CAUSEYMIRE WIND FARM, CAITHNESS

CONCLUDING REPORT

HABITAT ENHANCEMENT AND MONITORING

2004 – 2019

Report to Sustainable Solutions Group
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Dr Tom Dargie
Boreas Ecology

Dr Tom Dargie MCIEEM CEnv
Boreas Ecology
Loch Fleet View, Skelbo Street, Dornoch, Highland IV25 3QQ
Tel/Fax 01862 810877
tomd@boreasecology.com

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Caveat

The results in this document are based on a monitoring programme which has run for 15 years. They contain evidence of considerable habitat change since 2004. Monitoring work did not include experimental design or follow-up field studies to explore the causes of change. Discussion of alternative potential causes is given. Without further research, the alternatives put forward are regarded as no more than initial hypotheses by the Causeymire Wind Farm Environmental Management Committee. Readers of this report should not misrepresent any hypothesis discussed here as a proven driver of changes observed during site monitoring between 2004 and 2019.

Acknowledgements

I would like to acknowledge the essential assistance I have received during the 15-year duration of this monitoring programme on the habitat of Causeymire Wind Farm and adjacent ground.

RWE Innogy (2004 to 2014) and now Ventient Energy/Sustainable Solutions Group have given me access to the site when required. Richard Buckland (SSG) has been the main contact for this final report and has fully supported this work with induction and access advice, plus comments on a report draft.

Innes Miller (land owner) and grazing tenants (Danny Miller and the late Donald Miller) gave me access to the habitats around the windfarm and have assisted with multiple requests for background information on deer and stock numbers, stock management and, in earlier years, muirburn.

Mark Middleton undertook the fieldwork applying the RSPB habitat condition monitoring method in 2004, 2005, 2006, 2007, 2009 and 2014 (September in all years). Work in 2019 was undertaken by the author, assisted by Andrew Weston. It was done between late June and mid-August.

I thank Dr Andrew Nolan of the John Hutton Institute for providing Macaulay Institute 2001 quadrat records used in preparing the ecology chapter for the 2001 Causeymire Wind Farm EIA.

RSPB and SNH have commented on reports in earlier years, with RSPB providing detailed feedback on earlier discussion on the causes of increasing Bog-moss *Sphagnum* cover, plus monitoring data in 2010 from one of their reserves, for comparison with trends at Causeymire.

Executive Summary

1. This report considers habitat monitoring and enhancement, as required under planning conditions for Causeymire Wind Farm. The wind farm was constructed in 2003 and 2004. The report includes work undertaken in 2019, representing Year 15 of post-construction monitoring in a sequence of 1, 2, 3, 5, 10 and 15 years post-construction.
2. Monitoring results from selected earlier years (2004, 2009, 2014) are also included here and together with 2019 findings are used to provide an overview and explanation of site habitat change over 15 years. The overview includes an assessment of the accuracy of the Causeymire Wind Farm EIA submitted in 2001.
3. Habitat enhancement and monitoring have been undertaken in a large study area extending well beyond the wind farm. The general aim has been to provide improved habitat for breeding birds but bird monitoring has been done separately.
4. Work has been undertaken in a defined large Habitat Monitoring Survey Area (HMSA). Extent was 1129 ha between 2004 and 2014 but was reduced to 946 ha in 2019 due to recent adjacent windfarm development on former survey ground.
5. Most monitoring used a repeatable RSPB method, with results processed by GIS (Geographical Information System) methods. Other methods have been applied to drainage impact assesssment and the condition of turbine bases, hard standings and track verges.
6. Monitoring has focussed on several subjects: a northern Habitat Enhancement Area; drain blocking to protect large bog wetlands east of turbines plus impacts on blanket bog surface drainage around turbines and tracks; reducing grazing pressure over a wide area around the windfarm; tracking habitat condition over a large area around the windfarm footprint plus turbine bases, hard standings and road verges.
7. **Habitat Enhancement Area (HEA)** This was a small (7.7 ha) electric-fenced field in the north of the HMSA where remedial measures aimed to provide Heather 50 cm tall which might attract breeding raptors. The site was well away from the risk of turbine collision. In addition to largely excluding deer, a poorly-growing conifer plantation was removed from the HEA and fertiliser applied to higher dry ground in an attempt to increase Heather height. A 10 cm rise in height was achieved between 2004 and 2014 (21 to 31 cm, 50% increase), notably more than Heather height on equivalent habitat elsewhere (19 cm, little change over time). Discussion of 2014 reporting agreed that a 50 cm target could not be achieved, mainly due to the wet condition of the much-disturbed blanket bog. The target was too ambitious. There have been other notable habitat benefits in the HEA, including the elimination of bare peat by 2019 and a fourteen-fold increase in the percent cover of *Sphagnum* since 2004 (3% to 43%). Tree removal probably contributed to the large increase in *Sphagnum* cover between 2004 and 2019. Overall, HEA condition is much better in 2019, compared to 2004.
8. **Drain blocking and track drainage** Selective drain blocking was completed in 2004, to prevent headward erosion extending east towards very fine dubh lochan and bog pool systems east of turbines. This has been particularly successful in the area of Turbine 6, re-wetting former pools which seem to have been part of a damaged (drained) eccentric raised bog, a rare bog-type in Britain. Restoration at Causeymire is probably the first documented case for an eccentric bog in Britain and this is a major benefit which deserves wider publicity.
9. Up to 2014, drain blocking was considered a successful enhancement, based on visual checking of blocked drain integrity. Survey in 2014 of a wider drainage network installed in the 1950s found evidence for widespread drying of ditch conditions close to windfarm roads. This was due to faulty culverts.

10. In addition, impacts from one sector of the windfarm floated road and new ditches installed to drain two turbine bases have resulted in complete loss of *Sphagnum* from pre-windfarm ditches. These were choked with *Sphagnum* in a walkover survey undertaken in 2004. This is a local disappointment which was not anticipated in the Causeymire EIA which predicted impacts confined to the construction phase.

11. **Reduced habitat grazing pressure** The main method of habitat enhancement proposed in the EIA was a reduction of grazing. This was implemented successfully, first by reducing and then, from 2009, eliminating sheep grazing. Cattle numbers have been maintained or increased to control the height of tall vegetation in fen and wet grassland habitats. Deer numbers are controlled via stalking.

12. Cattle grazing impacts are largely confined to fen habitat, marshy grassland and the verges of windfarm tracks. There is field evidence for an increase in grazing pressure from deer between 2004 and 2019. Overall, there has been marked reduction in grazing, particularly for the most sensitive and important habitat, blanket bog. Much bare peat is the result of excessive grazing and that has fallen dramatically since 2004 and is now rare except in areas of former commercial peat extraction.

13. **Overall habitat condition and change** The RSPB monitoring method shows large improvements in the extent of several indicators of good bog condition and breeding bird habitat, particularly increased cover for Heather and Bog-moss *Sphagnum*. There is considerable overlap in the locations of the increases, suggesting they have occurred together over much of the bog within, around and distant from the windfarm. The increase in *Sphagnum* is particularly large on both drained and undrained blanket bog.

14. Using the 2019 monitoring area of 946 ha and average percent *Sphagnum* cover, extent has increased remarkably from an initial 2004 baseline figure of 11% (115 ha), rising to 48% (452 ha) in 2019. The 337 ha of recent *Sphagnum* establishment is concentrated in drained and undrained blanket bog which now have covers of 55% and 74% respectively.

15. *Sphagnum* cover values are strongly skewed. Median percent cover values are a more accurate measure for estimating extent and the equivalent figures are a 2004 baseline of 8% (75 ha), reaching 46% (434 ha) in 2019. This estimates *Sphagnum* cover increase as 359 ha. In 2019 drained and undrained bog had 54% and 81% cover respectively using median values.

16. The *Sphagnum* cover increase is a major positive benefit which seems to have started with windfarm construction, increasing over a decade to 2014, with only a slight further rise in 2019. The 2019 extent might represent stability for current environmental and management conditions.

17. The *Sphagnum* increase is not easily explained. This is unfortunate, on account of the scale of *Sphagnum* increase (which seems very large) and the dominant current paradigm which portrays wind farms as major drying agents when established on deep peat (i.e. *Sphagnum* extent should decline within a bog hosting a wind farm).

18. It is possible that the increase in *Sphagnum* is related to windfarm microclimate change downwind from turbines but this conclusion is speculative. Early monitoring in 2004, 2005, 2006, 2007 and 2009 show that *Sphagnum* increase began immediately following windfarm construction, continuing at a near-exponential rate within bog habitat. The *Sphagnum* cover in 2004 was very similar to results collected in 2001 for the Causeymire Wind Farm EIA.

19. The *Sphagnum* cover on bog habitat at Causeymire is now probably higher than that cover on many other parts of the Flow Country. It has developed following site enhancement measures and is the outstanding result of site management. It was not anticipated in the EIA or in preparing enhancement proposals.

20. Trends in a large set of other monitored attributes became clearer over time, in part due to a long time interval for observation and in part due to additional analysis which was partitioned by habitat and drainage. Blanket bog, fen and former peat extraction areas were shown to respond differently to changes in grazing management.

21. **Turbine bases, hard standings and track verges** The habitat condition of turbine bases, hard standings and road verges was recorded in 2010, 2014 and 2019 using bespoke systematic techniques. A high vegetation cover developed in bases and along verges. Cattle grazing and nutrient impacts have been important in affecting species composition in bases and on verges. In addition, verge results also show that drier conditions have developed, allowing a high Heather cover following declines in the cover of Multi-headed and Hare's-tail Cottongrasses.

22. **Overview of enhancement and EIA assessment** Monitoring results show clearly that management based on enhancement measures has resulted in much-improved site condition, particularly for bog habitat, the main objective of EIA proposals and more detailed specifications made in 2004.

23. This development is located in ground which is much-modifed by a range of activities. Grazing mangement has operated probably more than a century, with very high sheep numbers between the 1960s and mid-1990s. As part of that grazing, fen and bog habitats have been extensively drained, leaving the Bad a Cheo blanket bog plateau as the only large bog sector remaining intact. Afforestation has affected a sizeable part of the HMSA and a large tract of former wet peatland at Dale Moss has been deep-drained and surface-milled for commercial peat extraction and then left to regenerate naturally without restoration.

24. A key measure of pre-windfarm site condition is given by *Sphagnum* extent. Analysis for this report revealed that 2001 Macaulay Institute samples for the Causeymire Wind Farm EIA had a low average cover of 15.1% covering blanket bog and fen habitat. That is little different from windfarm monitoring in 2004 (14.7%) for the same area and habitats as Macaulay work.

25. As a measure of improved condition, monitoring for the same area as Macaulay work shows the following sequence over time: 14.7% (2004) → 29.4% (2009) → 35.8% (2014) → 32.5% (2019). A high *Sphagnum* cover suggests much more active bog and fen habitats (i.e. increased rates of peat formation).

26. Breeding bird habitat condition should have improved at Causeymire if bog and fen environments have improved condition, as suggested by multiple RSPB indicators.

27. Predictions on windfarm impacts on ecology and surface hydrology in the Causeymire EIA have in general been validated, apart from some restricted road and turbine drainage effects which have developed in the operational phase. Recent published work assessing peatland windfarm EIAs in Scotland is disputed on the basis of exaggeration, using Causeymire findings.

1 Introduction

1 Causeymire Wind Farm was constructed between 2003 and 2004 and comprises 21 wind turbines. These are numbered from 1 to 24. Three turbines (T11, T12, T13) were excluded from construction in 2003- 4.

2 This report summarises work completed in 2019 to satisfy planning conditions and a Section 75 Management Agreement (S75) which includes post-construction work at Causeymire Wind Farm in Caithness. It also includes comment on trends from earlier years. Specifications for habitat enhancement and monitoring are given in Dargie (2004).

3 The Section 75 Management Agreement contains proposals to improve habitats for wildlife, particularly birds, around the Causeymire wind turbine array. The area used for habitat monitoring between 2004 and 2014 (the Habitat Monitoring Study Area, HMSA) covered 1129 ha, extending east from the River Thurso and north from the Little River, to Westerdale Road. It contains varied habitats (Figure 1, Table 1), most of which are established on deep peat (>0.5 m depth). It extends well beyond the ground covered by the Section 75 Management Agreement area (361 ha, marked in Figure 1).

4 The HMSA was initially 1129 ha in extent. Two additional wind farms (Achlachan in the north, Bad a Cheo in the south-east) have been constructed since survey in 2014, each with their own habitat management proposals. That management might have already produced effects which could complicate interpretation of Causeymire work. These areas were therefore excluded from 2019 survey after consultation and agreement with Scottish Natural Heritage, RSPB and The Highland Council. This excluded ground is shown in Figure 1 and reduces the 2019 HMSA area to 946.3 ha.

5 The main means intended for achieving habitat improvement has been via changed grazing.

6 Sheep numbers were reduced from 500 in 2003-4 to 250, starting in 2004. This reduced total was managed differently by year (Simon Harrison, pers. comm.). Sheep numbers in 2007/8 were 250 overwintering ewes, then 155 ewes and 190 lambs in summer. In 2008/9 180 ewes were overwintered, then 160 ewes and 240 lambs in summer. No sheep have been grazed on most of the HMSA since 2010 (D. Miller, pers. comm.), apart from a small area in the north-west adjacent to the River Thurso, used by a different grazing tenant. Numbers here are unknown.

7 Cattle also graze the HMSA and some adjacent improved grassland immediately to the north-east. Numbers have increased from 20 in 2004. The following figures and estimates were supplied for the 2009 monitoring report by Danny Miller (pers. comm.):

- In 2007 40 cattle used the combined area (HMSA plus improved fields) year round, plus followers. Between July and December 2007, an additional 40 heifers used the combined area.
- In 2008 45 cattle used the combined area year round (plus followers). Between July and December 2008, an additional 36 heifers used the combined area.
- In 2009 40 cattle used the combined area year round (plus followers). Between July and December 2009, an additional 49 heifers used the combined area.

- In the above years the HMSA was estimated to represent 60-70% of the grazing used by cattle.

8 Further changes have been made to cattle grazing since 2010 which in 2014 had three different timed elements (D. Miller, pers. comm.):

  - Breeding heifers use the area from May to September/October, with numbers perhaps increasing by about a third since 2009. (This is interpreted here as an increase from about 90 to about 120, based on numbers supplied by D. Miller in 2010.)
  - A “mob” of 30-80 cows grazed much of the HMSA (and improved pasture in the north-east) in early Spring, for a month. New electric fencing was erected to exert grazing pressure on some of the rankest vegetation.
  - A similar “mob” of perhaps 100 cows graze much of the HMSA (and improved pasture in the north-east) in mid-Winter.

9 The 2014 numbers and timings were continued into 2015 and 2016, followed by reductions in numbers from 2017 to 2019 (D. Miller, pers. comm.). Two “mobs” totalling 65 cows and calves grazed in the summer (69 in 2019), with variable spring numbers: 78 cows in 2017, 54 in 2018 and 71 in 2019. The two “mobs” have different preferred grazing locations. One herd is mainly on in-bye land in the north-east, plus immediately adjacent fen which contains a little wet heath. This herd also has access to grazing in the wider hill and turbine area. It is estimated that 75% of summer grazing time/pressure is spent on the in-bye ground, parts of which are semi-improved. The second herd has access to riverside habitats alongside the River Thurso, as well higher ground up to the western parts of the southern parts of the turbine array. It is estimated that 60% of summer grazing time/pressure applies to riverside habitats, with 40% to higher ground which is mainly fen. Spring grazing covers 60 days from late February, with reduced grazing (10-15%) upon inbye/field pasture. There is therefore heavier grazing pressure on semi-natural habitats (mainly fen and marshy grassland) in this period. There is now no winter grazing.

10 Overall, these stocking numbers are intended to produce a notable reduction in grazing pressure from domestic stock. Cattle avoid the poor feeding on open bog and move between preferred areas of fen/marshy grassland which is mainly dominated by Purple Moor-grass *Molinia caerulea* and Soft-rush *Juncus effusus*. Use of cattle should therefore ensure better habitat conditions for open bog as a result of reduced sheep grazing, as well as a lower and more open structure in fen and marshy grassland.

11 Deer graze the HMSA area and adjacent fields. Numbers are controlled by stalking. The cull totals (Innes Miller, pers. comm.) for 2008-9 were 15 stags and 19 hinds; for 2009-10 9 stags and 9 hinds. A deer count on 1 March 2010 recorded 42 deer in the HMSA. There has been no more recent deer count. Since 2010 the site cull was increased to around 35 and the number present on a year round basis is thought to be around 80. In 2019 it is reported (Innes Miller. pers. comm) that the year-round population of red deer is 50 hinds with 20 calves and an uncertain stag total. Annual culls of stags of 12 – 20 have been achieved in recent years, with a hind cull of 15 – 20.

12 As a secondary improvement, 1350 metres (1.35 km) of moorland grips (drains) were blocked using peat-plug dams in 2004. These sectors were either eroding or had little Bog-moss *Sphagnum* content in 2004. Elsewhere, the majority of drains within and adjacent to the wind farm in 2004 were filled with *Sphagnum* within 10-20 cm of the

drain top and on the basis of RSPB published advice in 2004 did not require blocking . Damming the sectors with poor *Sphagnum* content is likely to increase the wetness of surrounding ground (probably little more than 5 metres each side of a blocked sector), perhaps affecting 2.7 ha of ground. Drain-blocked sectors are a very small proportion of site drains which total 71.7 km based on mapping captured into GIS from good-quality 1989 vertical aerial photography (Fig. 1).

13 This length total excludes many additional drains and furrows installed as ground preparation within site forestry in the north-west, plus drainage within widespread former domestic and commercial peat extraction areas. Overall, the peat and mineral soils of the HMSA are very extensively drained apart from ground east of the turbine array. Here the peat is very deep and there are extensive areas of blanket bog pool and dubh lochan on ground named on Ordnance Survey maps as Bad a Cheo. The pools and dubh lochans are concentrated in two areas, each within a slightly lower saucer-shaped depression which suggests slightly increased wastage, perhaps via methane emissions to atmosphere as a result of very high groundwater, at or very close to the ground surface. A further area of bog pools, orientated parallel to contours, is present south of the turbine array.

14 Further east still, outside the HMSA, experimental forestry plots were maintained by the Forestry Commission from 1965. These areas were removed by harvesting and mulching from 2017 onwards, to make way for the construction of Bad a Cheo Windfarm, operational from 2019.

15 The far north of the HMSA includes a sub-compartment, 8.8 ha in size, with most ground ploughed for forestry. In 2004 this had poorly-growing Lodgepole Pine which had been planted perhaps a decade earlier. This was surrounded with an electric fence in 2005, designed to reduce deer grazing and to encourage taller Heather growth and perhaps occasional use of the enclosure in the long-term by raptors for breeding. It is termed the Habitat Enhancement Area (HEA).

16 The HMSA has been monitored using a habitat condition survey method designed by RSPB for peatland habitats. RSPB supplied the details in 2004. The method uses fixed transect lines spaced 500 metres apart, running north-south. Ground character is recorded for 100 m north-south transect sectors, and for observations at points marking the start and finish of 100 m sectors. A more intensive west to east transect-spacing is used only at Causeymire for the Habitat Enhancement Area (50 metres apart). The RSPB method was used in 2004 (considered as baseline year 0), 2005 (Year 1), 2006 (Year 2), 2007 (Year 3), 2009 (Year 5), 2014 (Year 10) and 2019 (Year 15). These timings agree with those for breeding bird and bird vantage point surveys, as required under planning conditions.

17 This report covers the following items on habitat enhancement and monitoring done between 2004 and 2019:

- The results of blanket bog habitat monitoring using the RSPB methodology first adopted in 2004. Results are produced for both the HMSA and the HEA.
- The condition of wind turbine bases and hard standings, plus road verges which were initially restored in the last stages of construction.
- The success of measures applied in the HEA to increase the height of Heather. This was discussed in 2015 by the Environmental Management

Committee. It was agreed that there had been an increase in Heather height but insufficient to provide breeding habitat for raptors, the original intention in 2004. It was also agreed that no additional enhancement measures were required in the HEA, since it was unlikely that tall Heather could be achieved. The 2015 position is reviewed here in the context of 2019 results on Heather height.

- An interpretation and overview of habitat change and habitat condition between 2004 and 2019 in relation to enhancement and other significant factors (e.g. the effects of wind farm operation, grazing and deer management). Interim interpretation in earlier reports established that habitat type and drainage impacts were important in understanding habitat change over time. Results in 2019 are therefore structured in relation to habitat and drainage, as in earlier reports.

18 Work in the report on 2014 conditions included detailed inspections of many ditches and culverts, including a map of ditch habitat condition and discussion on the impacts of new ditches excavated by the previous windfarm owners, RWE Innogy. A site visit by the Environmental Management Committee in 2015 saw examples but made no comment or recommendation for further work. This work has therefore not been repeated in 2019 other than making rapid observations which suggested that conditions remain similar to 2014. The 2014 findings are discussed again in this report, in relation to other habitat change recorded nearby using the RSPB methodology.

