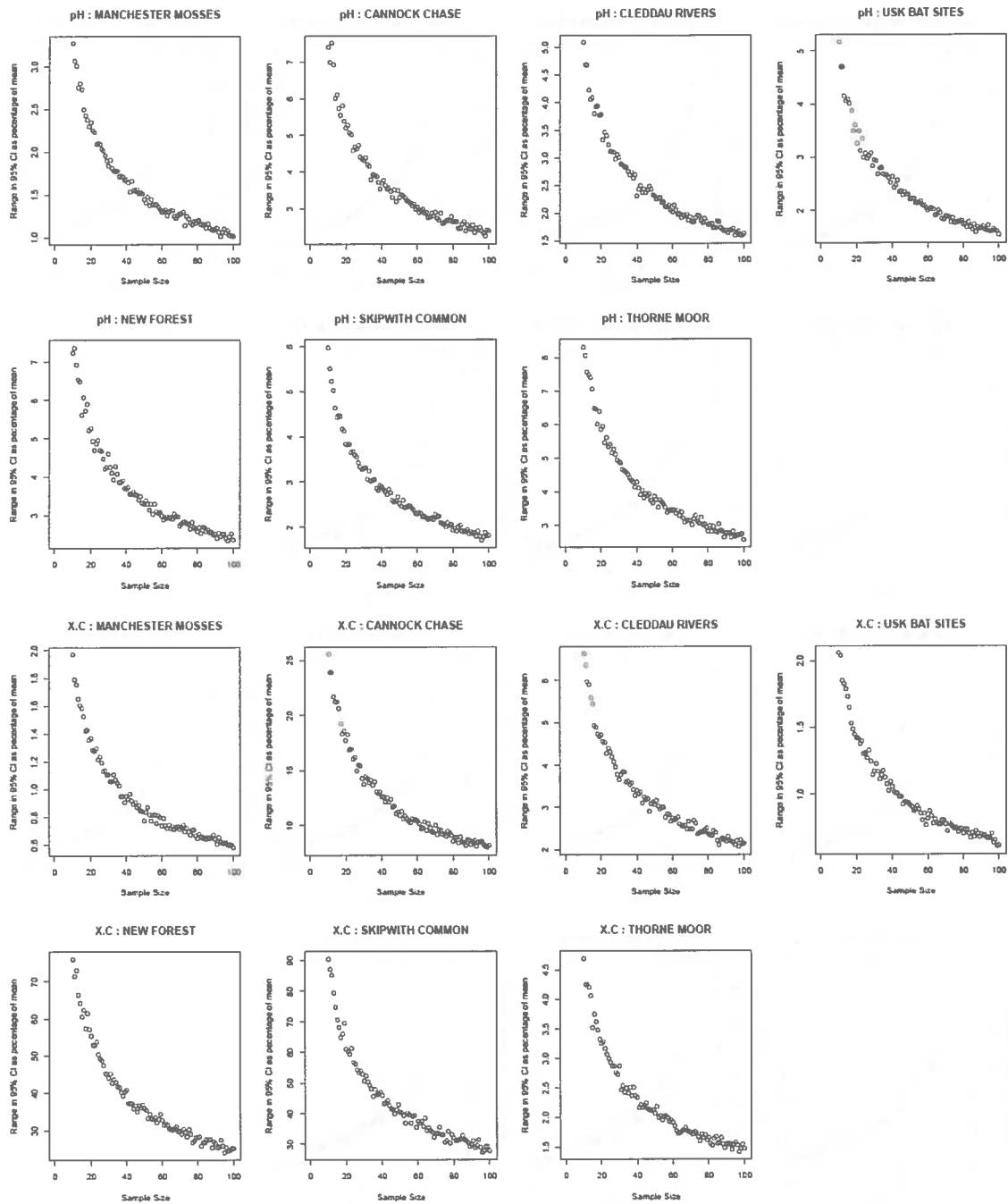
P. Henrys and D. Monteith, NERC Centre for Ecology & Hydrology, 12<sup>th</sup> June 2014.