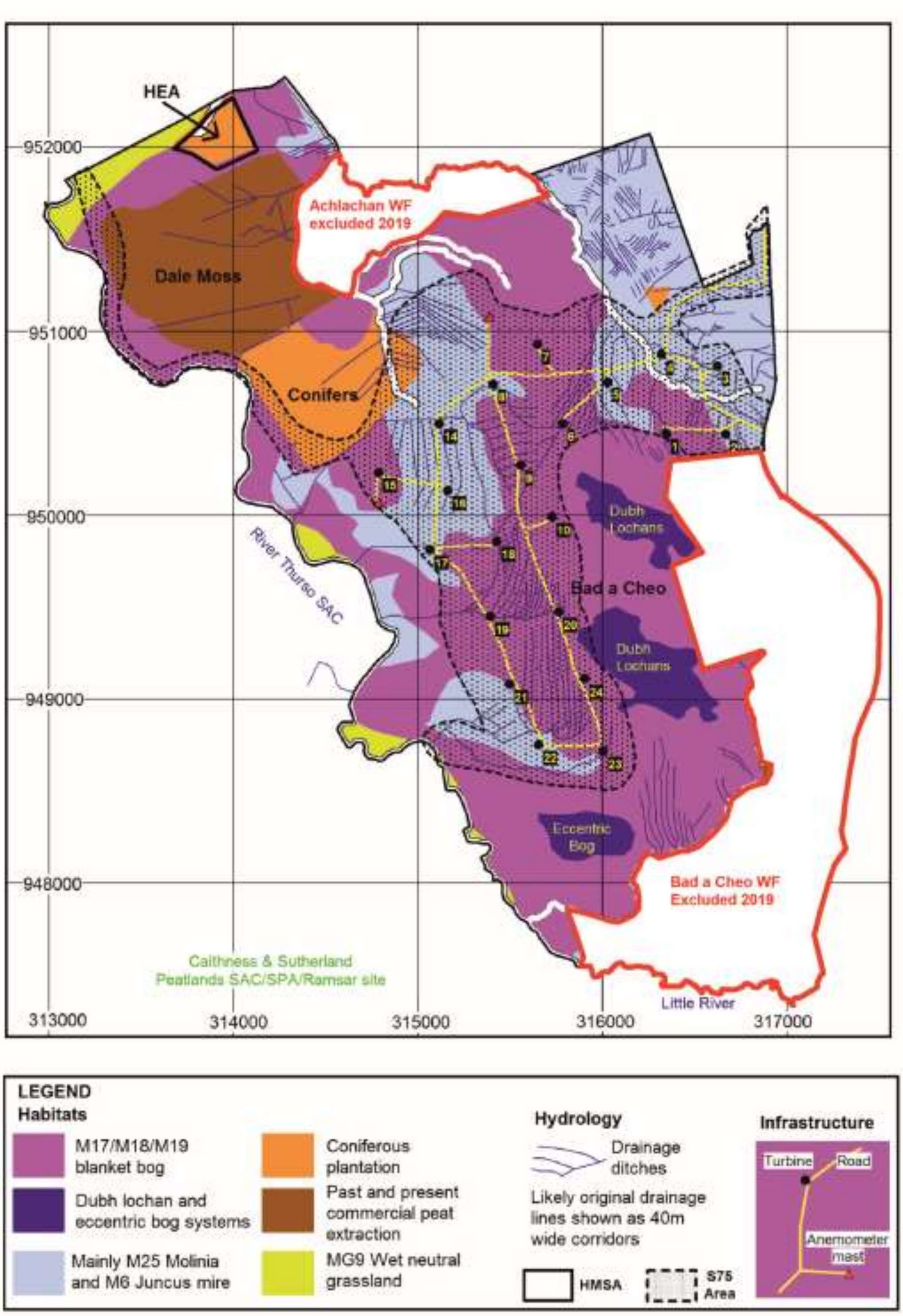


Figure 1 Habitats, drainage, HEA (Habitat Enhancement Area) and windfarm infrastructure within the HMSA (Habitat Management Study Area)

HMSA boundary adjustments made in 2019 are shown, to avoid new adjacent windfarms

Table 1 Main habitats present in Habitat Management Study Area (HMSA)

Habitat	**Further information**	**2019 Extent ha**
Intact mire M17-M18-M19	NVC blanket bog comprising a mix of M17 *Trichophorum germanicum - Eriophorum vaginatum*, M18 *Erica tetralix – Sphagnum papillosum* and M19 *Calluna vulgaris – Eriophorum vaginatum*. Bog pools containing NVC M1/M2 vegetation are occasional to locally abundant within this vegetation. Actual NVC status is often difficult to assign (except for pools) due to surface patterning (hummocks and hollows) present at a scale more intense than a standard 2m x 2m NVC quadrat. Usually represents ground with active blanket bog (active = normally peat-forming). Bog conditions indicate habitat which is solely dependent on nutrients derived from rainfall.	463.2 (formerly 515.7 ha)
Molinia mire M25 and M6/M23 rush pasture	NVC M25 *Molinia caerulea – Potentilla erecta* mire and rush pasture with abundant *Juncus effusus*. These are fen conditions (wetlands under the influence of groundwater or surface water which has passed through mineral-rich conditions). At Causeymire these usually represent ground which is flushed or which has a marked seasonal fluctuation in watertable, sufficient to prevent major peat formation. Rush pasture indicates areas of surface water seepage flow and these flushes can be extensive around more confined watercourses. Large areas contain old drains to increase grazing value. Hydrology is varied. There are patches of other bog and swamp types present in wetter ground, including treacherous S23 *Carex rostrata-Potentilla palustris* tall-herb fen. There is acidic grassland and wet heath on drier area but these are rare. Areas have been re-seeded in the north-east to produce improved grassland. These habitats also extend into old re-vegetated peat cuttings which occur between areas of mineral soil and deep peat supporting intact mire. These habitats occur on deep peat, shallow peat and mineral soil.	233.1 (formerly 247.4 ha)
Commercial peat extraction	Old extraction area present in north (Dale Moss), deeply drained areas in west with slow succession to heath and very dry blanket bog. Further east there is wetter ground with only shallow drains and no extraction. Here, the remnants of former pool systems are still present, some with *Rhynchospora alba*.	86.8 (formerly 188.7 ha)
Natural watercourses	Drainage corridors, mainly containing NVC M25 and M6 *Carex echinata – Sphagnum fallax/denticulatum/inundatum* flushed peatland, creating narrow dry edges to adjacent peatland due to local lowering of bog watertable.	41.6 (formerly 55.4 ha)
Plantation	Mainly Lodgepole Pine established on deep ploughed peat, initially used as a Christmas tree enterprise in the largest plantation area (trees are now too mature). Growth was poor in the smaller far north sector (including the HEA) but improved in the HEA after electric fencing reduced grazing pressure. Trees here were felled after 2012, although there is continued strong growth in a young plantation west of the HEA. A small triangular plantation in the north-east has Sitka Spruce and is mainly used as a shelter for deer.	54.5 (no change)
Dubh Lochan and Eccentric Bog Pool systems	Wettest areas of intact blanket bog, with concentrations of bog pools containing NVC M1 *Sphagnum denticulatum/inundatum*, M2 *Sphagnum cuspidatum/fallax* and M3 *Eriophorum angustifolium* bog pool communities. The pools are surrounded mainly by wet forms of M17-M18-M19 vegetation, particularly in an eccentric (raised) bog (*sensu* Rydin & Jeglum 2006), the most southern of the three large-pool systems present in the HMSA. An eccentric mire is different from blanket bog, with long linear pools oriented parallel to bog surface contours on slopes which are very slight. Elsewhere, on blanket bog, areas containing many hundreds of small pools are also present but are not mapped (e.g. east of the largest forestry area in the north-west; south of Turbine 1 extending into the Bad a Cheo former experimental forestry plots. In earlier reports this included M17-M18-M19 ground surrounded by peat extraction in the south of the pre-2019 HMSA).	47.6 (no change)
Wet neutral grassland	Dominated by NVC M6 *Carex echinata – Sphagnum fallax/denticulatum*, M6c *Juncus effusus*) rush pasture and coarse wet grassland belonging to NVC MG9 *Holcus lanatus – Deschampsia cespitosa* community. Marks flushed peat or mineral soil, where either upper peat has been removed or alluvium deposited adjacent to watercourses. Mainly located beside the River Thurso.	19.5 (no change)

2 Results of 2019 habitat monitoring and change 2004-2019

2.1 Background

19 The RSPB habitat monitoring scheme designed for blanket bog habitat was first undertaken on site in September 2004 by Mr. Mark Middleton, who repeated the work in 2005, 2006, 2007, 2009 and 2014. The approach and results are discussed in Dargie (2005, 2006, 2007, 2008, 2012, 2015). RSPB methods are presented here in Appendix 1, as a reference. The work was repeated in July and August 2019 by Dr Dargie, assisted by Andrew Weston.

20 Causeymire Wind Farm is surrounded by the large Habitat Management Study Area (HMSA) within which north-south belt transects are located. The primary transect lines are separated at 500 metre intervals and follow the 250 and 750 metre eastings of the UK National Grid. A more intense 50 metre eastings grid is used within the HEA in the north, to produce sufficient samples to describe the habitat conditions present.

21 Various habitat attributes are recorded along 100 metre lines, in both the HMSA and HEA, plus other characteristics at points spaced at 100 metre intervals. Attribute counts (see details in Appendix 1) are made at every right footfall along a line sector, based on the character of the ground immediately in front of the right foot (an imaginary point). This technique is known as the step-point method and it is used widely in high and low latitudes as a method for recording the percentage cover of defined attributes (after expressing counts as a percentage of all right footfalls on one 100 metre sector). An example of its use and statistical strength is given by Vittoz *et al.* (2010), including data from the Cairngorms.

22 Analysis of data for line pacing is made by attaching calculations (percent cover or percent frequency) to points positioned at the centre of a line segment. The generalisation of lines into point data is important, since it allows maps of specific attributes to be presented in an easily-interpreted way.

23 There are 189 sampling positions in the points dataset (start/end of line segments) and 173 positions in the paced line information. The locations of these two point dataset samples are shown in Figure 2.

24 Spreadsheet analysis and GIS were used to check data carefully against field sheets and then to obtain two primary data sets (points, lines) of core information: averaged data for field attributes, standardised using percentage values in the case of line information against the number of right footfalls counted for each line segment. In 2019, as in previous survey years, field records were entered on to formal recording sheets originally produced by RSPB. This information was captured into spreadsheets. Combined 2004-2019 spreadsheets for points and lines were developed for import into GIS and other software to allow mapping of 2004 and 2019 conditions, with key variables also considered for 2009 and 2014 to further understand important changes which might be occurring.

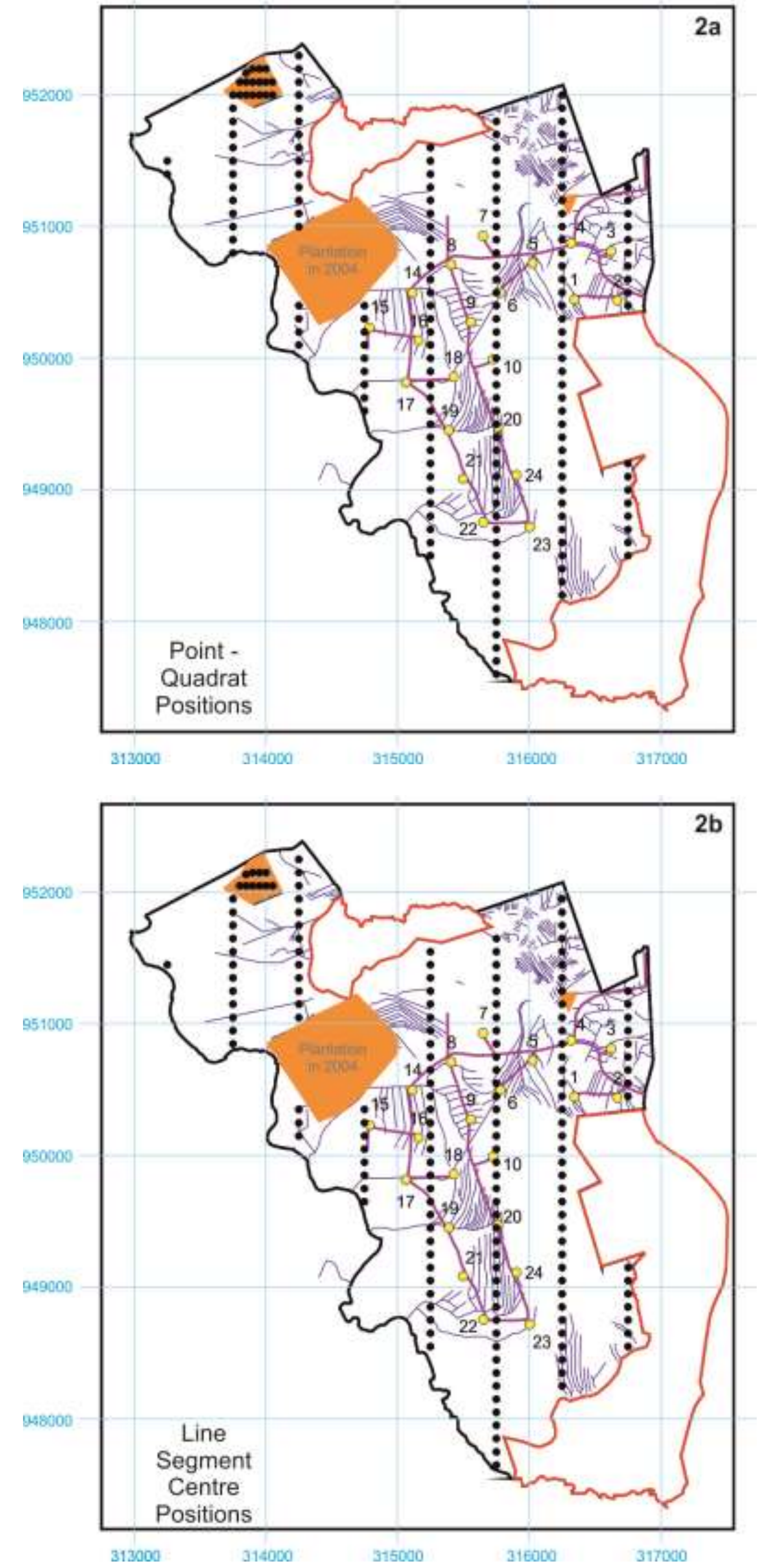


Figure 2 Location of Causeymire point (2a) and line segment centre samples (2b)
RSPB Habitat Condition Monitoring Method
Black filled circles mark sample positions

25 GIS was used in earlier reports to capture extra site detail which had not been included in the Causeymire Environmental Statement (National Wind Power & Miller 2001). This information was first included with 2006 results (Dargie 2007). The detail was mainly extracted by heads-up digitising from 1988 Scottish Development Department 1:23,000 vertical aerial photography which had been orthorectified, plus knowledge of the site (i.e. ground truth). The extra information includes the following, located in Figure 1:

- Areas of peat extraction with extraction boundaries updated using Google Earth which includes 2003 and 2004 aerial photography of the Causeymire site. The 2019 HMSA includes an area of former milled peat extraction at Dale Moss.
- Key habitats – ombrotrophic bog (this includes the National Vegetation Classification (NVC) types M17 *Trichophorum germanicum – Eriophorum vaginatum*, M18 *Erica tetralix – Sphagnum papillosum* and M19 *Calluna vulgaris- Eriophorum vaginatum*) and areas of *Molinia* fen (NVC M25 *Molinia caerulea – Potentilla erecta* mire) which also include some marshy grassland (mainly NVC types M23 *Juncus effusus/acutiflorus – Galium palustre*, M6 *Carex echinata – Sphagnum fallax/denticulatum* vegetation and MG9 *Holcus lanatus-Deschampsia cespitosa* coarse wet neutral grassland).
- The approximate limits to large dubh lochan and eccentric bog pool systems.
- Forested areas within the HMSA.
- Major streams running through blanket peat, providing local drawdown of the watertable in adjacent peat.
- Visible lengths of Cuthbertson drains, probably ploughed in the 1950s and 60s, usually cut in a ‘herringbone’ pattern. Sectors blocked in 2004 are not marked in Figure 1 (see Figure 9). Drains visible within mainly M25 *Molinia* mire are mapped but there are more in such ground, not visible on aerial photography. They can probably only be accurately mapped in the field using GPS.

26 Drainage effects from past and present land management were very extensive at Causeymire, well before windfarm construction. GIS analysis in earlier reports calculated that more than half of the 2004-2014 HMSA was affected by drained ground within and around different land uses and natural watercourses. That result was obtained by applying buffers to recorded drains or large blocks of drained ground: commercial peat extraction (20 metre buffer), very old domestic peat cuttings (20 metres), turbines and hardstandings (20 metres), Cuthbertson drains (20 metres), forestry plantation (40 metres, based on published research) and natural watercourses (20 metres).

27 A map of drained ground including surrounding buffers is shown in Figure 3. 2019 point and line segment samples were individually checked against the GIS drained ground layer. Each was allocated to a drained or undrained (intact) category. In the case of line segments this allocation was necessarily subjective because many 100 metre line lengths overlapped both drained and non-drained ground. The category allocated required more than half of a line length.

28 Each point and line segment sample was also allocated a habitat category based on the mapping in Figure 1 which also corresponded with habitat records made in field recording.

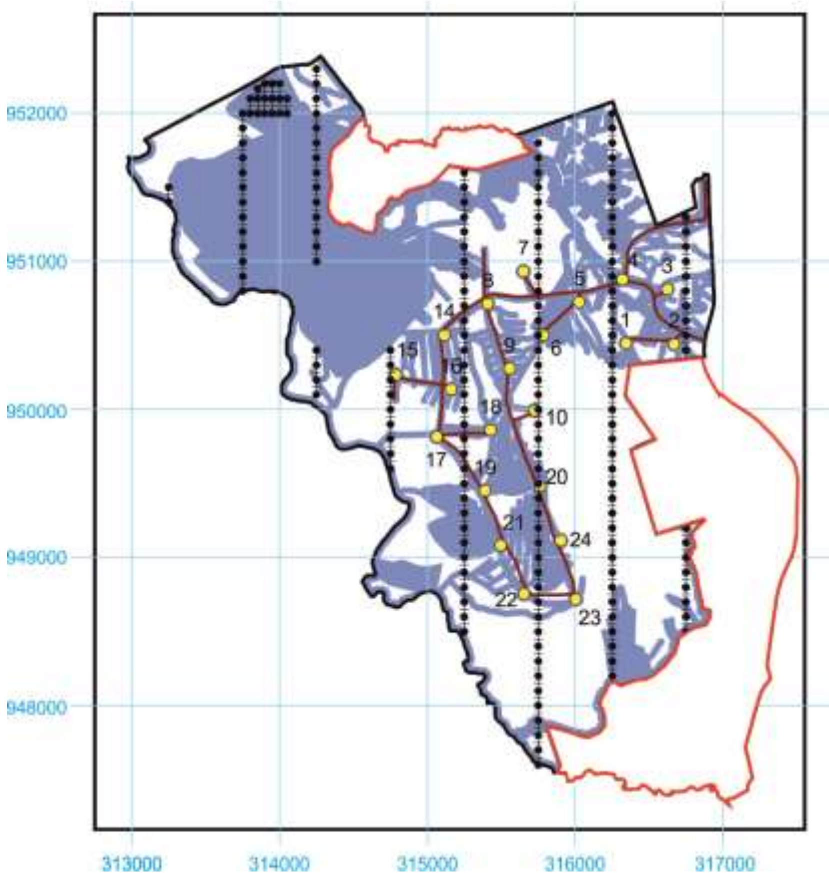


Figure 3 Drained ground extent within the 2019 HMSA
Drained ground mapped in blue (includes buffers estimating indirect effects)
Monitoring positions marked as circles (points) and crosses (line centres)

2.2 Presenting results

29 Results in this report concentrate on 2004 and 2019 findings. Full discussion of sample year to sample year change between 2005 and 2014 has been given in earlier reports and is not repeated here.

30 The full datasets used for 2019 work are large and are not included as appendices. They are supplied separately to the client and consultees as spreadsheets.

31 Point and line data results are summarised respectively as mean values in Appendix 2 and Appendix 3. A brief summary of these results is given in section 2.3 (Point data results) and section 2.4 (Line segment results). Results are broken down into the following key habitats: Drained Bog, Intact (undrained) Bog, Drained Fen, Intact (undrained) Fen, Habitat Enhancement Area (HEA) and Former Peat Extraction. This breakdown was recommended in feedback to the report on 2009 results (Dargie 2012).

32 The 2019 results cover mean values for 2004, 2009, 2014 and 2019, applied to the 2019 MHSA. Results for 2004, 2009 and 2014 usually differ from those reported in earlier years due to the change in MHSA area and the exclusion of points and line segments within Achlachan and Bad a Cheo Windfarms.

33 The definition and measurement of each attribute in Appendix 2 and Appendix 3 are given in RSPB instructions, in Appendix 1. For clarification, measurements of plant species obtained by pacing 100m transect lengths are considered to be estimates of percent cover. This pacing technique is a variant of the step point method (Evans & Love 1957) which is used to calculate percent cover of plant species in range environments. It is considered to be a robust and effective technique for monitoring percent cover changes over time (Vittoz *et al*. 2010). Other attributes, such animal print and dung counts, are better considered as percent frequency measures because these are obtained within 0.5 metres of a step, not from the exact front of the step.

34 There is a considerable amount of information in Appendix 2 and Appendix 3. Earlier reports considered that some RSPB point variables did not show clear patterns in distribution or trends over time, largely due to their absence in many records (i.e. very limited occurrence). It is stressed here that most variables contain a large number of zero values (absence at a point or on a line sector). These zeros skew the statistical distribution of results and this, together with the systematic nature of sampling, makes it difficult to test for differences between variables or in trends in one variable over time.

35 Statistical analysis was applied in earlier reports to the run of mean values for variables. That work used the Mann-Kendall test for detecting a monotonic trend (i.e. either only increasing or decreasing), with a null hypothesis of no trend (i.e. the observations are randomly ordered in time). An assumption of this test is a minimum of four values in a time sequence. It was applied in earlier work to survey dates with irregular time intervals (1, 2 and 5 years). That was sub-optimal but was declared as such, using results to filter out the strongest monotone trends as the main trends for a particular set of time sequences.

36 That testing has not been applied to results incorporating 2019 results. A quick scan of results in Appendices 2 and 3 indicated that few variables would be shown significant and that others, with very strong trends over time but slight slippage or increase in

2019, would be judged non-significant. The search for monotone behaviour is also ecologically naïve over longer periods of time, when habitat succession is known to slow down and be susceptible to either cyclical behaviour (e.g. Heather growth, pool-hummock relief change on bogs) or reversals due to extreme events (e.g. severe drought). Testing with this technique might be suitable in the early stages of monitoring but in the medium to long-term hypothesis testing based on more robust methods ought to be considered. This is beyond the scope of this monitoring programme and would require specialist advice, given the non-random sampling in RSPB methodology.

37 Results are interpreted subjectively, concentrating on what are the clearest patterns. This is necessary because ecological relationships and trends are often not linear. In addition, mean values obscure what might be important spatial patterns in emerging habitat trends. Subjective interpretation is done carefully, using graph and map analysis in addition to the results in Appendices 2 and 3. It is also based on the experience of interpretations made in earlier reports, particularly large differences between habitat types and the effects of drainage (most of dates to pre-windfarm times).

38 Graphs are used as an important interpretation tool, based on results in Appendices 2 and 3. These are presented as four sets:

- Point data graphs, attributes recorded for the 1 m radius circular quadrat specified in the RSPB methodology (Figure 4).
- Point data, attributes recorded as cane frequency (1 to 10) for attributes above or below a 1 m cane divided into 10 10cm lengths as per RSPB methodology (Figure 5, all attributes excluding bog moss *Sphagnum*; Figure 6 all attributes involving bog moss *Sphagnum,* plus Deer Grass *Trichophorum germanicum*). Quantity is based on the amount of attribute aerial tissue above or below the cane, counted as presence within one or more cane 10 cm lengths. This is a form of shoot frequency measurement. Shoot frequency is related to percent cover.
- Line segment attributes, expressed as percentage of steps taken to cover each 100 metre segment (Figure 7). Attributes scores based on presence counts under the front of a pace are regarded as percent cover estimates. Scores based on presence within 50 cm of a step are regarded as frequency values.

39 As in earlier reports, some of the strongest changes over time are associated with bog moss *Sphagnum*. Individual values in years 2004, 2009, 2014 and 2019 are plotted as Box diagrams in Figure 8 to illustrate further those trends, split into habitat subsets.

40 The following approach has been used to produce attribute maps for analysis. Each selected attribute map was generated using the Surfer 13 package marketed by Golden Software Inc. Contour lines for all Causeymire analysis were interpolated using kriging, a geostatistical technique based on a linear least-squares regression method. The contour maps produced by Surfer are then added as a GIS layer to other information (turbine locations, tracks). Contour intervals vary between attributes due to a wide range between variables, but the same interval is used per variable for two maps, representing 2004 and 2019 results. Colour shading is used for contour surfaces, with increasingly red tones for higher values. This is a form of ‘heat mapping’.

41 Care is needed in interpreting the contour surfaces – these are only fully accurate around the input sample positions (marked on the maps as small cross symbols). Trends depicted beyond observation points are less accurate. Particular care is needed for local high scores confined to one or very few points. The kriging method generates a

symmetrical 'butterfly-winged' surface to the immediate west and east of the high-scoring points. Nevertheless, such effects still help interpretation as long as it realised that the attributes concerned are probably much more localised than the butterfly pattern suggests. This distortion is confined to only a few attributes and in general contour surfaces are excellent ways to appreciate the spatial component of habitat change.

42 The following 2004 and 2019 map comparisons are included for point (quadrat and cane) results, with contour maps in Appendix 4:

- Bare peat percent cover;
- Live Heather *Calluna* percent cover;
- Litter and graminoid percent cover (graminoids are grasses and 'grass-like' plants such as sedges, woodrushes and rushes);
- Other mosses (i.e. non-*Sphagnum* species) percent cover;
- Heather *Calluna* height (cm);
- Non-woody vegetation height (cm);
- Average vegetation height (cm) from two sward stick measurements;
- Heather *Calluna vulgaris* (frequency, out of 10);
- Four-leaved Heath *Erica tetralix* (frequency, out of 10);
- Multi-headed Cottongrass *Eriophorum angustifolium* (frequency, out of 10);
- Hare's-tail Cottongrass *Eriophorum vaginatum* (frequency, out of 10);
- Purple Moor-grass *Molinia caerulea* (frequency, out of 10);
- Bog Asphodel *Narthecium ossifragum* (frequency, out of 10);
- Other Mosses (frequency, out of 10);
- Woolly-hair Moss *Racomitrium lanuginosum* (frequency, out of 10);
- Acute-leaved Bog-moss *Sphagnum capillifolium* (frequency, out of 10);
- Feathery Bog-moss *Sphagnum cuspidatum* (frequency, out of 10);
- Papillose Bog-moss *Sphagnum papillosum* (frequency, out of 10);
- Deer-grass *Trichophorum germanicum* (frequency, out of 10).

43 The following 2004 and 2019 map comparisons are included for line segment (step point counting) results, with contour maps in Appendix 5:

- Bare peat percent cover;
- Cattle dung frequency;
- Cattle print frequency;
- Deer dropping frequency;
- Deer and/or sheep print frequency;
- Grouse dropping frequency;
- Frequency of bog pools with *Sphagnum* >50% ;

- Woolly hair-moss *Racomitrium lanuginosum* percent cover;
- Frequency of *Racomitrium lanuginosum* hummocks;
- *Sphagnum* percent cover.