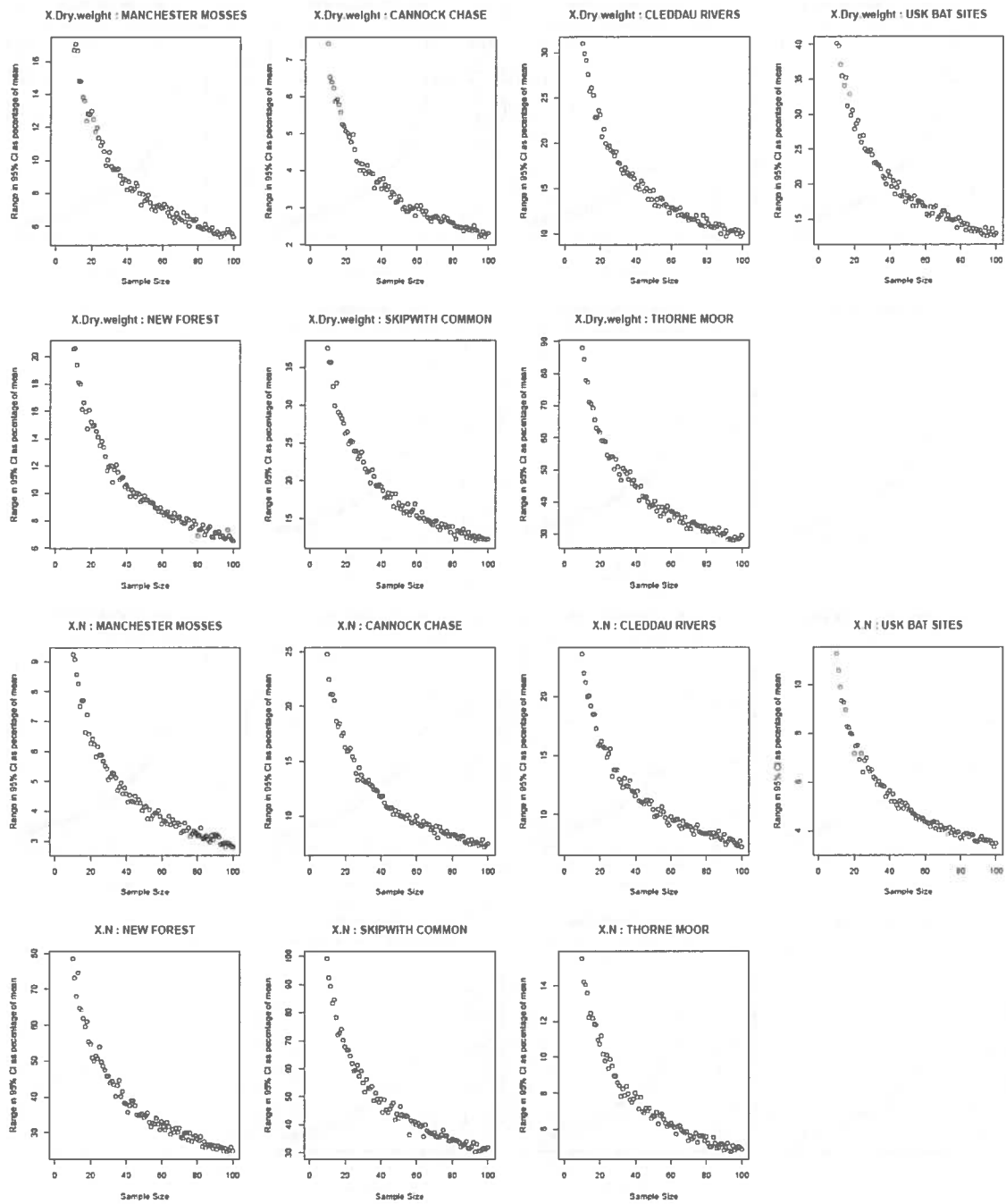
A histogram of the data for each site showed that in the majority of cases an assumption of normality for the distribution of the data would have been flawed. (Please note: x axes represent value for chemical variable provided in each header; X in graph headers represents percentage - e.g. X.C = % C or % carbon, X.N = % N or % nitrogen.