44 Interpretation of change 2004 to 2019 is given in Chapter 3.

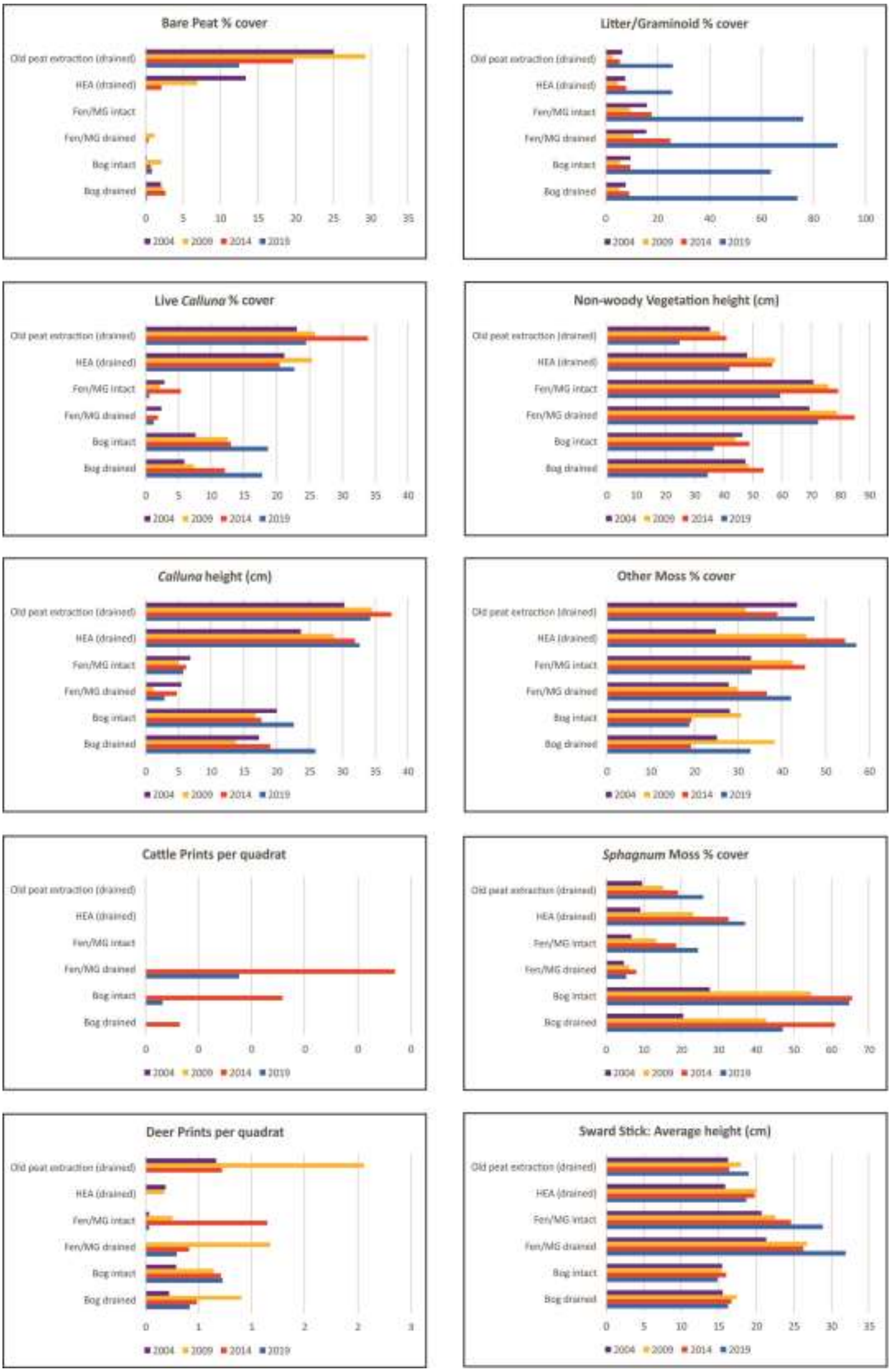


Figure 4 Point sample averages over time, quadrat and sward stick attributes

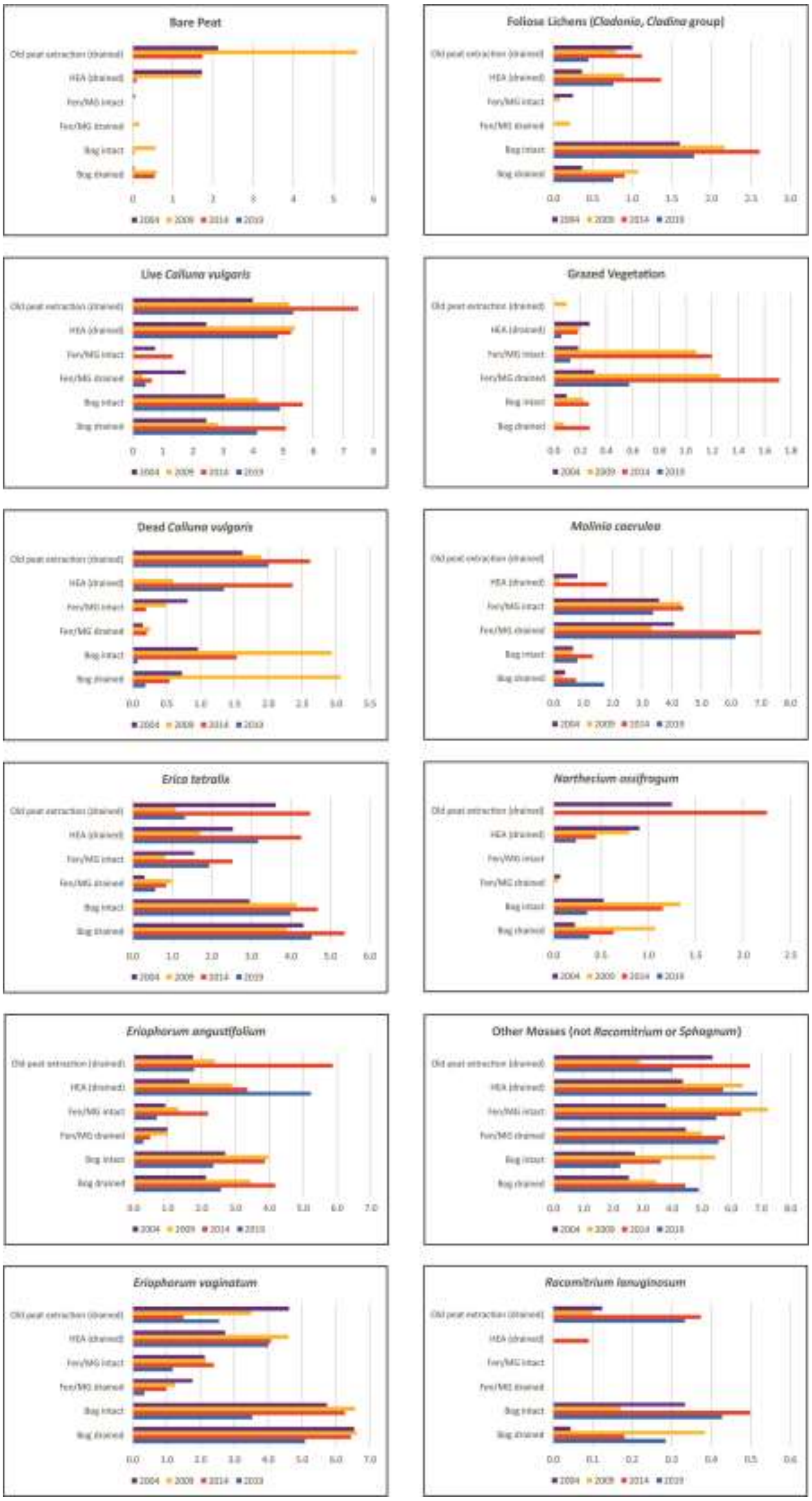


Figure 5 Point sample (cane) species averages over time, Attributes Part 1

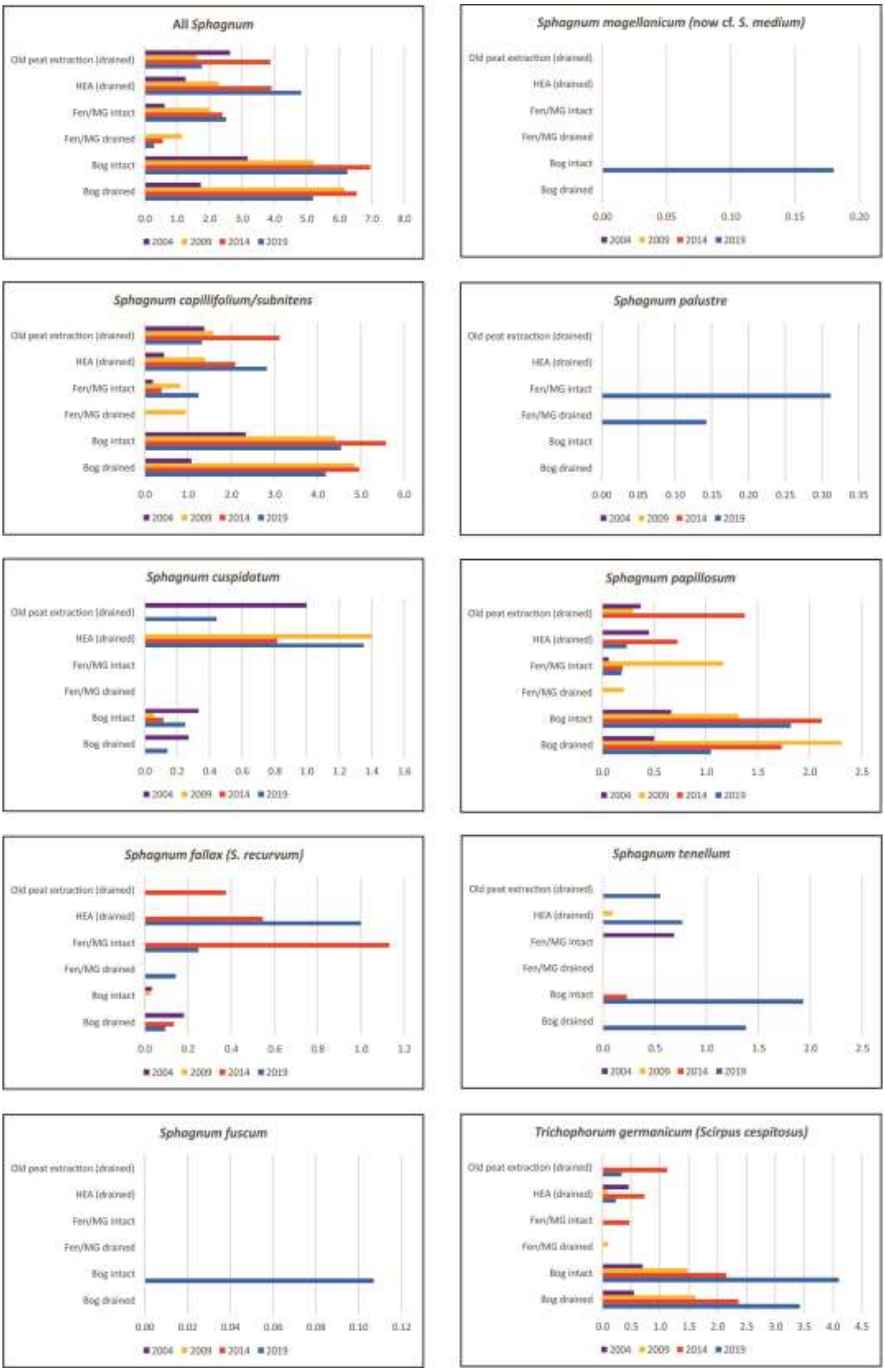


Figure 6 Point sample (cane) species averages over time, Attributes Part 2

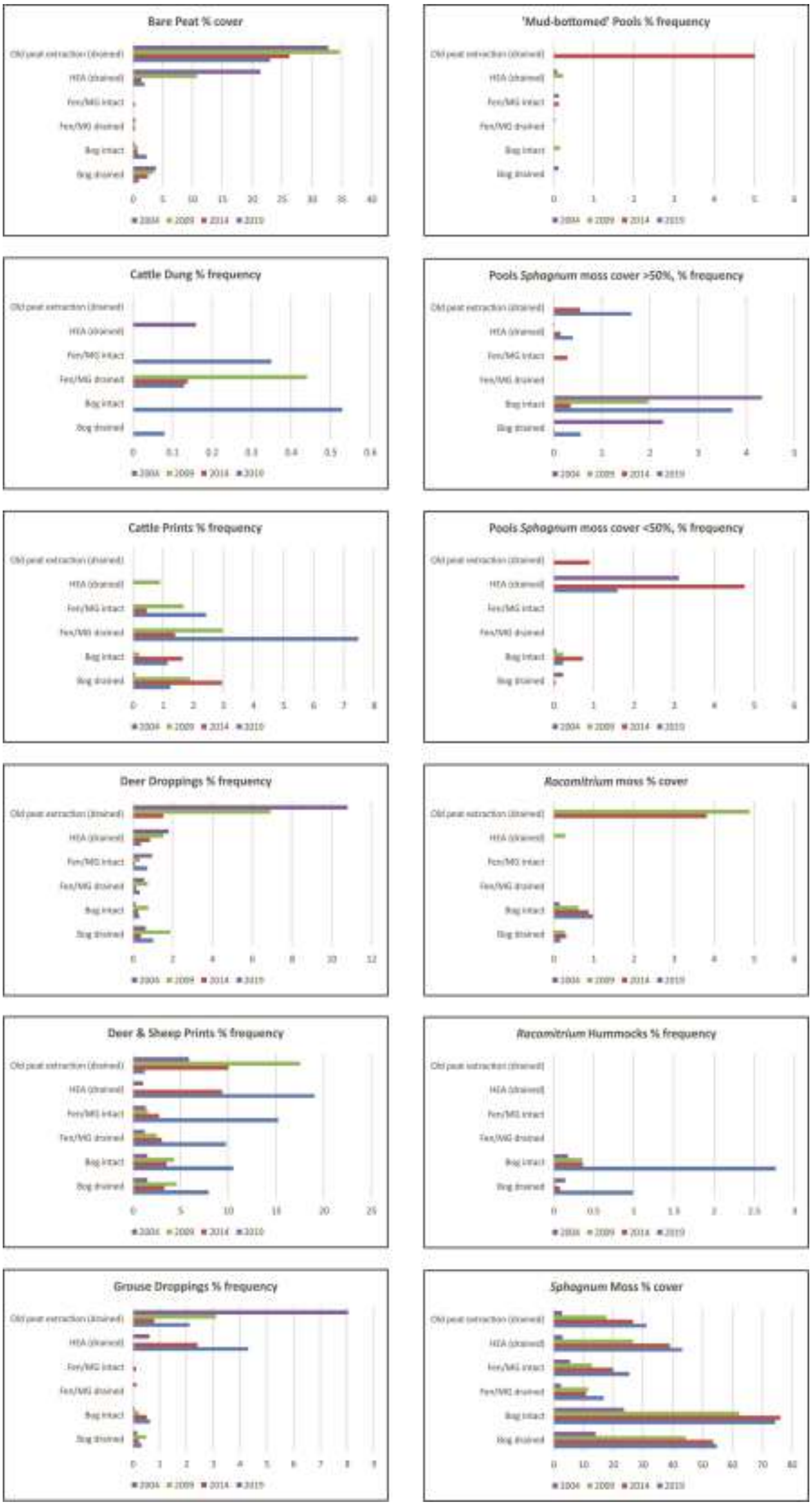


Figure 7 Line sector pacing averages over time

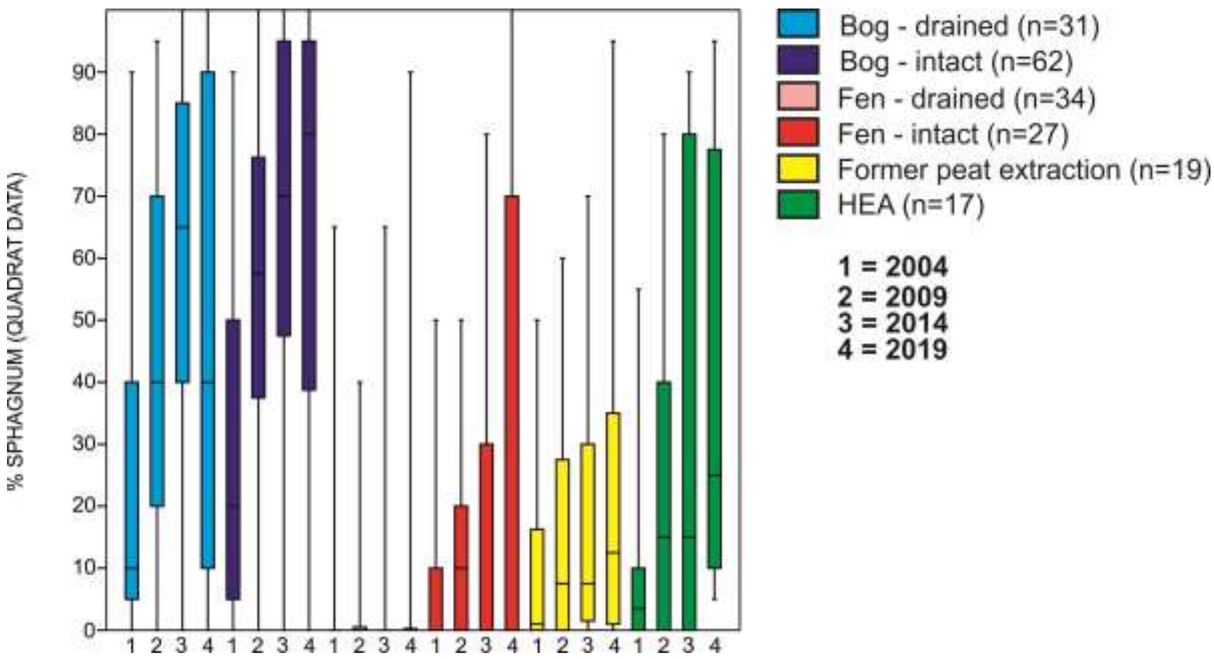


Fig 8a Point (quadrat) Data

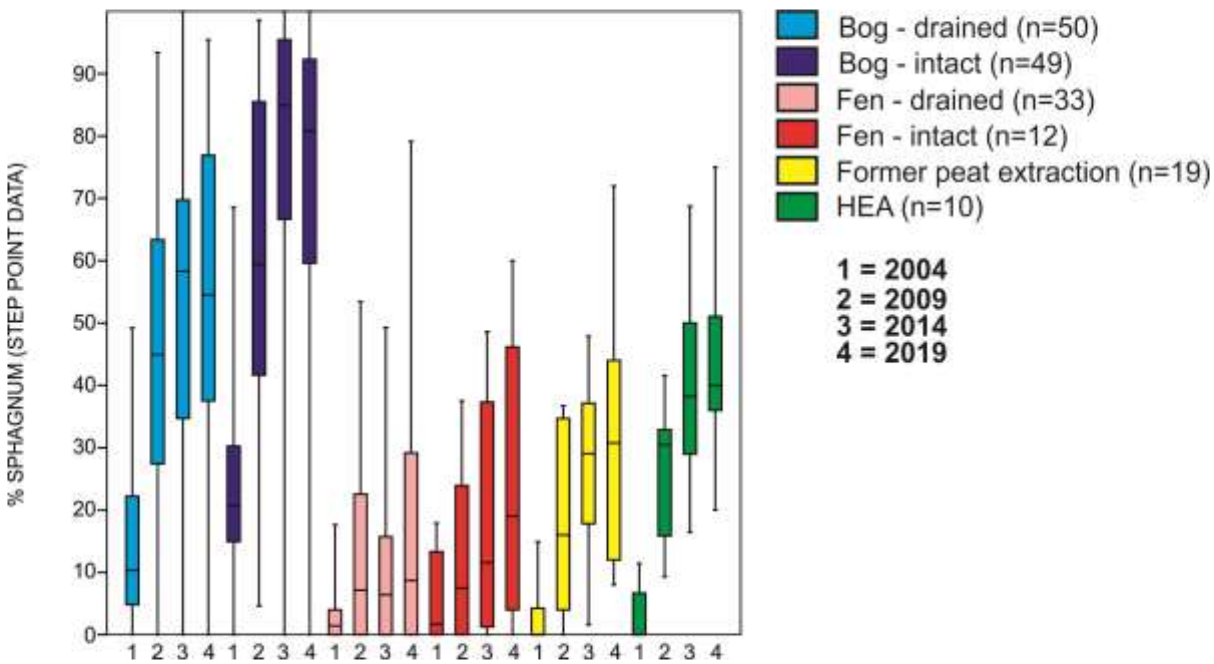


Fig 8b Line (step point) Data

Figure 8 Boxplots: *Sphagnum* cover change in relation to habitat and drainage

2.3 Point data results

45 The key features in point data graphs (Figures 4 to 6) are as follows:

- Several attributes show consistent monotone change, always increasing or decreasing over 15 years: bare peat and *Narthecium ossifragum*, both in the HEA (the only reducing attributes), live Heather *Calluna vulgaris* cover on intact and drained bog, increasing Heather height in the HEA, Other moss cover in the HEA, *Sphagnum* moss cover percent cover in old peat extraction (Dale Moss) plus drained and intact fen, sward stick height in intact fen. Monotone trends in cane-recorded species attributes (Figures 5 and 6) are rarer and confined to *Sphagnum* (All *Sphagnum* and *S. capillifolium/subnitens* in the HEA) and *Trichophorum germanicum* (intact and drained bog). Given the number of attribute graphs (32) and habitat categories (6), monotone behaviour over 15 years is uncommon (12 out of 192 possible age sets).

- A larger set of attributes (30 out of 192) show increases between 2004 and 2014, then a fall in 2019 results. This pattern could be interpreted as differences between 2019 surveyors and earlier work (a single surveyor) but this is unlikely because these patterns are scattered across many variables. In many cases the 2019 reduction is slight.

- The result for Litter/Graminoid % cover shows 2019 records much higher than earlier years. This does appear to be a difference between surveyors. There is no clear definition of this attribute or its recording in RSPB instructions (Annex 1). The difference seems to be summation of both litter and graminoid cover in 2019, but perhaps only graminoid litter between 2004 and 2014. Such litter is locally abundant at Causeymire, mainly made up of the former leaves of Purple-moor grass *Molinia caerulea*, the only deciduous grass in the British flora. Other graminoid species (particularly *Eriophorum vaginatum* and *Trichophorum germanicum*) are not large litter producers. This difference is unfortunate. Graminoid cover (grass, sedge, sedge-allies and rushes) is important when compared with cover values for dwarf-shrubs and cryptogams (mosses, liverworts and lichens). Increasing graminoid cover is regarded as an indicator of increasing nutrition (especially from aerial deposition) and increasing grazing pressure in the uplands of NW Scotland (Ross *et al*., 2012). Increasing litter cover is a sign of undergrazing. Litter and graminoid cover require separate recording in the RSPB methodology.

- A very small number (2, out of 192) of variables show only slight change between survey years: sward stick height for intact and drained bog.

- Many variables (33, out of 192) are either not recorded for certain habitat groups or are rarely found, with very low average values for a survey year. Examples include bare peat records in intact and drained fen and the absence or near-absence of cattle prints in old peat extraction, the HEA and intact fen. Species largely restricted in the UK to nutrient-poor wetlands are understandably recorded as absent or with very low cane averages in fen conditions (e.g. *Narthecium ossifragum, Racomitrium lanuginosum, Trichophorum germanicum*). Other species requiring some level of higher nutrition are restricted to fen (e.g. *Sphagnum palustre*). Some *Sphagnum* records probably represent surveyor differences too, being recorded only in 2019 in only a few locations (hence very low cane averages): *S. fuscum, S. magellanicum, S. palustre*.

- The remaining variables and habitat groups (115 out of 192) cover what might be random fluctuations, representing a mix of records with sufficient samples (variables perhaps changing year to year at random, unrelated to habitat conditions) and averages which are a poor representation of Causeymire variation due to insufficient sample numbers for estimating mean values.
- Notable contrasts are present within several variables between fen and bog environments (Figure 4). In quadrat records the contrast is shown well by Heather *Calluna* % cover and height (both very low for fen), plus low average *Sphagnum* cover for fen compared to bog. There is a more subdued difference for bare peat which has a low cover for bog but only patchily occurs in fen conditions. There are also other height contrasts, for non-woody vegetation and sward stick height, where bog values are consistently lower over time.
- Cane averages (Figures 5 and 6) reinforce these contrasts between fen and bog. Most species attributes have markedly lower scores for fen, or are entirely absent from fen conditions, e.g. *Racomitrium lanuginosum*. This pattern reflects the design of the RSPB methodology, in which mainly bog-specific attributes were included. The only frequent predominantly-fen species recorded (except for species recorded as additions, such as Soft Rush *Juncus effusus*) is *Molinia caerulea*. Some fen-preferring *Sphagnum* species are uncommon (*S. palustre*) or are not separated from a bog-preferring species (the category, *S. capillifolium/subnitens*, where *S. subnitens* is mainly restricted to fen and *S. capillifolium* to bog). Grazed vegetation is a further case of a variable showing higher scores in fen environments, showing that fen is preferentially grazed (but lightly, with low scores compared to most other attributes).
- Only one group of related variables shows consistent or near-consistent similar trends over time for both fen-bog and drained-intact subsets: *Sphagnum* moss % cover (Figure 4) and All *Sphagnum* in cane results (Figure 6). In the case of *Sphagnum* moss % cover this trend also applies to the HEA and old peat extraction at Dale Moss. These variables are important because they point to one or more likely common drivers of change, perhaps affecting all or most of the HMSA. The *Sphagnum* cover has either increased consistently over time or reached a peak in 2014, with only a slight decline in 2019. This trend was of course found early in monitoring work and is covered in all reports from 2005 onwards.
- Individual *Sphagnum* attributes have weaker change results. *S. capillifolium/subnitens* makes up the bulk of cover for this moss group but it only shows a monotone increase for the HEA, with near-monotone results for intact and drained bog. *S. papillosum* is an important additional species in bog results but has a weaker pattern in drained areas and declines after 2009. Other *Sphagnum* species have weak patterns over time.
- For other variables, consistent trends over time are uncommon and restricted to specific habitat or habitat/drainage subsets. A decline in Bare Peat occurs over time in the HEA. There is an increase in Heather *Calluna* cover upon bog habitat and that is strongest under drained conditions. A consistent increase in *Calluna* height is only shown for the HEA. Other Moss cover increases consistently over time only in drained fen. An increase in deer prints is confined to intact bog. Increasing vegetation height is restricted to intact fen. Only the HEA shows increasing Multi-headed Cottongrass *Eriophorum angustifolium* and declining Bog Asphodel *Narthecium ossifragum*. Hare’s-tail Cottongrass *E. vaginatum* declines consistently only in drained fen. Deer Grass *Trichophorum germanicum* increases only in bog conditions, both drained and intact.

46 Mapping of selected point data measures for 2004 and 2019 shows the location of change (Appendix 4).

47 The locations and reduction over time for bare peat are largely confined to the northwest of the HMSA. There is a considerable reduction on the western line transect across Dale Moss, on ground which is a former peat extraction area. The HEA also experiences a large fall in bare peat conditions. One area of high bare peat persists over time on the eastern Dale Moss transect. A very local area of new bare peat is recorded in 2019 in the south of the HMSA, at just one sample point.

48 High Heather *Calluna* cover was largely confined to the northwest of the HMSA in 2004, with only one high-scoring location recorded elsewhere, close to T16. Over 15 years there has been a notable increase in *Calluna* cover over bog areas in several parts of the main HMSA, particularly within the turbine array and to the east of the southern road loop. Cover remains high in the northwest, including the HEA, with a slight shift to the north in the area of highest values. The cane frequency map (0 to 10) suggests there was markedly more local variation in cover compared to quadrat records for 2004 but the two 2019 maps for *Calluna* are much more similar.

49 The marked contrast in litter/graminoid cover between 2004 and 2019 has already been attributed to a difference in surveyors and their interpretation of this measure. The much higher values in 2019 should be ignored and this attribute has to be set aside. There are a few locations on the west and northwestern side of the HMSA where 2019 values are lower than 2004, on ground mainly grazed by cattle in 2019. Only here is there likely evidence of reduced litter/graminoid cover.

50 There has been a strong general increase of Other Mosses at Causeymire, particularly southwest of the southern track loop and north of T4 and T8. There are also two areas of decline, close to the River Thurso. It shows a marked fall in 2004 and 2019 for areas of intact bog east and south of the southern road loop, but extends further east with high values in 2019.

51 The very large increase in Bog Moss *Sphagnum* noted in averages occurs throughout much of the HMSA. It is particularly strong north of T7, around T15 and east plus south of the southern track loop. There are weaker increases in the northwest (on the western transect across Dale Moss), close to the River Thurso further south, plus the northeast. The cane frequency maps for three most frequent species (scaled 0 to 10) suggest that most of the strong general increase has been made by *S. capillifolium*, with *S. papillosum* locally important.

52 Heather *Calluna* height has increased widely over Dale Moss in the northwest. Elsewhere there have been modest increases to give a consistent 20 cm minimum within the southern track loop and to the east, as well as north of T7. There is a notable reduction in height within the northwestern array and on ground near to the conifer plantation in that area.

53 Non-woody vegetation shows reduced height over most of Causeymire except for the northeast of the HMSA and close to T8 and T16.

54 Vegetation height measured using a sward stick shows a modest increase in height over 15 years, with stronger responses in the northeast. There has been little change in height to the east of the southern track loop.

55 The cane frequency maps for *Calluna*, *Sphagnum* and other species (*Erica tetralix, Eriophorum angustifolium*, *E. vaginatum, Molinia caerulea, Narthecium ossifragum,*

Other Mosses, *Racomitrium lanuginosum*, *Trichophorum germanicum*) show quite complex patterns of change. Their summaries are part of interpretations in Chapter 3.

2.4 Line data results

56 Compared to points, line recording involves a much smaller set of variables (12), providing 72 result time sequences when expanded to individual habitat sectors (6).

57 Monotone or near monotone trends over time are more frequent than in the point result set, with 17 occurrences: Bare Peat (3, all declining over time, for old peat extraction. HEA and drained bog), deer droppings (2, declining, in old peat extraction and HEA), deer/sheep prints (4, increasing, for both fen and both bog sectors), *Racomitrium* % cover and hummock frequency (1 each, increasing for intact bog) and *Sphagnum* percent cover (6, increasing in general in all sectors with slight fall back in 2019 for intact and drained bog).

58 The marked contrast in scores between fen and bog sectors noted in point results is reduced somewhat for line findings, especially for *Sphagnum* results which show higher averages for fen conditions, but still with fen values much lower than for bog.

59 The higher number of monotone and near-monotone trends in line data, together with the difference in fen/bog contrast, perhaps reflects a technique that is more robust than 195 point observations, each derived in part from a small circular quadrat size (3.14 m^2). Pacing records are assessed using a smaller number of line sectors (173) but involve observations made at around 9650 paced positions, each of which is a point observation. The step-point method is a well-known and well-used method outside the UK for recording percent cover and is considered robust for long-term monitoring in studies of plant species change in UK and European montane habitats (Vittoz *et al*., 2010). Earlier reports on 2009 and 2014 survey also considered line data to be the better form of data collection, in terms of yielding the most accurate average values.

60 The key features in line (paced) data graphs (Figure 7) are as follows:

- The majority of line attributes occur with relatively low frequencies or percent cover (<10%). Bare Peat (old peat extraction and HEA only) and *Sphagnum* moss % cover (all sectors) are the only variables with high scores, apart from deer droppings (old peat extraction, 2004 only) and deer/sheep prints (mainly 2019 records).
- The year to year line trends for Bare Peat and *Sphagnum* moss closely follow those in quadrat results (Figure 4), with clearer monotone or near monotone results for *Sphagnum* in line results.
- There is a weaker correspondence between quadrat/cane and line results for cattle and deer prints, plus *Racomitrium* moss occurrences and trend, but no marked deviation. There is a marked increase in *Racomitrium* hummock frequency in 2019 for intact and drained bog. This is an easily observed feature upon line transects which is defined by size in RSPB instructions, so is unlikely to be a difference between surveyors. Overall frequency is low (1-2.5% of sampled bog surface).
- Three categories of bog pool were recorded. Results for ‘mud-bottomed’ pools show very low frequency except for a strong peak in 2014, confined to old peat extraction areas. That type of ground is restricted to that sector and is only clear when dry. Pools classified by *Sphagnum* content differ in sector preference. High *Sphagnum* cover is mainly found in intact bog and is much reduced on drained bog areas. Low cover

pools are mainly recorded in the HEA where they refer to sporadic occurrences in forestry ditches, not pools proper.

- Cattle dung is only recorded occasionally at very low frequency, perhaps relating to the timing of survey in relation to stock being on site. Prints are much more frequent and occur in fen and bog since 2009, following cattle introduction after 2004. Drained fen is generally preferred over other sectors, especially in 2019, though this result is due to cattle close to the River Thurso at the time of survey in July and August.
- Grouse droppings have been recorded mainly for old peat extraction ground and the HEA. They are very rare within fen (the habitat lacks much Heather, the main food source). Small amounts are present on bog, increasing consistently over time for intact areas. A decline over time in old peat extraction is reversed in 2019, which also coincides with a strong increase for HEA frequency.

61 Mapping of paced line data measures for 2004 and 2019 shows the location of change (Appendix 5).

62 As with point data, the locations and reduction over time for bare peat are largely confined to the northwest of the HMSA, with the largest reduction on the western line transect across Dale Moss. There are two very local areas of new bare peat recorded in 2019 in the south of the HMSA, on separate single line sectors.

63 Cattle dung in 2004 was confined to the HEA, where cattle had access to an edge of marshy grassland. In 2019 it was found adjacent to the River Thurso, the only ground with cattle in the survey period. Cattle prints in 2004 were confined to the most western transect, used by grazier with no other access to the HMSA. In 2019 prints were mainly recorded adjacent to the River Thurso, plus a few records close to T3.

64 Deer droppings in 2004 were locally abundant close to the shelter of the conifer plantation in the northwest, mainly on the most western transect of Dale Moss. No droppings were recorded here in 2019 and much smaller frequencies were recorded close to the HEA and west of the southern turbine loop.

65 Deer and sheep prints were uncommon in 2004 and mainly confined to the southwestern part of Dale Moss, close to the conifer plantation, plus the southeastern HMSA. Print frequency was much increased in 2019, with very different locations for the main occurrences. Frequencies are low at Dale Moss, in contrast to high values in the northeast of the HMSA and a large expansion in the southeast. The prints in both years were always of deer and even in 2004 there was little evidence of sheep using the surveyed sections of Causeymire.

66 Grouse droppings were abundant on the western side of Dale Moss in 2004 but absent elsewhere. In 2019 their frequency is much lower in the northwest, but highest in the HEA. There are scattered occurrences east of the southern track loop.

67 Bog pools with >50% *Sphagnum* have a similar distribution in 2019 to that in 2004 but there has been a local marked decline inside the southern track loop (between T20 and T24) and a further contraction to the south, east of the area of eccentric raised bog. A local 2019 increase in this attribute upon Dale Moss, in the northwest, refers to atypical pools, formed in the floor of deep drains. There is a further slight expansion close to T6, in an area of 2004 ditch blocking. The report on 2014 survey (Dargie 2015) interpreted this response as an example of restoration revealing a former eccentric raised bog, within surrounding blanket bog.

68 Woolly hair-moss *Racomitrium lanuginosum* is restricted to bog habitat and at Causeymire is rarely found in quantity. In 2004 higher cover (3-4%) was restricted to two line sectors upon intact bog to the east of the southern track loop. In 2019 higher cover (>3%) was present in seven line sectors in four locations, a restricted expansion.

69 *Racomitrium* hummocks were recorded under or within 50 cm of a line transect in six line segments at four locations in 2004, one location coincident with the *Racomitrium* record for step-pacing. There was a marked increase in line segment records (17) in 2019, found in 8 locations. There are new 2019 locations around T6, south of the turbine array (in the area of the eccentric raised bog) and east of the array. All locations are associated with bog habitat and with the exception of T6, associated with undrained ground. The area around T6 contains drains blocked in 2004.

70 *Sphagnum* results show higher values in 2004 which relate to undrained areas of blanket bog, with very few line segments (8) showing percent cover scores >40%. There are dramatic increases shown by 2019 results, with expansion throughout Causeymire and increases in undrained bog resulting in many line segments (34) >80%, including five of 100%. This is not due to a difference in surveyors. Results between 2004 and 2019 show survey-on-survey increases to 2014, with near-maintained scores for 2019. Earlier reports noted an immediate expansion in 2005 within and east of the turbine array, followed in 2006 by the start of increases to the north (Dargie 2006, 2007). This 2004 – 2019 result closely matches expansion recorded in point data and is discussed in more detail below in section 2.5.

2.5 **Sphagnum** ***results in point and line data***

71 Results for *Sphagnum* have shown the clearest trends over the 15 year monitoring period, with monotone or near-monotone results for all sectors when examined using average values (Figure 4, Figure 7). A clearer understanding of this set of results is shown using Box plot diagrams (Figure 8). These summarise frequency values for all samples in all habitat/drainage subsets, showing median (as opposed to average) values, as well as up to four quartile values. The lowest or two lower quartiles are absent for some 2004 results and all drained fen sample sets, due to the frequency of zero values.

72 Point data have a wider range of percent cover values for the two central quartiles compared to line results. In addition point results fail to adequately represent *Sphagnum* cover in drained fen conditions whereas cover values between 2 and 10% are recovered by line sampling. This comparison is the clearest illustration of a difference in accuracy between point and line step-pacing, with the latter suggested as the better technique.

73 Both sampling methods show very large variation in *Sphagnum* quantities. These range between 0 and 100% for bog categories. Median values are never centred in the middle of the two central quartiles (which might suggest a normal distribution) and, instead, show mainly strong positive skewness (more values lower than the median). Negative skewness is also present (e.g. 2014 drained bog, point and line data, plus 2014 and 2019 line results for old peat extraction habitat. This consistent deviation from normality, plus the use of regularly-spaced sampling, justifies summarising and interpreting results in a cautious descriptive manner (as opposed to attempting statistical testing).

74 Using line results, as the likely better quality, the increase in *Sphagnum* extent over time is obvious and shows major differences between habitats. For example, using mean values, drained and intact bog have more than trebled their 2004 *Sphagnum* extents. Table 2 provides a larger set of statistics covering *Sphagnum* line records.

75 It is important to appreciate the scale of *Sphagnum* increase within the HMSA around Causeymire Wind Farm. One way to do this is to convert baseline (2004) and 2009/2014/2019 figures into extents (hectares) based on the 2019 area of the HMSA (946.3 ha).

76 Using Table 1 mean values for all line segment samples, the *Sphagnum* area increase observed is 115 ha (2004) < 352 ha (2009) < 433 ha (2014) < 452 ha (2019). Therefore, within a study area of a little under 10 km^2, there has been an estimated increase in *Sphagnum* extent of 337 ha, an expansion occupying more than a third of a large study area.

77 Given the skewed nature of results in Figure 8b, an equivalent calculation based on a median value should be considered. Then, the observed *Sphagnum* area increase is 75 ha (2004) < 328 ha (2009) < 402 ha (2014) < 434 ha (2019). The estimated increase in *Sphagnum* area is then 359 ha, a higher value than that based on all-sample means.

78 Reporting the increase in estimated area of *Sphagnum* cover is best done by including both mean and median results: 337 – 359 ha, based on mean and median values recorded in 2004 and 2019.

79 The nature of the monotone or near-monotone increase in *Sphagnum* varies by habitat sector. Drained and intact bog achieve roughly two-thirds of expansion in the period 2004 – 2009, with a further good increase between 2009 and 2014. Both bog sectors have small reductions in extent in 2019. The five-yearly percent increases in extent of drained bog between 2004 and 2014 are less than for intact samples, but not by a wide margin. Both bog sectors show slight reductions in percent cover in 2019. The overall pattern for both types over 15 years is perhaps close to logistic expansion (a near-exponential start which then slows sharply until an upper value is reached, when amounts can then oscillate, such as the falls 2014 to 2019).

80 Further possible logistic patterns of increase are present in HEA and Former Peat Extraction sector results (Figure 8b), but with no lower results in 2019.

81 The HEA is dominated by bog, with a small area of marshy grassland along its north-western edge. The HEA sector is heavily dissected by forestry drains and supported poorly-growing Lodgepole Pine until 2009 and 2010, when almost all trees were felled in an attempt to provide conditions for taller Heather growth. Just a handful of trees were retained as a screen close to the Westerdale road just north of this sector. The exponential phase of *Sphagnum* increase in the HEA is clear and occurred while there was a tree cover, with observations suggesting that tree growth improved in 2007 and 2009.

Table 2 Statistical breakdown of *Sphagnum* % cover results in line (step-point) data for 2004, 2009, 2014 and 2019

Year/Sector	N (sample total)	Mean	Standard error	Standard. deviation	Median	25 percentile	75 percentile	Skewness	Kurtosis
2004	173	12.20	1.02	13.38	7.94	0.72	19.05	1.36	1.84
2009	173	37.19	2.16	28.44	34.67	12.01	56.26	0.43	-0.86
2014	173	45.76	2.48	32.57	42.47	16.43	75.00	0.16	-1.27
2019	173	47.79	2.35	30.95	45.83	20.00	76.00	0.04	-1.21
Bog Drained 2004	50	14.30	1.75	12.35	10.17	4.84	22.53	0.90	0.01
Bog Drained 2009	50	44.56	3.45	24.42	44.11	27.06	63.86	-0.02	-0.77
Bog Drained 2014	50	53.66	3.70	26.15	57.34	34.37	70.06	-0.20	-0.53
Bog Drained 2019	50	54.78	3.62	25.60	54.36	37.13	77.48	-0.14	-0.90
Bog Intact 2004	49	23.69	1.96	13.74	20.75	15.04	29.75	1.04	1.57
Bog Intact 2009	49	62.37	3.35	23.43	59.42	43.69	85.39	-0.23	-0.79
Bog Intact 2014	49	76.12	3.59	25.11	84.93	66.94	94.95	-1.50	1.82
Bog Intact 2019	49	74.30	3.27	22.88	80.77	60.76	92.16	-1.18	1.31
Fen Drained 2004	33	2.51	0.63	3.62	1.45	0.00	3.62	2.53	8.69
Fen Drained 2009	33	11.74	2.49	14.29	7.14	0.00	19.09	1.45	1.54
Fen Drained 2014	33	10.97	2.30	13.23	6.41	0.00	15.60	1.59	2.13
Fen Drained 2019	33	16.86	3.67	21.08	8.70	0.00	28.59	1.49	1.76
Fen Intact 2004	12	5.53	1.85	6.41	2.95	0.00	11.67	0.96	-0.49
Fen Intact 2009	12	12.93	3.62	12.53	10.66	0.70	23.64	0.61	-0.71
Fen Intact 2014	12	20.18	5.41	18.76	14.23	1.73	36.60	0.43	-1.52
Fen Intact 2019	12	25.57	6.00	20.80	26.19	4.04	44.61	0.19	-1.51
Former Peat Extraction (drained) 2004	19	2.90	1.10	4.80	0.00	0.00	4.23	1.57	1.14
Former Peat Extraction (drained) 2009	19	17.86	3.39	14.77	16.00	4.00	34.67	0.13	-1.78
Former Peat Extraction (drained) 2014	19	26.83	3.34	14.55	29.03	17.81	37.14	-0.24	-0.63
Former Peat Extraction (drained) 2019	19	31.22	4.29	18.70	30.77	12.00	44.00	0.78	0.07
HEA (Habitat Enhancement Area) (drained) 2004	10	3.05	1.33	4.22	0.00	0.00	6.76	1.00	-0.28
HEA (Habitat Enhancement Area) (drained) 2009	10	26.79	3.28	10.36	29.74	15.64	33.89	-0.46	-0.79
HEA (Habitat Enhancement Area) (drained) 2014	10	39.03	4.83	15.28	37.58	27.26	50.38	0.47	0.35
HEA (Habitat Enhancement Area) (drained) 2019	10	43.21	5.27	16.66	40.00	34.00	54.80	0.83	0.33

82 The Former Peat Extraction sector shows a remarkable increase from almost no recorded *Sphagnum* in 2004 (mean 2.9%), rising to 31% (mean and median) in 2019. This ground is partly drained by very deep (3 m) ditches spaced at 20 metre intervals, along all of the western transect through the area. The peat on interfluves had been partly harvested by milling, creating a gentle convex topography where *Sphagnum* has developed in frequent patches mixed with quite tall Heather. There are much shallower drains for much of an eastern transect, where there has only been partial surface removal of peat. There is more *Sphagnum* developing here and this ground also contains bog pools, a few even with White Beak-sedge *Rhynchospora alba*. It seems likely that small remnant amounts of *Sphagnum* in the east of the sector in 2004 provided a spore source for spread over the last 15 years.

83 *Sphagnum* expansion in fen sectors does not seem to have a logisitic pattern. Using median scores, a very low 2004 score (1.5%) increased in drained fen to a 2009 level (7.1%) which has changed little since (8.7% in 2019). Intact fen has a stronger and clear monotone increase but this is roughly linear over time, rising from 3% in 2004 to 26% in 2019.

84 The *Sphagnum* patterns for fen conditions are therefore different to all other sectors, suggesting the Causeymire fen environment has been less responsive over time, compared to bog sectors with much variation in past management (intact, drained, the drained and afforested HEA, plus ground at Dale Moss drained and harvested for peat extraction).

85 The excellent very large expansion of *Sphagnum* in the bog sectors shows that a very strong response is possible over a very short period of time (the near-exponential increases between 2004 and 2009). The strong performance of peat containing drains and the windfarm footprint is additional evidence of resilience, on top of strong response.

86 Mire ecologists view the *Sphagnum* content of UK bogs and appropriate fens as an important indicator of bog condition. For example, guidelines (JNCC, 2009) for monitoring the condition of blanket bog in statutory sites – SSSI/SAC/SPA/Ramsar designations - specify, in counts of indicator species, that each *Sphagnum* species represents a separate indicator, for assessing the condition of vegetation composition (frequency of indicator species).

87 Looking back on Causeymire monitoring results since 2004, as evidence of condition using JNCC guidance, the intact and drained blanket bog sectors around the windfarm would be in mainly favourable condition on all dates, but with unfavourable condition in places. There have been two causes of unfavourable condition.

88 First, there was disturbance to vegetation structure, with observed signs of burning into the moss layer when muirburn was undertaken as part of a separate Rural Stewardship agreement operated by the grazing tenant between 2004 and 2009. Within the Section 75 area (i.e. not Dale Moss, drained for former commercial peat extraction), the original intention was to regenerate Heather on former peat beds and to use a mechanical swipe for Heather management where growth was too strong. Examples of burning damage were discussed in Dargie (2012). There has been no recent burning at Causeymire and there has been an excellent recovery of the moss layer in most former burnt areas.

89 Second, the most recent drainage installed by RWE Npower has altered the physical structure of the blanket bog surface, over and above drainage related to windfarm construction. These installations involved a 98 metre deep drain south from T20, cut in 2009, plus a 102 metre ditch south of T24 and a 141 metre ditch running southwest from the floated road at ND 15826 49235 between T20 and T24. Both the latter ditches were excavated in 2013. This drainage work was done to cope with flooding around the turbine bases at T20 (first) and then T24, plus standing water on the floated road where a spring emerged at its lowest point, for water draining through and along the roadstone. Drainage water from all these ditches has killed *Sphagnum* throughout other ditches receiving water downstream. At the moment this appears to be a permanent effect.

90 Notwithstanding the effects of recent new drainage and observed drying in pre-windfarm ditches affected by windfarm roads (Dargie 2015), bog condition at Causeymire close to the windfarm is without doubt in favourable condition. However, under JNCC rules, the drainage damage results in overall unfavourable condition if those guidelines are applicable to the Causeymire area.

91 The major expansion of *Sphagnum* cover within bog habitat at Causeymire, including in the former peat extraction area and the HEA, plus notable expansion in intact fen, should be taken as the overall largest and clearest improvement in habitat conditions over the past 15 years. It is a remarkable achievement and an unexpected result which was not anticipated in the Causeymire EIA or proposals for monitoring (Dargie 2004).

3 Interpretations of habitat change and habitat condition

3.1 The approach to interpretation

92 Earlier habitat monitoring reports have included interpretation material, particularly those issued for 2009 and 2014 survey (Dargie 2012; Dargie 2015). That interpretation has been made in the following contexts covering habitat enhancement and monitoring:

- The aim within the HEA has been to increase Heather *Calluna* height (Dargie 2004). This was done initially by reducing deer access and browse and later largely removed a young Lodgepole Pine plantation in 2009 and 2010. Deer grazing was reduced by installing electric fencing between surveys in 2004 and 2005. Results to 2014 corroborated a reduction in deer grazing via reduced deer prints and increased sward-stick vegetation height. Line segment results show a marked increase in deer prints for 2019 survey. The clearest habitat changes were increases in Bog Moss *Sphagnum* and Other Mosses cover, at the same time as bare peat cover fell. Presumably much of the moss expansion was upon former bare peat. The *Sphagnum* expansion prior to 2009 was thought to be restricted to forestry ditches but changes 2009-2019 show notable increases in *Sphagnum* typical of drier ground, *S. capillifolium/subnitens*. The main target of habitat management was an increase in Heather *Calluna* height and that was achieved, but not to a height considered suitable for encouraging raptor breeding (50 cm height), the initial intention. Results up to and including 2014 reported Heather Beetle *Lochmaea suturalis* damage, especially in 2014 when large amounts of dead Heather were recorded. This was probably important in limiting the height growth of Heather.
- Two habitat enhancement measures were required for Causeymire ground outside the HEA (Dargie 2004): blocking drains around the margins of blanket pools systems at Bad a Cheo and reduction in grazing pressure for ground in the vicinity of the windfarm.
- The pool systems targeted are east and south of the windfarm footprint. The pools are potentially affected by extensive pre-windfarm drains installed as herring-bone nets, probably in the 1950s (Figure 1). Selective drain blocking was undertaken after a walk in 2004 over all ditches upon bog habitat. The work used a contractor recommended by RSPB and employed a machine-dug peat-turf plugging method within selected (eroding) ditch lengths. This selective approach was based on a site inspection by RSPB in 2003 which considered that most ditches were stabilising naturally by infill and that only eroding ditches should be blocked, since these could destabilise the bog surface layer. RSPB written guidance based on Flow Country experience was also provided. Monitoring up to and including 2009 involved only inspection of blocked lengths. This found only a single failed plug in 2007 east of T19 (the lowest plug in the sequence), with two further failures in 2009 (immediately above the initial case). There have been no further failures since 2009. The report on 2014 monitoring went further and looked at drainage conditions around windfarm roads, plus the impacts of new ditches constructed to alleviate local flooding problems on the track and around two bases (T20 and T24).

- A bespoke ditch condition monitoring scheme was used in the 2014 report. Discussion of the findings by the Causeymire Wind Farm Environmental Management Committee in 2015 considered adverse effects to be small, after seeing some of the road and new ditch impacts in a site visit.
- A further target of management was general habitat improvement through reduced grazing pressure by stock and deer control (Dargie 2004). This was to apply to ground around and beyond the windfarm, where the EIA had stated that reduced sheep numbers (halving the stocking density) would be used. To track habitat changes it was agreed to apply a 2003 recently-developed RSPB technique for long-term monitoring of habitat condition across the peatlands of Caithness and Sutherland (see Appendix 1). This has been applied to the full land ownership area (the HMSA) at the same intervals as bird surveys specified in planning conditions (years 1, 2, 3, 5, 10 and 15 after construction), to allow correlation with bird data if that was desirable. It is these results which have provided considerable information on change, particularly the unexpected very large expansion in *Sphagnum* extent. The reports covering 2009 and 2014 monitoring included initial interpretations of this expansion. As part of that work, at the suggestion of RSPB (Appendix 4 in Dargie 2012), reporting has included the separation of different habitats and management areas, plus drainage, from 2009 findings onward. The 2014 report also noted that the technique had not been applied to bird monitoring control areas from the outset of habitat monitoring, something not raised earlier by the Environmental Management Committee.
- Turbine base, hardstanding and road batter monitoring have been systematically reported since 2009 survey. There was no requirement under planning conditions or proposals for habitat enhancement and monitoring to report on the condition of vegetation within the windfarm footprint. It has been included because it gives insight into the longer-term drainage impacts of windfarm construction within peatland, as well as the biodiversity potential of backfilled turbine bases and roadside batters. Unused areas of hardstanding at T1, T2, T9 and T10 were dressed with peat and hydroseeded with a grass-Heather seed mix in mid-summer 2006 and the 2007 survey report described initial revegetation. The approach since 2009 has been to use fixed point photography of bases, selected parts of hardstandings and road verges to provide visual evidence of condition, plus quick walkover records of the main species present. Spreadsheet records of the species information are then interpreted in report text.

93 The material in this chapter presents a final interpretation of habitat monitoring results, since this is the end of the required 15-year monitoring period. It makes reference to the initial ecological and hydrological assessment in the Causeymire EIA (National Wind Power & Miller 2001) and habitat management objectives (Dargie 2004).

94 At the outset in 2004 it was not anticipated that HEA management or HMSA habitat monitoring would be as complex as found in subsequent reports. The design of monitoring has been sufficient to track change with reasonable accuracy. However, it has not been rigorous enough for strict statistical analysis based on hypothesis testing and in 2019 work lacks full understanding of the drivers underlying what has been considerable change.

95 There were no hypotheses at the start of monitoring. The regular spacing of line segments and point location sampling prevent the application of strict statistical tests and power/confidence analysis to results.

96 The lack of sampling within two bird monitoring control areas, beyond the HMSA is a further weakness but not as severe as it would seem because the HMSA is very large and extends well beyond the windfarm footprint. The HMSA ground beyond the footprint is extensive and at least equivalent in size to the control areas. Those cover 427 ha and would have required additional transect lengths totalling 7.5 km for sampling. There is also no habitat information about the control sites and hence their comparability with the windfarm area and HMSA is uncertain.

97 Given the weaknesses posed by an initial lack of rigour in habitat monitoring, the final interpretations offered here are broad hypotheses rated as possible or unlikely on the basis of one or several lines of evidence strength. No hypothesis is rated as probable and that is done deliberately, to reflect the lack of full scientific rigour in monitoring design.

3.2 Habitat change 2004 to 2019 within the Habitat Enhancement Area

98 Appendix 2 shows little change in Heather *Calluna* cover between 2004 (21.1 %) and 2019 (22.7%), with a maximum recorded in 2009 (25.4%). The recorded frequency of dead *Calluna* (cane data) (e.g. 1.12 in 2004, 1.35 in 2019), compared to live material (4.5 in 2004, 4.82 in 2019) suggests a high level of Heather Beetle damage in most years, particularly 2014 (live 5.3, dead 2.4) when damage might have been a third of aerial biomass.

99 Appendix 2 Heather height in the HEA shows an increase for each quinquennial survey year, rising from 29.3 cm in 2004 to 32.6 cm in 2019. This is just over a 10% gain in average height over 15 years and is well short of a 50 cm target hoped for at the start of monitoring. Heather beetle damage is a likely contributor to the shortfall. Larger taller plants would probably be attacked more easily and high rates of damage could prevent the development of large Heather patches which foster a microclimate producing better height growth and a structure of over-mature tall plants favoured for raptor nesting.

100 Work to secure higher Heather in the HEA has not been negligible. Electric fencing was installed in 2004 around the 1.14 km perimeter to reduce deer browsing and that largely worked initially, evidenced by very large falls in dung and deer print values. Almost all conifers were removed by felling most of the poorly-growing trees in 2009 and 2010, with fertiliser added to higher dry ground. Results confirm beneficial effects, although deer prints are common in 2019. There is a marked reduction in bare peat (recorded as 13% cover in 2004) until none was recorded in 2019. Tree shading and needle litter were probably important in producing bare peat surfaces, with tree removal then allowing a rapid expansion in Other Mosses (increasing by 10% to 57% between 2009 and 2019) and *Sphagnum* (which increased by 14% to 37% cover, 2009-2019).

101 A final possible factor restricting Heather height growth is the pre-forestry habitat of the HEA. Most was blanket bog, with parts cut for peat but mainly restored by natural regeneration of an active bog surface (see Figure 3 in Dargie 2004, an air photo dated 1988). Heather on blanket bog does not develop a high cover or height unless the ground has been dried by extensive peat pipe development and that seems rare or absent in the Causeymire area. It is more typical of montane blanket bog.

102 Elsewhere at Causeymire drained bog (the closest to HEA peat with forestry ditches installed) has Heather cover ranging between 10 and 20%, plus a height of 20-25 cm. The fact that Heather achieved a height of 32.6 cm in the HEA suggests that there was some success. In addition, this area seems to support the current largest densities of Red Grouse, based on dropping counts. The tallest Heather stands at Causeymire are nearby in former deeply-drained peat extraction ground on Dale Moss. Even here, the tallest average height achieved 2004 to 2019 was 37.5 cm.

103 In conclusion, HEA management measures achieved an increase in Heather *Calluna* height, but insufficient to reach a target height of 50 cm, suitable to attract breeding raptors. The dominant bog conditions of the HEA site do not appear to capable of supporting strong Heather growth, despite being drained for forestry.

3.3 Effects of ditch blocking, road drainage and new ditch excavation

104 This section considers blocked drain sectors examined in earlier reports but, as in 2014 reporting, extends more widely here to take in changes to unblocked drains too, particularly the effects of new drain installation at T20 and T24, plus the effects of the wind farm road on adjacent ditches along the eastern side of the turbine loop (between T8 and T23, a distance of roughly 2 km). The widened monitoring is necessary due to surprisingly widespread impacts observed in September 2014 verge inspections. The ditch monitoring then was done in September and November 2014.

105 Since this is the final report covering habitat monitoring, two subsections (3.2.1 and 3.2.2) are added which discuss drainage results in relation to predictions made in the Causeymire Wind Farm EIA (National Wind Power and Innes Miller 2001) and a recent review (Wawrzyczek *et al*. 2018) of Scottish windfarm impacts on peatland ecosystems, particularly surface hydrology and drainage.

106 Sample visual checks were made in 2019 and concluded there had been little change since 2014.

107 Blocked drain sectors at Causeymire total 1.3 km and represent only a small fraction of drain length on site. Almost all of the blanket bog drainage network was walked in 2004 (>20 km), identifying sectors for blocking using published procedures developed by RSPB for an EU LIFE programme for the Flow Country peatlands (Wilkie & Thompson 1998; Wilkie & Mayhew 2003). These were drains on gently sloping ground which were either eroding or had little or no *Sphagnum* content. Such drains were rare at Causeymire and most drain lengths were, instead, nearly brim-full with a diverse *Sphagnum* content, even including the occasional development of hummocks above drain level. *Sphagnum cuspidatum* was the commonest species and acts as an aquatic species in a drain environment. It also occurs in very wet hollows and pools on intact bog. Drains were blocked using peat turf plugs by a very experienced contractor who had done much of the RSPB ditch blocking in the 1990s.

108 The RSPB advice adopted in 2004 has since evolved into a wider range of drain-blocking techniques, with associated good practice (e.g. Armstrong *et al*., 2009). Full drains would also now have plastic piling installed at more lengthy intervals than peat turf blocks, to maintain high water levels and minimise drain flow during dry periods (Norrie Russell, RSPB Forsinard, pers. comm., 2010).

109 Several site drain sectors blocked in 2004 were inspected in 2008, 2010 and 2014. All blocked sectors intersecting line transects were observed in 2019. Survey in January 2008 reported almost all dams as full, with slight overtopping. There were many cases of dying *Calluna* (due to waterlogging) and many cases of expanding *Sphagnum*, particularly *S. cuspidatum* in open water.

110 Blocking drains south-west of T6 has been particularly effective. Inspections in all years has found water backed up for several metres into blind tributary channels and then flowing even further beyond on the flattest terrain, for much greater distances compared with blocking elsewhere. Extensive *Sphagnum* growth is occurring in these areas. This effect had not been seen before by RSPB (Norrie Russell, RSPB, pers. comm., 2010).