Because of this non-normality in the observed data we used a Monte Carlo bootstrap approach to resample the observed data with replacement, based on a pre-specified sample size. The mean was calculated from each sample drawn. We determined 2.5% and 97.5% quantiles for each variable using 1000 simulations under each sample size, to investigate the range (and hence margin for error / tolerance) that was most likely for a given sample size.





Essentially, these plots provide us with the span of observations around the mean with 95% confidence.



The following table provides the number of samples required to ensure a span around the mean of no more than 5% (95% confidence) with respect to measurement of the key variables pH, %carbon and % nitrogen. This demonstrates that for most sites there is at least one determinand that is sufficiently variable to merit more than 50 samples to meet this criteria. This is the technical limit for sample numbers given available resources, and for some sites problems of physical access in 2011 resulted in considerably fewer than 50 samples being collected in the time available. We conclude that soil samples should be taken at a similar frequency to the 2011 survey, i.e. as many samples as possible to be collected over the course of each survey week.

Site	pH	%C	%N	Minimum no. samples required
Cannock Chase	24	>50	35	>50
Cleddau Rivers	12	18	>50	>50
Manchester Mosses	10	10	36	36
New Forest	22	>50	>50	>50
Skipwith Common	16	>50	>50	>50
Thorne Moor	26	10	>50	>50
Usk Bat Sites	14	10	44	44

## Appendix 2: MultiMOVE – Model description and calculation of Habitat suitability scores.

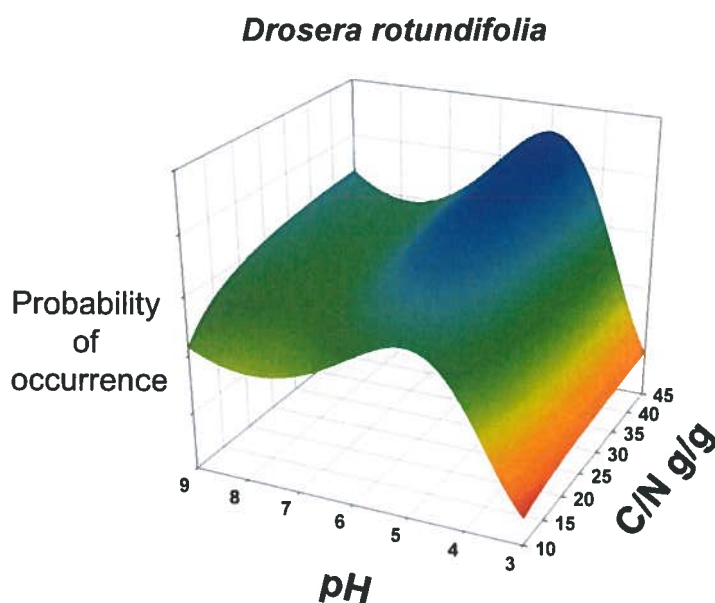
### Model description

The MultiMOVE R package consists of empirical realised niche models for 803 higher plants and 327 bryophytes. MultiMOVE was used to model the favourability of abiotic conditions for each species as inferred from either observed soil data or the species composition of the plant assemblage. Niche models also included the response of each species to vegetation canopy height and local climate.

MultiMOVE comprises a small ensemble of three statistical modelling techniques; Generalised Linear Models, Multiple Adaptive Regression Splines and Generalized Additive Models. All are well established methods but each has strengths and weaknesses which mean that averaging the outputs from all three techniques is likely to lead to a more robust projection than relying on just one of the techniques (Smart et al 2010a; Randin and Dirnbock 2006). Ensemble approaches thus exploit the power of each method but without the results being heavily influenced by the biases inherent in each method (Araújo and New, 2006).

The datasets used to build the MultiMOVE models are described in Smart et al (2010b). The input variables are the same for every species and type of model. Three climate variables are used along with estimates of soil pH, soil moisture, % carbon, % nitrogen and cover-weighted canopy height. These variables are assumed sufficient to define the essential features of the realized niche of each plant species. Figure 1, for example, shows the modelled niche surface of Round-leaved Sundew in two dimensions indicating that the species grows optimally in peaty (high C:N) and acidic (low pH) situations. Canopy height is extracted from database values for each species rather than the observed canopy height making the projection more likely to reflect the long-term successional status of the vegetation. The soil variables can either be estimated from mean Ellenberg values for species growing in the target vegetation or based on actual measurements (De Vries et al 2010). Translation between soil data and mean Ellenberg values is achieved via a further series of regression equations (Rowe et al 2011; Smart et al 2010b and see below).