111 A possible explanation for the tributary pools and hollows is that the ground SW of T6 is part of a former eccentric bog (a very wet pool-dominated form of raised bog where narrow linear pools are developed parallel to surface contours and the highest part of

the bog is displaced from the mire centre). The tributaries represent former linear pools aligned parallel with bog surface contours. Restoration here deserves attention due to its unique nature as a possible first example of eccentric bog restoration in Britain.

112 The blocked drains SW of T6 in 2014 and 2019 were brimful and adjacent ground was very wet from drain overspill. The water level observed in 2010 was slightly lower, reflecting several weeks of very dry weather in NW Scotland. 2019 conditions were especially wet underfoot, despite survey in a dry spell of weather in a summer that was wetter than normal.

113 There is an abundance of *Sphagnum cuspidatum* in pools, although flow through the central drain line on what is an above average slope has pushed *Sphagnum* to the side. *Sphagnum* growth in lateral pools was mainly *S. papillosum* in 2010 but had changed to *S. cuspidatum* in 2014. *S. papillosum* was developing profusely on the bog surfaces beyond, but in 2019 *S. cuspidatum* was equally common on bog surfaces affected by overspill. As in 2014 reporting, this suggests progressive rewetting, extending over time, away from the blocked ditch line. This location continues as an excellent result for habitat condition.

114 The blocked drains east of T22 have a high surface cover of *Sphagnum cuspidatum*. Most shrub growth within 1 m either side of the ditch is dead due to waterlogging and there is stimulated growth by *Eriophorum vaginatum* and *E. angustifolium*. This continues as an excellent result for habitat condition, except at its head where *Sphagnum* has been lost due to the impact of water originating from drainage of the T24 base (see below).

115 Partial failure of the lowest dam of a sector east of Turbine 19 was noted in January 2007, when water leaking below the block material resulted in the water level being lowered substantially immediately to the east. This had occurred since a July 2006 inspection and might have been caused by very heavy rains in late October 2006 (perhaps the heaviest rainfall for a century). The lowered level had no visible effect on dams and water levels uphill and further east. Two further dam block failures were noted in 2010, immediately above the 2006/7 initial problem. Inspections in 2014 and 2019 showed no further failure. This short sector of failures is the only negative to the Causeymire 2004 ditch blocking effort (a 2-3% failure rate). An all-UK survey of drain-blocking found a failure rate of just over 5% for peat turf structures (Armstrong *et al*. 2009).

116 Verge monitoring along the eastern side of the turbine array loop (between T8 and T23) in September 2014 revealed likely wind farm effects on unblocked drains close to the wind farm road. These were investigated further in November 2014 by walking almost all the drainage network in this road sector. Verge inspections in 2010 did not note these effects and it is likely that they have mostly developed since 2010. The effects were still present in 2019.

117 Several variables were recorded in this walkover: the positions of major change in *Sphagnum* level within a ditch, its quantity relative to other vegetation within the ditch sides (DAFOR values: dominant, abundant, frequent, occasional, rare, plus absent), the character of culverts, the absence of culverts, areas with diverted drainage, the locations of new ditches cut within the last 6 years.

118 Fourteen ‘banana’ culverts (distorted into a concave shape by road material weight and vehicle passage) were found at the north and south ends of the eastern loop road, as two separate groups. No culvert on this road length was unaffected. Such culverts cannot

transfer drainage water efficiently from one side of the road to another and in some cases water accumulates in the central concavity and flows through breaks into the underlying material.

119 The length of road between the two separate lengths with 'banana' culverts marks a sector of floated road failure during wind farm construction. The road here is below the level of the adjacent bog and its old drains. Culverts could not be installed.

120 The field observations suggested serious problems affecting several lengths of the drains surveyed, affecting their ecological condition. Almost all the problems seem to arise from windfarm impacts, with no evidence of natural factors causing poor ecological condition apart from a single short sector on a locally steep slope.

121 Results were used to develop a simple classification of drain ecological condition within a GIS database. It is assumed that a poorly functioning drain, filled with *Sphagnum* and occasionally spilling its contents over the adjacent bog surface represents a state of favourable condition which supports adjacent bog biodiversity and ecological function, including continued peat formation. The classification classes are:

- <u>Favourable condition</u> – poorly functioning as a drain, choked with very high quantities of *Sphagnum*, near-brim-full *Sphagnum* content. Blocked or not blocked status noted.
- <u>Unfavourable declining condition</u> – *Sphagnum* content reduced but quantity still at least occasional, sometimes with expansion of higher plants, either of which suggests drier conditions; *Sphagnum* or other vegetation content sunken, with spillage frequency much reduced. All cases involve drains which are not blocked.
- <u>Unfavourable declining condition, severe</u> – *Sphagnum* absent or rare, cause of loss easily identified; *Sphagnum* abundant but freshly sunken, cause of water loss easily identified. Blocked or not blocked status noted.

122 The classification is mapped in Figure 9, as either favourable or unfavourable condition. The map shows the locations of blocked drain sectors and 'banana' culverts. A more detailed breakdown of drain ecological condition is given in Table 3, including the likely cause of poor condition. Table 3 also includes information on new drains inserted by RWE Innogy to aid base and road drainage, plus estimates of bog drain lengths lost during construction.

123 The results in Table 3 apply only to the drain sectors mapped and not to the other known drain systems at Causeymire (e.g. see Fig. 1). Condition assessment has not been extended elsewhere but observations from line transect work suggest that problems are confined to drainage close to the windfarm footprint.

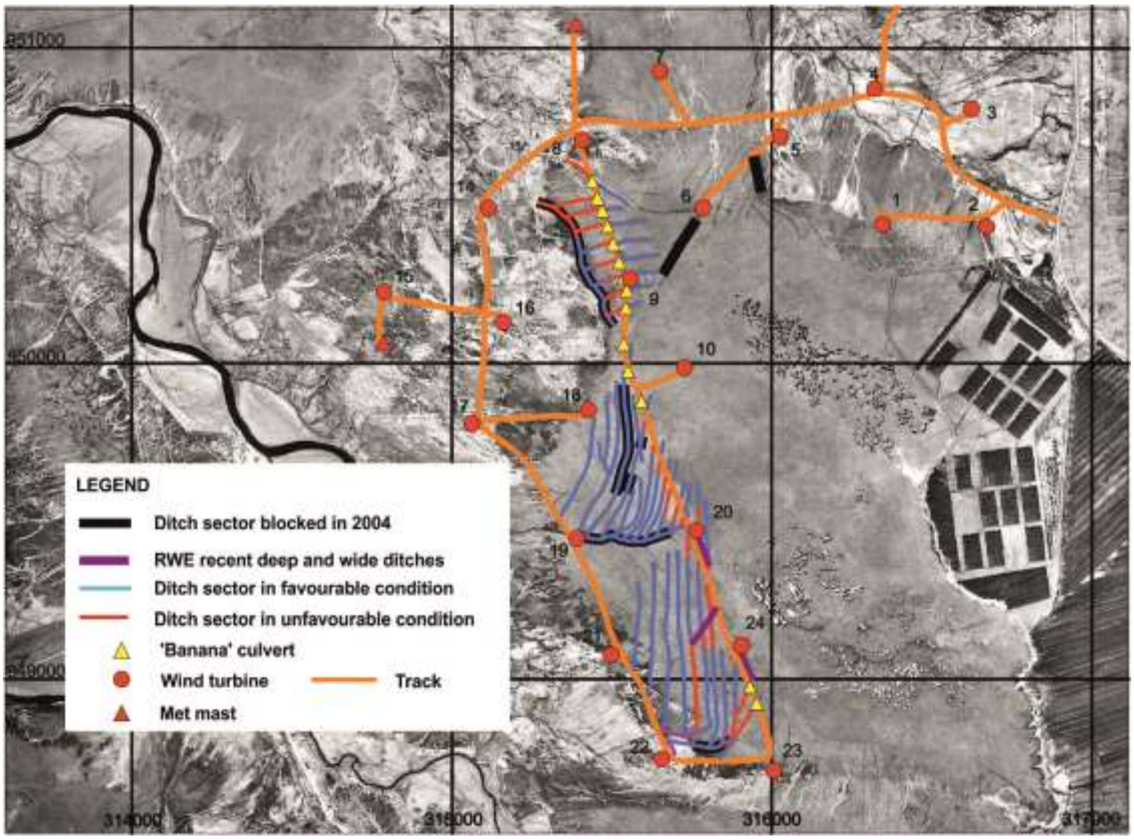


Figure 9 Habitat condition status of drains within the southern wind farm road loop
Air photo background dated 1988 (pre-afforestation in northwest)

124 The following impacts are covered in Table 3 and Figure 9:

- 'Banana' culverts in the north of the survey have significantly reduced water transfer from east to west. Ditches in the east are full of *Sphagnum*, ditches in the west around T9 have a reduced quantity and the *Sphagnum* surface is sunken.
- 'Banana' culverts in the north further downslope towards T8 have fractured and water travelling through road material passes into and then out of the culvert base and into ditches on the western (lower) side of the road. This nutrient and mineral-enhanced water has killed all or most *Sphagnum* in these ditches and, as yet, there is little replacement vegetation until a blocked drain sector is reached. Here, *Sphagnum* has been killed too and more soligenous (nutrient-enriched) vegetation is developing (e.g. Pondweed *Potamogeton polygonifolius*). About 30% of the blocked sector is affected by *Sphagnum* loss.

Table 3 Habitat condition assessment for drains close to eastern side of road loop

Drain mapping category	Length (m)	% total length of drain surveyed (12,622m)	Grouped Categories	Grouped Categories drain length (m)	Grouped Categories % total length of drain surveyed (12,622m)
No *Sphagnum* or other vegetation, provides T20 base drainage	102	0.8	RWE Recent Ditching Impact: loss of bog habitat and carbon capture (0.068 ha) (excludes adjacent drawdown effects)	342	2.7
No *Sphagnum* or other vegetation, provides road drainage north of T24	141	1.1			
No *Sphagnum*, very little other vegetation, provides T24 base drainage	99	0.8			
Lost to road, bases and hardstandings	279	2.2	Pre-2004 ditches destroyed by wind farm construction	279	2.2
Blocked, *Sphagnum* dominant to abundant (excludes further two sectors outside loop close to T6 (205m) and T5 (116m))	1181	9.4	Drains in Favourable Condition	9597	76.0
Diverted flow due to hard standing, *Sphagnum* frequent to dominant	101	0.8			
Not blocked, *Sphagnum*: dominant	47	0.4			
Not blocked, *Sphagnum*: dominant to abundant	8267	65.5			
No Survey	171	1.4	No survey	171	1.4
Sphagnum: occasional to frequent, extent reduced, road impact reducing water entry into drain likely	104	0.8	Drains in Unfavourable Declining Condition	866	6.9
Sunken, *Sphagnum* abundant: water entry into drain from bog overland flow curtailed by adjacent road	179	1.4			
Sunken, *Sphagnum* frequent: steeper local natural slope above base excavation	29	0.2			
Sunken, *Sphagnum* occasional: water entry into drain from bog overland flow curtailed by adjacent road	554	4.4			
Blocked Sector, *Sphagnum* absent: base/road drainage effect	24	0.2	Drains in Unfavourable Declining Condition (Severe)	1368	10.8
Blocked, *Sphagnum* rare, RWE road drainage effect	174	1.4			
Sphagnum absent: RWE base/road drainage effect	978	7.7			
Sunken, *Sphagnum* still abundant: recently severed by new deeper RWE ditch	158	1.2			
Sunken, *Sphagnum* rare: water entry into drain from bog overland flow curtailed by adjacent road	34	0.3			

- There are lengths of drain immediately west of the road close to the T10 spur junction which show reduced water entry due to road interception of water flowing west off the eastern bog. Drain lengths in favourable condition resume over a varying distance which seems to increase moving towards T20.

- Drainage between T20 and T24 is possibly complex. A new drain east of the road had been cut (probably in 2013) for 100m, to prevent flooding in the T24 base depression. Drainage water then joins with water in a pre-windfarm ditch. All *Sphagnum* in the short length west of the confluence has been killed.

- It is then likely that T24 base water enters road material and flows south within this until it emerges as a spring about 100 metres north of T24 (ND 15826 49235), on the western side of the road, below the level of the running surface. The road surface here has been raised with more stone, probably to avoid ponding. A new RWE drain (probaby cut too in 2013) then takes the spring water south-west for 141 metres to join a pre-windfarm ditch.

- The new 141 metre ditch is deep at its eastern end (>1.2 m) and it severs two lengthy pre-existing drains. Their southern continuations show sunken *Sphagnum* for about 100 metres.

- All *Sphagnum* has been killed in the ditch receiving the road water drainage via the new 141 metre drain, for a length of about 280 m.

- A new drain was cut SE from T24 in 2009 to prevent flooding of the T24 base. It joins a short length of pre-windfarm ditch before passing west under the road via a 'banana' culvert. All *Sphagnum* in the pre-windfarm ditch to the west has been killed.

- Impeded flow around the first 'banana' culvert south of T24 seems to divert water into road material and it travels south to the next culvert, also a 'banana' shape. Pipe fractures here seem to divert the water into the pre-windfarm drain on the western side of the culvert. All *Sphagnum* in this drain has been killed. *Sphagnum* is abundant in this drain on the eastern side of the road.

- The two pre-windfarm drains without *Sphagnum* at the southern end of the road between T24 and T23 flow into a blocked drain sector. The uppermost blocks contain no *Sphagnum*. All blocked drains here were examined in 2010 and all contained abundant *Sphagnum*. T24 and road drainage effects have probably developed here over the last four years.

125 The observations above relate to degraded conditions within 17% of the ditch network length examined. They were not seen in 2010 work on verges and it is likely that most have developed in the last nine years, although it is also possible that the 'banana' culvert and road drainage effects between T9 and T8 have taken place over a longer period.

126 On the basis of 2014 work, this was considered a potentially serious issue for environmental management at Causeymire. If much of the damage had developed in a short period (e.g. the drainage water effects from T20 might only have been 1-2 years old), it could progress to damage the condition of much greater lengths of bog drain. The survey results here, and for 2019, do not consider all bog drains within and downstream of the wind farm, so these effects might be more extensive.

127 Effects on fen drains further downstream might also be occurring, although this habitat should be more resilient to hydrochemistry effects. The cause of *Sphagnum* loss within bog drains is unknown. The role of blocked drains in potentially buffering the effects of base and road drainage needs consideration too. The potential effects of overspill from ditches carrying water with different hydrochemistry, at times of high water levels, could affect large tracts of inter-drain habitat.

128 The EIA-stated impacts of windfarm developments on blanket bog ecology, peat and drainage in Scotland has recently been subject to review (Wawrzyczek *et al*. 2018).

129 Parts of that review must be handled with very great caution because it contains gross exaggerations in diagrams, reproduced here in Figure 10. For example, track widths equivalent to 80 metres are drawn and peat depths in cross-sections, from extrapolated scaling, would be >100 metres (which is ridiculous). There is also a serious mismatch in size-scale in diagrams between bog patches with pool systems (about 2 km diameter at Causeymire, as an example) and the applied schematic windfarm layout, i.e. the bog sectors should be made larger and reduced markedly in number, to match realistic turbine spacings (310 to 420 metres at Causeymire). The exaggerations in diagrams suggest that distance effects illustrated by faded arrows are exaggerated by perhaps a factor of 6.

130 In addition, a cross-section shown for a floated road is very different from the majority of these structures, as given elsewhere in some of the EIAs studied. Roads built at Causeymire (not included in the review study), for example, have no lateral drains alongside floated roads. Lateral drains are typical of cut or cut-and-fill roads which are used on shallow peat or mineral soils.

131 Nevertheless, even with the caveats of great distortion and road design errors above, drainage effects from windfarm infrastructure upon blanket bog hydrology and pre-existing drainage will occur. In the case of Causeymire, after 15 years, those effects can be considered in relation to the extent of impacts inferred in the Figure 10 diagrams from Wawrzyczek *et al*. (2018), compared with those anticipated in the Causeymire EIA produced in 2001 (National Wind Power & Miller 2001).

132 The windfarm was one of the earliest large developments in Scotland and the Causeymire EIA therefore did not cover aspects which are now standard or compulsory in scoping advice provided by statutory agencies (SNH and SEPA), such as inclusion of a habitat map, carbon calculator work (Nayak *et el*. 2008; Smith *et al*. 2011), peat slide risk assessment or assessment of groundwater-dependent terrestrial ecosystems.

133 The Causeymire EIA includes a chapter on ecological and hydrological assessment that was completed by consultants/staff from Scotland's foremost land use and soil research centre, the Macaulay Institute (now the John Hutton Institute), plus a local ornithologist. Several conclusions in the EIA were reached related to blanket bog habitats and ecohydrology. They are evaluated in the two subsections below, including reference to Wawrzyczek *et al*. (2018).

3.3.1 Habitat loss

134 Habitat loss (Table 6.4 in the EIA) was considered potentially significant if it occurred within or close to the bog pool (dubh lochan) habitat on the highest peatlands, known as Bad a Cheo.

135 In addition, in a reference to hydrological integrity, the EIA stated (paragraph 6.49) "*However, as a precautionary measure, it is suggested that a suitable buffer of at least 20-40m wide is left on the perimeter of the development site in order to maintain the hydrological integrity of the dubh lochan area. As noted above, the minimum separation distance between the lochans and any of the constructed components of the proposed windfarm development is approximately 150m, and therefore at a considerably greater distance than the recommended buffer*."

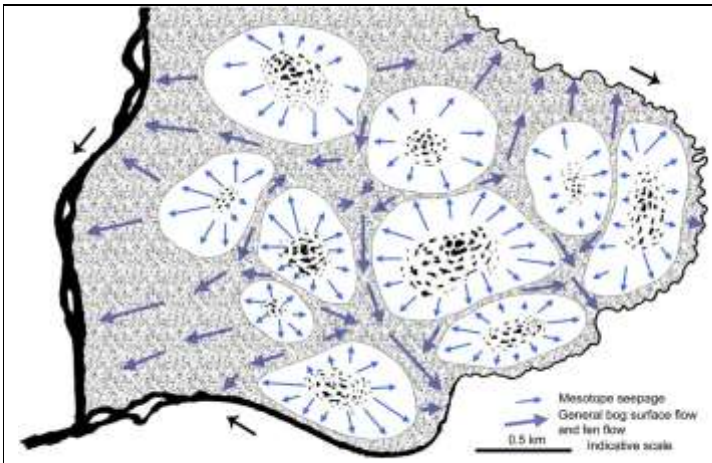


Fig. 1. The Tope System - Indicative blanket mire macrotope bounded on all sides by major river systems or streams running on mineral soil. Individual blanket bog units, or bog mesotopes, are white with black shading representing pools or hollows. Seepage from the centre of each bog mesotope is indicated by mid-blue arrows. The wider peat surface, including a range of interconnecting fen mesotopes, is shaded grey. Direction of fen seepage is indicated with purple arrows.

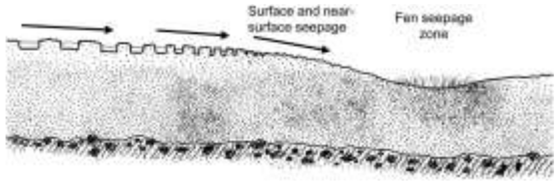


Fig. 2. The Tope System - Indicative cross section of a bog mesotope with microtope patterning (left) connecting with a fen mesotope (right) which then connects with an adjacent bog mesotope (right, out of picture). Peat is shown stippled, with stippling indicating the density of peat. Sub-peat glacial till soil is shown by hatching.

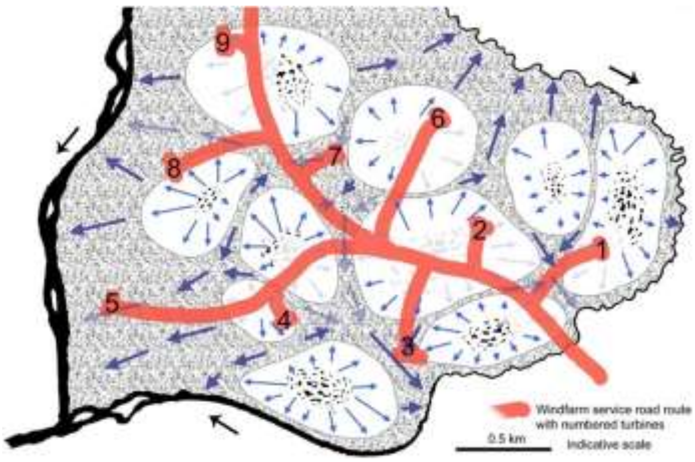


Fig. 3. The Tope System and impacts – Indicative long-term impact of a windfarm road (shown in red, with numbered turbines) constructed through the mestopes of the blanket mire ecosystem shown in Fig. 1. Mesotope flow lines in both bog and fen systems potentially impacted by the development are shown as faded arrows. Microtope patterns potentially affected within mesotopes are also shown as faded patterning. Note that some mesotopes, and parts of mesotopes, are indicated as being unaffected, although the long-term impacts are difficult to predict.

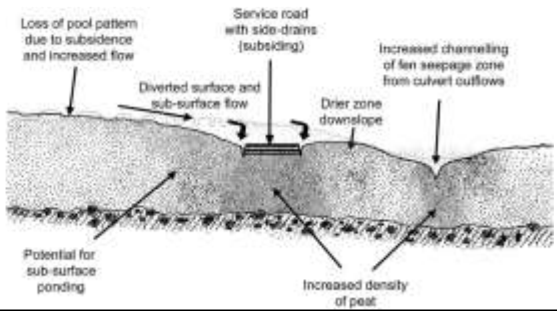


Fig. 4. The Tope System and impacts - Cross section of the blanket bog and fen mesotope system shown in Fig. 2, but now with a windfarm road constructed through the system in the manner of the road leading to Turbines 4 and 5 in Fig. 3 above. Compression and drainage impacts caused by road construction have caused the peat to become denser within the region of the road, while the fen system now receives more focused water inputs from culverts beneath the road, and has itself been channelled to speed water removal from the site. The original level of the peat surface is shown in faint grey.

Figure 10 Tope System blanket bog - fen mire natural patterning with hydrological seepage - flow linkages and suggested impacts from indicative windfarm roads and turbines

Source: Wawrzyczek, Lindsay, Metzger & Quétier (2018) *Environmental Impact Review* 72, 157-165.

136 There is only reference in the EIA to a single dubh lochan area, when in fact there are two concentrations of these waterbodies (see Figures 1 and 9). The closest infrastructure to dubh lochans in the north is 190 metres away, at T10. The closest infrastructure to the southern lochans is 124 metres at T24. The latter is closer than stated as a mitigation measure but three to six times the minimum distance stated in the EIA as a precautionary measure.

137 This outcome shows that a suitable avoidance distance did result but with an element of chance, given a lack of full habitat survey which did not cover the southern dubh lochan area.

138 Wawrzyczek *et al*. (2018) make the point that there are important environmental information gaps in the 21 EIAs which were examined in their study. The Causeymire development was not included in that study (it is below a 50 MW minimum threshold) but the Causeymire EIA does contain such a gap, habitat mapping identifying the various habitats in an ecohydrological context.

139 The Causeymire EIA presents information on vegetation types based on the National Vegetation Classification (NVC). The list refers to 72 2m x 2m quadrats collected by the Macaulay Institute in 2001 at Causeymire using grid-sampling (200 metre spacing using the OS grid). Each quadrat was later allocated to an NVC type using a published software comparison technique. The EIA contains a map of quadrat locations with quadrat numbers. There is no information on the NVC type for a particular numbered quadrat and the EIA does not contain the quadrat species information or its allocated NVC type. It is therefore impossible to use the EIA account on vegetation as part of an ecological assessment. This is an obvious important information gap.

140 Habitat loss elsewhere is not included in the EIA summary of effects and that is justified in the text (paragraph 6.72) as follows: "*There will be loss of limited areas of habitats within the site amounting to approximately 3% of the site area. but none of this occurs in areas of nationally or regionally important species assemblages. None of the potential ecological effects identified are considered to be significant and the Causeymire site is therefore considered appropriate for development as a windfarm*."

141 That assessment is fair but there is no reference to a mitigation hierarchy in the EIA. No compensation is provided for non-significant loss, in the form of no net biodiversity loss or, better, biodiversity net gain (BNG). The latter is now good practice in England (CIRIA/CIEEM/IEMA 2019a, 2019b) for all development outside designated areas but it has not yet become a policy in Scotland (https://cieem.net/biodiversity-net-gain-in-scotland/).

142 A CIEEM (Chartered Institute of Ecology and Ecological Management) BNG policy paper available at the above link includes a case study close to Causeymire, at Thurso South Substation.

143 The mitigation hierarchy (in Scottish Planning Policy) and formalisation of biodiversity net gain (as good practice) both post-date the Causeymire EIA.

3.3.2 Modification of hydrological flow paths and drainage ditch disruption

144 Localised modification of hydrological flow paths is identified in the EIA (Table 6.4) as a potential impact which would change the soil moisture regime and therefore

habitat. It was assessed as not significant. Disruption of drainage ditches was assessed in Table 6.4 as potentially significant.

145 That risk relates directly to the main hydrological processes identified in Wawrzyczek *et al*. (2018): mesotope surface and near-surface seepage, general bog surface flow and fen flow.

146 Those processes are only listed in diagrams describing the Tope System in that paper. There is no definition or an elaboration of these flow components, nor is there direction of readers to detailed descriptions and hydrological models with full explanations which could then be used to assess impacts. The primary source of such models (Ivanov 1981) is given but only in the context of the tope hierarchy.

147 In short, the paper by Wawrzyczek *et al*. (2018) does not identify an available ecohydrological assessment framework which is proven as applicable for use on Scottish peatlands. This too is an important information gap, despite two decades of windfarm construction on peat in Scotland.

148 Paragraph 6.72 of the EIA states that most of the identified effects associated with vegetation, hydrology and soils are associated with the construction stage of the development, which will be limited in duration. The longer-term effects at Causeymire covering drainage effects on vegetation suggest this area of assessment was incorrect.

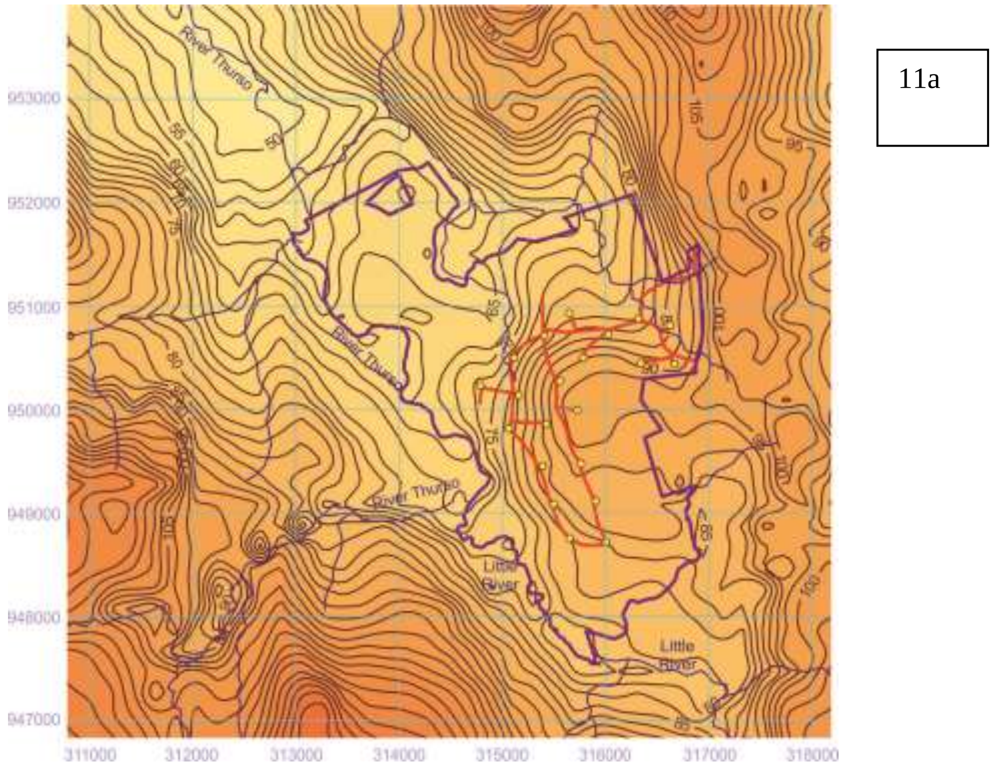
149 Negative drainage impacts (lengths in unfavourable condition, >2200 metres out of 12,600 metres surveyed) are extensive. This appears to result from a combination of pre-windfarm drainage of bog west of the Bad a Cheo pool systems (Figure 1) and excavations by the operator (RWE Innogy) between 2010 and 2014 (Figure 9).

150 The topography shown in Figure 11a, matched with habitats (Figure 1) and aerial photography (Figure 9) suggest that the bog – fen matrix illustrated in Wawrzyczek *et al*. (2018) is very different to HMSA conditions. The peatlands at Causeymire seem to represent a valleyside mire (Lindsay 1995; Chapter 8 *Bogs* in JNCC 1998), at a lower elevation than higher watershed mires which lie east of the A9.

151 The main valleyside mire contains at least three pool systems, one an eccentric bog (Figure 1). The two northern dubh lochan areas are set within overall bog, with no intervening fen. Fen habitat is only weakly developed between the southern dubh lochan area and the eccentric bog. These three areas of pool and dubh lochan concentration are set at different elevations, from 93m in the north, to 89m and then 84m for the eccentric bog. This tiered distribution without intervening fen is very different to Fig. 1 in Wawrzyczek *et al*. (2018). Further north upon Dale Moss, elevations are even lower and before peat extraction might have held dubh lochans.

152 The windfarm at Causeymire straddles the western edge of the highest and flattest ground of Bad a Cheo, with most road length placed on the slightly steeper side slopes of the valleyside mire lobe. Surface drainage from the bog therefore runs north, west and southwest over these flank slopes (Figure 11b).

153 Flowlines suggest the eastern side of the southern track loop runs almost parallel to surface seepage flow running south southeast. This in theory should reduce interference with surface drainage in this sector. However, the recent drains cut between 2010 and 2014 are associated with the most extensive effects (Figure 9) upon drains downstream. Drain depth and slope here seem sufficient to much-modify the pre-existing flow pattern and perhaps has changed the direction of some flow from southeast to southwest.



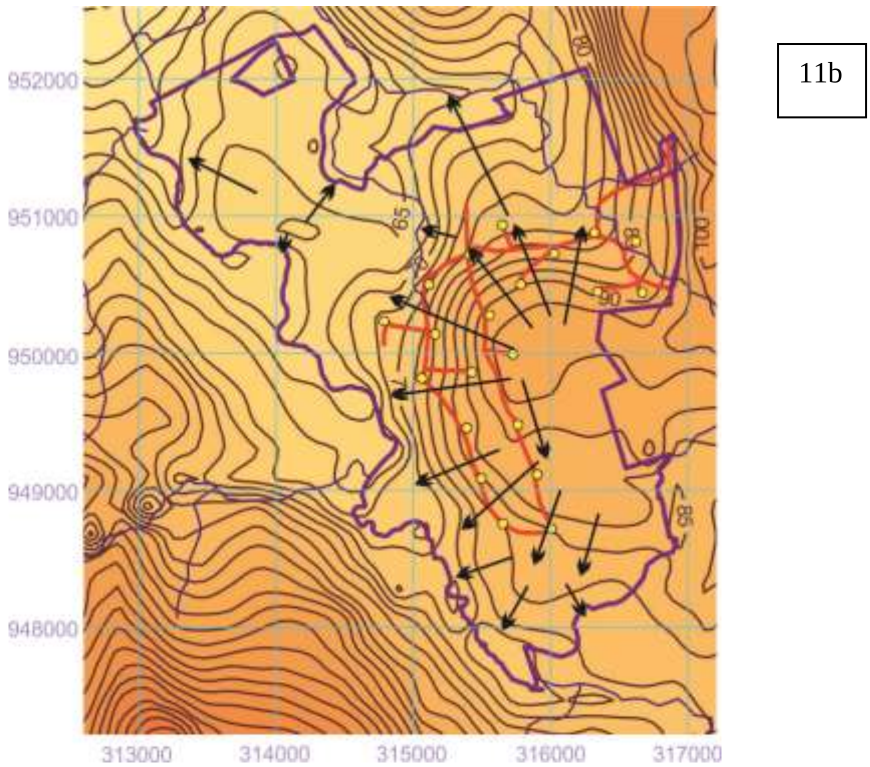


Figure 11Contoured relief (11a) around Causeymire HMSA area and mesotope flowlines (11b)

Contour interval 2.5 metres

HMSA boundary in blue, windfarm roads in red and turbine locations in yellow

Data source: NEXTMap Britain 25m resolution digital terrain model all-Scotland dataset

Derived from Intermap Technologies 2001-2003 all-UK airborne radar survey

154 The roadstone of the floated road, lying mainly within peat (as opposed to being above) has further modified flow, providing a corridor where flow is both southeast (roughly from the T10 spur junction) and northwest (from south of T24). The two flows meet to producing the spring noted at ND 15826 49235. This road alteration of diffuse flow has also concentrated flow, with a likely changed hydrochemistry (to explain the loss of *Sphagnum* in affected older drains). These effects were not anticipated in the EIA and interactions with pre-existing drainage, as conduits for changed conditions, have modified drain habitats adversely for 60 – 420 metres.

155 The impacts revealed by ditch work do not cover any effects on more diffuse flow. The only monitoring evidence for such effects is likely to be indirect, within the records for point and line segments.

156 *Sphagnum* cover data for lines and points on the 315750 easting transect contain some reductions between 2014 and 2019 for samples south of the road intersection at northing 949480. This is most marked for line segments, particularly from 949000 southwards where three 2019 results (samples 95 to 97) are half (29 to 50%) of 2014 values.

157 However, the start of depressed 2019 line segment values is 300 metres south of the road. That is counterintuitive – interrupted diffuse flow should begin very close to the road, especially if captured within roadstone. Some other factor is probably responsible, perhaps related to an increase in slope angle which occurs on the ground occupied by these samples (see Figure 11). Overall, *Sphagnum* results show little or no indirect evidence for road reduction of diffuse flow.

158 There is no marked change in *Sphagnum* cover for samples which lie north (above) the road, except for a large reduction in one point result (sample 103): 2014 45% to 2019 20%. It is sited very close to the windfarm track.

159 Ditch-blocking in 2004 potentially rewets adjacent bog, most notably close to T6 where *Sphagnum papillosum* and then *S. cuspidatum* have been noted infilling lateral depressions and spreading out over adjacent bog surfaces. Line segment and point samples do not show this clearly in results and the line transects elsewhere do not intersect blocked ditch sectors. It is therefore not possible to provide evidence that ditch-blocking has compensated for altered diffuse flow elsewhere.

160 As a summary, the following conclusions can be made regarding surface flow alteration by Causeymire Wind Farm roads:

- Diffuse surface and perhaps subsurface flow are concentrated locally via new ditches and altered conditions into pre-existing drains.

- Only a limited number of pre-existing drains have been affected and the maximum distance of negative impact within any drain sequence is 420 metres.

- The 2014 analysis of drainage impacts close to windfarm roads estimated negative impacts for 2224 metres for a network of 12,622 metres surveyed (17.6% of total length). That is a significant negative effect but one which is not excessive and involves surfaces which had already been altered by pre-existing ditch systems.

- The Causeymire EIA underestimated the scale of drainage impact but not markedly so. Assessment there should perhaps have recognised that long-term effects were likely into the operational phase, with complete mitigation by sound construction methods unlikely. The EIA coverage of drainage disruption was sound and assessment (potentially significant disruption of drainage ditches) was correct because culverting has been inadequate (banana effects) or made impossible by sinking of the floated road design. Hydrochemical effects are underestimated by the EIA but these are local and relate to further ditch excavation between 2010 and 2014.

- There is no evidence from Causeymire that the scale of drainage impacts matches the distances inferred by the tope model in Wawrzyczek *et al*. (2018). That analysis seems to rely upon inadequate scaling and over-simplistic depiction of a pristine tope system. It fails to consider the role of much-altered bog surfaces which are later used to host a windfarm and these conditions are likely to be extensive in most, if not all, of the windfarms selected for that analysis.

3.4 Interpretation of habitat condition monitoring results for the HMSA

3.4.1 Grazing pressure evidence in the HMSA and vicinity of the windfarm

161 This subsection considers historical and recent grazing pressure and its relevance to site environmental management, given that a reduction in grazing pressure was the main means proposed for improving habitat conditions within and close to the turbine array (National Wind Power & Miller 2001; Dargie 2004).

162 Feedback on 2009 reporting requested that information on stock and deer numbers should include reference to a standardised system which takes account of the different grazing requirements for different species, so-called livestock units (LU) (Chapman 2007). Table 4 contains information for 2003-2019 which was initially produced as part of a 2010 feedback response in Dargie (2012). Content is extended up to 2019 based on information supplied by D. Miller (grazing tenant) and I. Miller (landowner).

163 Stock and deer numbers extending as far back as 1960 have been provided as a spreadsheet by I. Miller and data here has been converted into livestock units for the period 1960-2019. This is set out in graphs showing the demands of different grazing animals (Fig. 12a) and the trend in annual stocking rate (LU/ha/yr) (Fig. 12b), based on a grazing area of 560 ha.

164 Supplied data on stock and deer numbers for the period of windfarm operation (Table 4) suggests a reducing grazing pressure on habitat, with the lowest values between 2010 and 2012, followed by an increase due to a change in cattle management. These trends correspond with recent year graphed change (Fig. 12a) which shows that a reduction in grazing from 2004 was only slight, followed by a steep fall after the withdrawal of all sheep grazing in 2009, then an increase in the period 2013-2016 and a fall to historically low pressure in the last three years.

165 As discussed in 2009 and 2014 reporting, the grazing pressure at Causeymire since wind farm construction has been above that recommended for maintaining blanket bog habitat in favourable condition, 0.06 LU/ha/yr (Chapman 2007).

166 The stocking rate values in Table 4 are of course dependent on the area of grazed ground and the 560 ha used is perhaps an underestimate because it excluded the Dale Moss peat extraction area and a large Lodgepole Pine plantation initially used for Christmas tree production. Deer certainly use both areas. However, including those sectors would not reduce average annual stocking rates close to 0.06 LU/ha/yr. Stocking levels at Causeymire seem to be between 17% (0.07 LU/ha/yr as a most favourable estimate since 2003/4) and almost 300% (0.17 LU/ha/yr) higher than that generally regarded as necessary to maintain blanket bog habitat in favourable condition.

167 These high stocking values (relative to blanket bog requirements) are probably not serious in terms of long-term blanket bog condition. A large minority area is occupied by fen, rush pasture and wet grassland (Fig. 1), some of it heavily drained and semi-improved in the north-east. These habitats have a much higher stocking rate (probably about 0.4 LU/ha/yr) compared to blanket bog. Together they can probably hold far more stock and deer than the blanket bog of the site. Cattle grazing and deer browsing are concentrated in these habitats in the north-east of the HMSA.

168 The trends in Table 4 do not match closely the patterns recorded over time using line segment data. The field evidence shows a strong increase in grazing between 2004 (Figure 13) and 2019 (Figure 14), particularly in deer tracks, prints and dung. Equivalent maps for 2009 and 2014 are given in earlier reports (Dargie 2012, 2015).

169 There might also have been local changes in habitat character driven by grazing. Species frequency maps in Appendix 4 for Purple Moor-grass *Molinia caerulea* 2004 and 2019 show an expansion over time for most of the HMSA and much of that is concentrated close to windfarm tracks. It is possible that nutrient increase via cattle dunging, plus cattle trampling disturbance on track margins (providing patches for *M. caerulea* spread and growth) are the drivers of this change.

170 There is further corroboration of *M. caerulea* expansion in results for the condition of track verges. This species was not recorded as part of that work but is by far the main component of grass and sedge cover. Those condition results suggest that bog habitat is more sensitive to cattle impacts (grass cover increasing on verges from 8% to 30% between 2010 and 2019, Table 6), compared to *Molinia*-dominated modified bog (grass increasing from 52% to 62%, Table 6).

171 It is important to note that there has been no major deterioration in HMSA habitat driven by over-grazing. There is no extensive ground damage and very few new areas of bare peat created by tracks and concentrated trampling.

172 In 2019 the Habitat Enhancement Area (HEA) contained a notable number of deer prints but almost no dung. This suggests that electric fencing around this enclosure is no longer functioning.

173 There has been a marked change in the location of the most frequent deer browsing since 2019. The 2014 survey showed a concentration in the northwest of the HMSA, particularly upon Dale Moss and over bog in what is now the southern part of Achlachan Windfarm. As part of that distribution, the northern edge of the Lodgepole Pine plantation was being used as shelter. Elsewhere in 2014, deer browsing was well-spread, with little difference in attribute distribution between bog or fen.

174 In 2019 deer browsing is concentrated in the northeast and southeast. There is very little evidence close to the Causeymire turbine array. It is possible that disturbance is responsible: maintenance/public use of tracks at Causeymire and Achlachan, plus the recent felling and mulching of timber within Bad a Cheo Windfarm.

175 There has been little change in the distribution of cattle grazing impact, with evidence in the northeast and within the River Thurso corridor on the western side of the HMSA. Records for turbine bases and track margins show that ground is also used by stock.

176 In 2014 reporting it was stated that there was a mismatch between field evidence and supplied data on stock and deer, and that it was likely to remain into future years. That is the case in 2019. This makes it difficult to consider grazing effects accurately as a component driving change in habitat condition.

177 Overall, monitoring results suggest that stock and deer management in the HMSA have maintained fen and bog habitats in good condition. There is no evidence of over-grazing. Muirburn is no longer used as a management technique and that is probably beneficial to Causeymire bog habitat. It was last used in 2009.

Table 4 Annual stocking rate[1] for habitat enhancement around Causeymire Wind Farm

[1] based on 560 ha area, excluding old peat cuttings, forestry and fenced improved pasture. Livestock Units (LU): ewe 0.12, ewe and lamb 0.15, beef cattle 12-24 months 0.6, suckler cow and calf 1.0, red deer 0.25. All cattle LU values for sucklers and followers have been reduced by a third to reflect partial use of nearby improved pasture and supplementary feeding.

* estimates used, no verbal data available.