Figure 1: Niche surface for Round-leaved Sundew projected by its MultiMOVE GLM along two abiotic axes.



### Interpretation

The MultiMOVE ensemble produces probability of occurrence values for each species as a function of the combination of environmental conditions found at the site and in each plot. Interpreting these probabilities directly is problematic because rare species will have a lower maximum probability at their niche optimum than common species simply because of differences in prevalence across the sampled region represented in the training data used to build each model. For example consider a species such as *Vaccinium oxycoccos* growing on wet heath. This diminutive plant may often be overlooked or be present at low frequency simply because it does not compete well with other habitat dominants and so tends to be more apparent in patches of shorter vegetation. The consequence is that while abiotic and climatic conditions may be entirely favourable it is less frequently recorded in sample plots that coincide with its environmental optimum than a more common dominant such as *Calluna vulgaris*. The resulting niche model would accurately estimate optimal conditions for *V.oxycoccus* but its maximum probability at this optimum would be lower than that for *Calluna*. The resulting raw probabilities at the environmental optimum would thus differ between these species making it impossible to compare them on an equal basis. For this reason all raw probabilities were adjusted using the favourability function of Albert & Thuiller (2008). The resulting values still range between 0 and 1 but can be compared on an equal basis between species. The function simply corrects the raw probabilities to values that would have arisen if the training dataset used to produce each model had an equal number of presences and absences. This results in an index that estimates the suitability of conditions on an equal basis for all species. It places the emphasis on the potential of the habitat to support the species *if it were in the local species pool* and reduces emphasis on outputs as a prediction of presence.

#### Solving the niche models based on soil (Hs\_S) or vegetation (Hs\_V)

Each niche model embodies quantitative understanding about the way a species changes in its abundance alongside spatial gradients of abiotic conditions including climate. Each model predicts the suitability of these conditions in terms of mean Ellenberg values. These can be calculated directly from the plant species composition in a quadrat (Hs\_V), with the proviso that circularity is removed by excluding the focal species from the calculation, or indirectly from observed soil data (Hs\_S). Thus Hs\_V estimates the suitability of conditions based on the indicator status of the plant species present whereas Hs\_S reflects soil conditions. Factors that cause a lag between the current plant species composition and soil conditions will therefore result in different values for Hs\_V and Hs\_S. Uncertainty in the modelled relationships between soil conditions and mean Ellenberg values will also influence the differences in these scores. The calculation of Hs\_V and Hs\_S can be summarised as follows,

$Hs\_V = (\beta_1 \cdot \text{Mean Ellenberg fertility}) + (\beta_2 \cdot \text{Mean Ellenberg wetness}) + (\beta_3 \cdot \text{Mean Ellenberg soil pH}) + (\beta_4 \cdot \text{cover-weighted canopy height}) + (\beta_5 - 7 \cdot \text{Climate variables}),$

where  $\beta$  are regression coefficients.

Hs\_S is calculated as above but where all three mean Ellenberg scores are NOT derived from the plant species composition but instead are derived from modelled relationships between each score and observed soil pH, % carbon, % nitrogen and soil moisture.

The formulae for estimating mean Ellenberg scores from soil measurements are as follows based on analysis of 1033 paired species composition and soil samples recorded in the GB Countryside Survey in 1998: MC= % volumetric soil moisture, C= % Carbon, N= % Nitrogen (see Smart et al 2010b).

Unweighted mean Ellenberg score	% variance explained	Equation
F (wetness)	70.1	$=\ln ((MC/(100-MC))+3.27)/0.55$
R (substrate pH)	77.9	$=0.5293-0.02503(MC)+1.665(pH)-0.1061(pH^2)-0.00566(C)$
N (substrate fertility)	78.2	$=\exp(0.7751-0.00006(MC)-0.00009(MC^2)-0.01475(C)+0.000099(C^2)+0.2639(pH)-0.01684(pH^2)+0.1908(N))$

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