Year	Sheep	Sheep LU	Cattle	Cattle LU	Deer	Deer LU	Total LU	Stocking Rate (LU/ha/yr)
2003/4	500 ewes	60	20 sucklers and followers, all year	13	80*	20	93	0.17
2004/5	250 overwintering ewes, 155 ewes and 190 lambs in summer*	27	40 sucklers and followers, all year	26	80*	20	73	0.13
2005/6	250 overwintering ewes, 155 ewes and 190 lambs in summer*	27	40 sucklers plus followers, all year plus 40 heifers July to December*	34	122	31	94	0.17
2006/7	250 overwintering ewes, 155 ewes and 190 lambs in summer*	27	40 sucklers plus followers, all year plus 40 heifers July to December*	34	70*	18	79	0.14
2007/8	250 overwintering ewes, 155 ewes and 190 lambs in summer	27	40 sucklers plus followers, all year plus 40 heifers July to December	34	60*	15	76	0.14
2008/9	180 overwintering ewes, 160 ewes and 240 lambs in summer	24	45 sucklers plus followers, all year plus 36 heifers July to December	37	50*	13	74	0.13
2009/10	180 overwintering ewes, 160 ewes and 240 lambs in summer*	24	Averaged as 34 for a full year, beef cattle	20	80	11	73	0.13
2010/11	None	0	Averaged as 34 for a full year, beef cattle	20	80	20	40	0.07
2011/12	None	0	Averaged as 34 for a full year, beef cattle	20	80	20	40	0.07
2012/13	None	0	Averaged as 56 for a full year, beef cattle	34	90	22	56	0.10
2013/14	None	0	Averaged as 56 for a full year, beef cattle	34	80	20	54	0.10
2014/15	None	0	Averaged as 56 for a full year, beef cattle	34	76	19	54	0.10
2015/16	None	0	Averaged as 56 for a full year, beef cattle	34	76	19	54	0.10
2016/17	None	0	Averaged as 40 for a full year, cows and calves	20	76	19	39	0.07
2017/18	None	0	Averaged as 40 for a full year, cows and calves	20	76	19	39	0.07
2018/19	None	0	Averaged as 40 for a full year, cows and calves	20	76	19	39	0.07

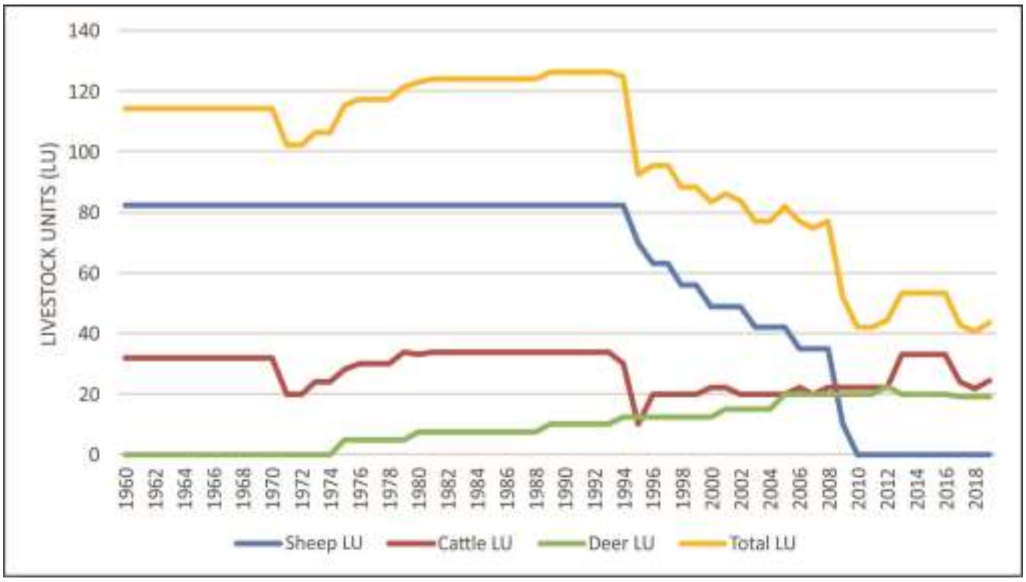


Figure 12a Stock and deer grazing levels within Causeymire HMSA, 1960 to 2019

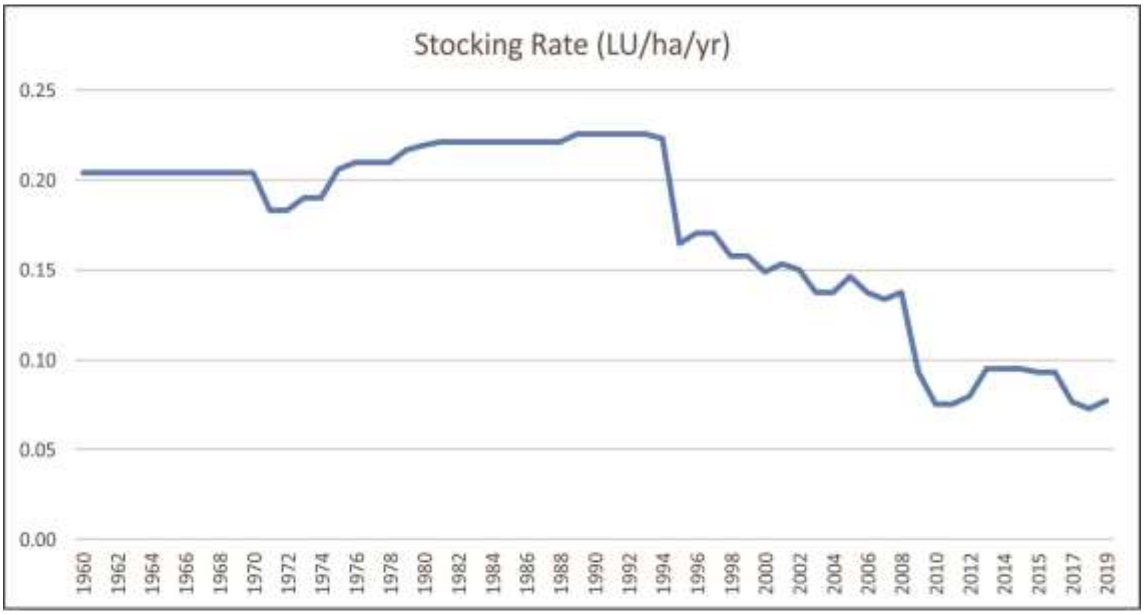


Figure 12b Trend in stocking rate, 1960 to 2019

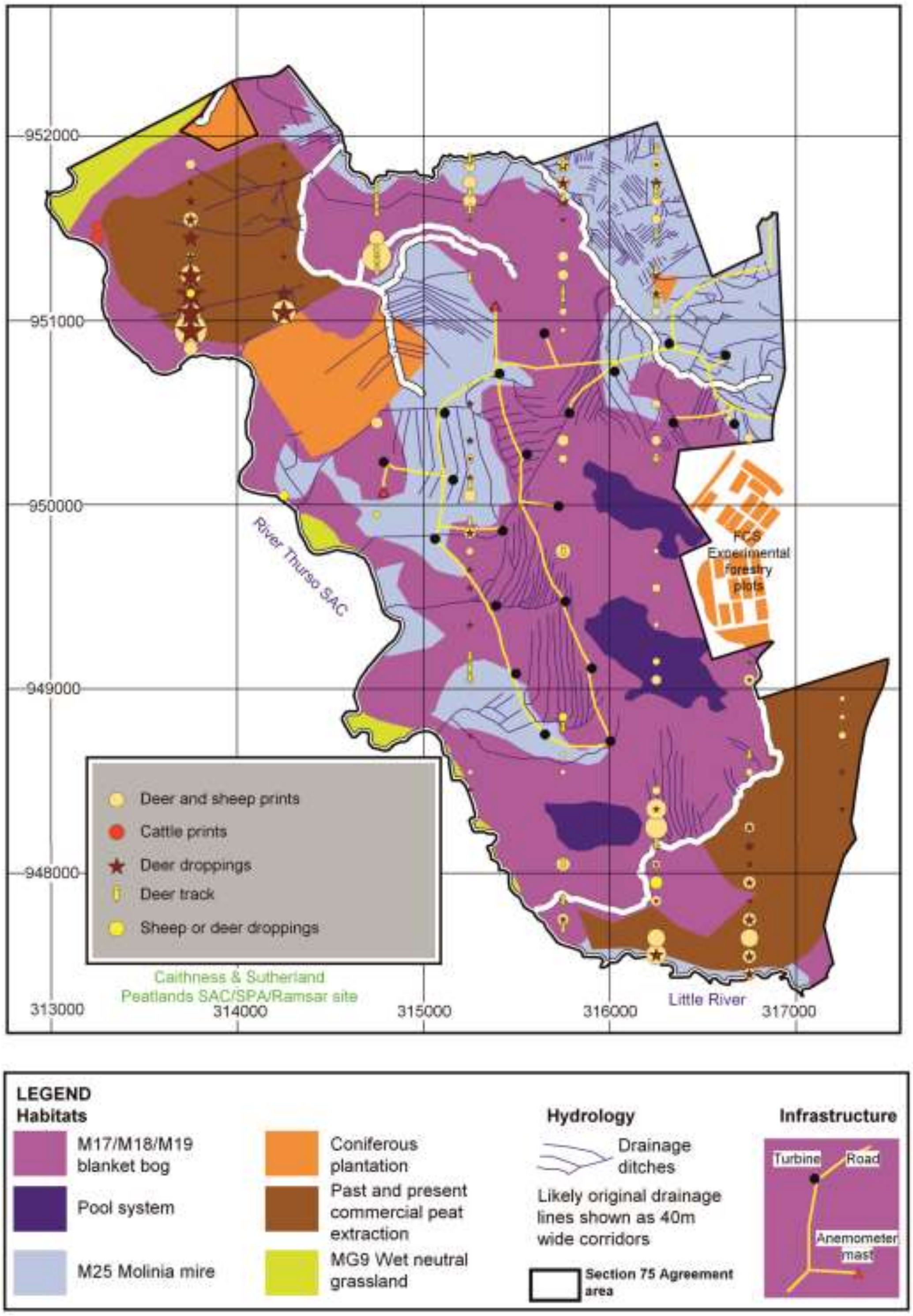


Figure 13 Herbivore impacts recorded in 2004 line data

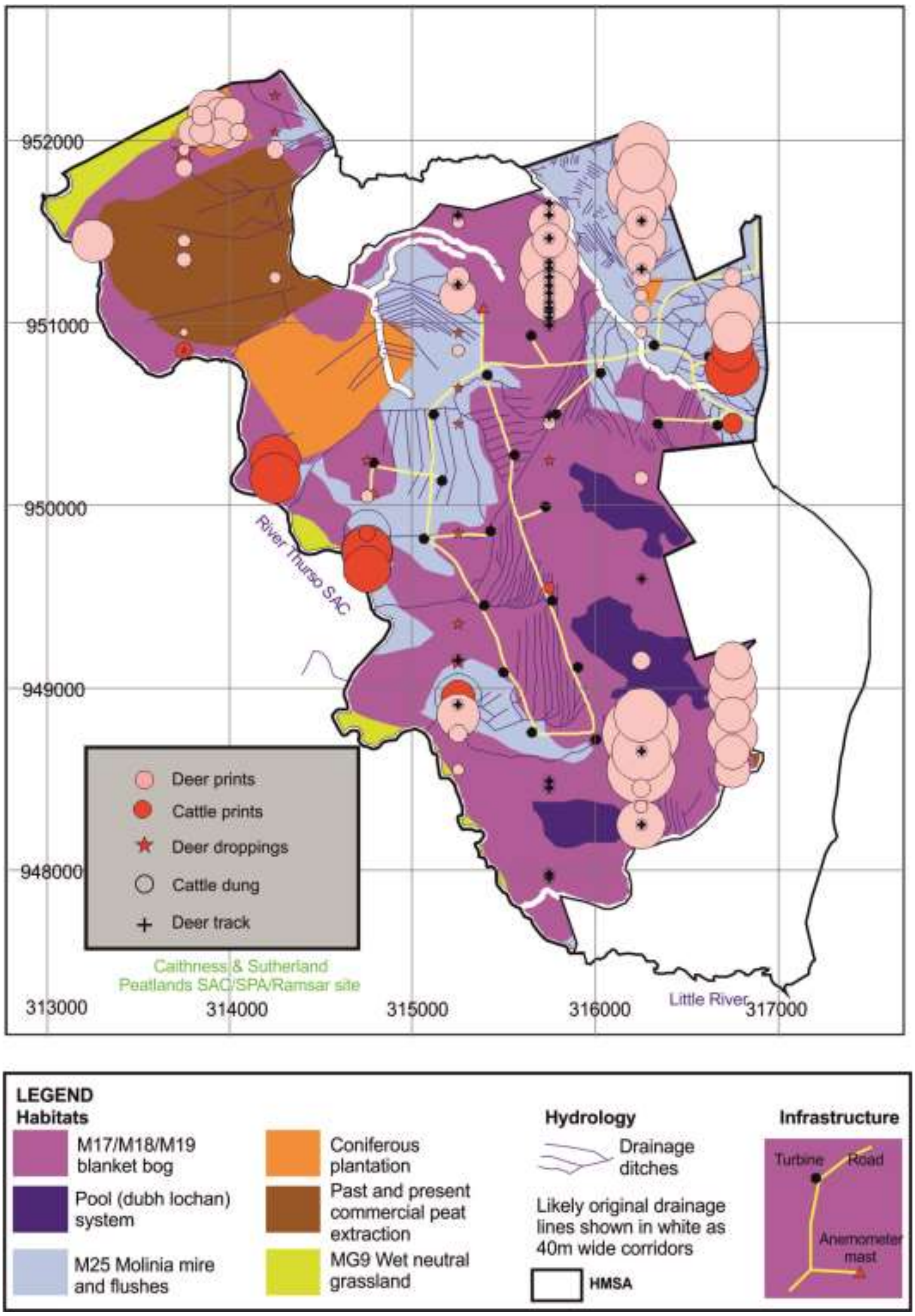


Figure 14 Herbivore impacts recorded in 2019 line data

3.4.2 Explanations for the unexpected significant increase in Sphagnum *extent*

178 The major change to emerge strongly from monitoring between 2004 and 2019 is the remarkable increase in *Sphagnum* cover, observed in both point and line segment results (see section 2.5).

179 Earlier reports, particularly that covering 2009 monitoring (Dargie 2012), have provided initial interpretation of the *Sphagnum* increase and that work is reviewed here.

180 Four hypotheses were put forward in Dargie (2012), covering factors which might operate over large areas and which, alone or in tandem, could explain this very large increase in *Sphagnum* extent:

- Hypothesis 1: Changes in grazing management – reduced grazing pressure reduces trampling, increases surface infiltration and surface wetness, allowing *Sphagnum* growth;
- Hypothesis 2: Increased annual or seasonal rainfall produces wetter bog surfaces, allowing *Sphagnum* growth;
- Hypothesis 3: Wind velocity deficit effects are created by wind turbine operations, reducing near-surface wind speeds and so reducing evapotranspiration. This is likely to produce a higher bog watertable, or rather reduce the depth of watertable fall during drying sequences in a summer. This might allow increased *Sphagnum* growth in areas which were formerly too dry;
- Hypothesis 4 (submitted by RSPB in 2011, after considering a draft version of 2009 reporting and attending a 2010 field visit): The habitat is recovering from a damaged state most likely caused by historic burning or over grazing prior to the period covered. The subsequent management, at least over the last 5 years [i.e. between 2004 and 2009], is clearly allowing recovery to values more typical of healthy blanket bog in the eastern Flows.

181 Each hypothesis is reviewed again below and key information updated where possible.

Hypothesis 1: Reduced grazing pressure

182 Increased infiltration following reduced peat soil trampling by stock, reducing water losses by saturation excess flow (runoff), is known to increase the wetness of peat, particularly in a peat with an acrotelm (Holden *et al*., 2007). This could stimulate *Sphagnum* growth.

183 The research cited by Holden *et al*. (2007) states that stock trampling tends to be restricted. It is concentrated upon and around tracks, in areas where animals gather for feeding, and around gateways. Given this spatial restriction, a relaxation of grazing is unlikely to bring about favourable conditions for *Sphagnum* growth on the scale seen at Causeymire.

184 This mechanism of *Sphagnum* increase is therefore only likely to act in addition to other ‘drivers’ of *Sphagnum* growth.

185 The field evidence from 2004 – 2009 monitoring at Causeymire was that grazing pressure, including trampling effects, has increased since 2004. This was counter to the assumptions of Hypothesis 1, making this explanation unlikely.

186 A review of stock and deer numbers in Dargie (2015) using Livestock Units showed a marked reduction in grazing pressure at Causeymire from the early 1990s to 2008, then a further reduction up to the present which has historically-low values. This result is the opposite of field evidence based on cattle and deer.

187 The timing of sharp falls in grazing pressure at Causeymire do not coincide with the equally sharp increases in *Sphagnum* cover, which began following the end of the construction phase of the windfarm.

188 A check of pre-2004 *Sphagnum* cover was made by requesting the quadrat data collected in 2001 by the Macaulay Institute. The average value found in 2001 records (15.1%, average of 72 quadrats) was very close to the average of 2004 quadrat (point values) for samples located only in the ground used for 2001 sampling (14.7%, 57 records). This checking is part of other research and is not presented in detail here. It suggests that 2004 *Sphagnum* cover was very similar to that recorded in 2001.

189 There is therefore no correspondence in timing between reduced grazing and *Sphagnum* increase starting in 2004/5/.

190 There is conflicting correspondence in location between expanding *Sphagnum* and ground with little evidence of grazing/browsing. Ground east of the turbine array matches low grazing but not south of turbines where strong *Sphagnum* expansion occurs in an area with deer tracks, dung and prints.

191 This hypothesis overall is weak and seems unlikely.

Hypothesis 2: Changing regional climate

192 A high *Sphagnum* cover within bog habitat would be considered by mire ecologists to be firm evidence of a shallow watertable close to the bog surface. An increase in rainfall might therefore be a climatic driver which is responsible, in whole or in part, of the Causeymire *Sphagnum* increase. This hypothesis was framed in 2010 as changing seasonal or annual rainfall.

193 Three lines of evidence were followed in Dargie (2012) to investigate this hypothesis. The first was the examination of rainfall records. No data exist for Causeymire for recent years. Old rainfall records were maintained by the Forestry Commission and the Macaulay Institute for the adjacent research plots at Bad a Cheo. A request was made for data but the records could not be found.

194 The second line of evidence was indirect: the comparison of *Sphagnum* growth records in the Flow Country to see if there is a comparable increase in an area without wind farm influence. If such an increase can be found for a site comparable to Causeymire then it would suggest that a regional factor such as rainfall is responsible, at the same time allowing dismissal of a wind farm effect (i.e. rejection of Hypothesis 3, see below).

195 A third line of evidence would be to attempt a correlation between tree ring width and rainfall close to a local rainfall station, extending the correlation by regression to tree growth close to Causeymire. That would have been a complex exercise and was not attempted. Only the first two lines of evidence were considered.

196 The only weather station close to Causeymire with long-term rainfall records is located at Wick Airport, approximately 23 km due east of the Causeymire site. Long-term records for many sites have recently been made available to the general public *gratis* on the Meteorological Office website.

197 The monthly averages for rainfall at Wick Airport were examined for a decade (2000 – 2009). The sequence was divided into five years pre-windfarm (2000 – 2004) and five years after windfarm construction (a period of known *Sphagnum* increase, 2005 - 2009).

198 In addition, months were allocated to three seasons: winter (November to February), summer (May to August) and the transitions of spring and autumn (March, April, September, October).

199 There was some evidence for an increase in rainfall:

- On a monthly basis the average for 2000 – 2004 was exceeded for 7 months in the period 2005 – 2009 (a split of 7:5);
- The three seasons analysis shows that the 2005 – 2009 winter was drier than 2000 – 2004, but that the transitional and summer periods were wetter. The summer rainfall increase (to 241.8 mm) is almost 16 mm, an increase of 7% on the 226.0 mm in 2000 – 2004;

200 The increase in summer and transition season rainfall was not very large and could probably be considered to be within the normal range of seasonal and annual rainfall variation. The following points should be borne in mind:

- The annual average for 2005 – 2009 is slightly lower (812.2 mm) than 2000 – 2004 (817.3).
- The transition seasons are strongly influenced in 2006 by a storm event in October 2006 (234.6 mm) which caused widespread flooding in Caithness and Sutherland. Most of that total will have been lost as runoff from peatlands, with little long-term effect on bog watertables.
- There is no consistent increase in summer rainfall in the period 2005 – 2009. Three years in this period were wetter than 2000 – 2004 but two were drier.

201 An increase in summer and transition seasonal rainfall was therefore present but not very marked. This lack of a consistent strong difference in rainfall amounts casts some doubt on this factor as the key ‘driver’ of *Sphagnum* growth.

202 Rainfall is only one element of a site water balance. Runoff and evapotranspiration are also very important controls of the bog watertable and there is no information on this or on watertable changes. The losses due to runoff and evapotranspiration are also likely to have changed over time as *Sphagnum* has extended its distribution, creating a surface layer (technically termed the acrotelm) which has probably thickened in areas of early *Sphagnum* growth. In reality, the role of rainfall needs to be explored by water balance modelling of all major input and output factors at Causeymire, plus the water stored within the peat. There is insufficient information to do this without a major hydrological research input.

203 The second line of evidence, change in *Sphagnum* in the Flow Country at a site distant from any wind farm effect, was explored using RSPB data collected from a site at Dorrery (ND010498) – *c*. 16 km due west of Causeymire.

204 Spreadsheets with *Sphagnum* data from quadrats (point samples) and line transects were supplied by RSPB for baseline records (surveys conducted over three years: 2002, 2003, 2004) and a resurvey in 2008. Quadrat sample datasets provided 95 points present in both survey phases. Line datasets contained 195 common line segments.

205 Point data results for Dorrery returned a rise in *Sphagnum* cover of 17.5%, from 10.6 to 28.1%. This was very different to results from Dorrery line transects where the initial cover, for a much larger number of samples, was much higher (36.7%) and the increase over time is only 3.1%.

206 Point data suggested a substantial increase which was close to the 14.7% increase found at Causeymire for point data (2004 – 2009). The line data suggested a more reasonable starting cover for peatland which had much less damage than for parts of Causeymire (36.7%). Studies in 2007 (Dargie 2008) at Causeymire suggested that line data was much more reliable, with lower variability, compared to point data. The accuracy of step point cover estimates has also been stressed by Vittoz *et al*. (2010). For that reason the modest Dorrery increase in *Sphagnum* cover of 3.1% is probably the more correct.

207 If 3.1% is the best estimate of cover change at Dorrery (over 4 to 6 years, with most change over 6 years), it is much less than the 14.7% increase in Causeymire point data and 23.2% increase for Causeymire line data for the same time periods. This suggests that the increase at Causeymire is 4 to 7 times larger than the more central Flow Country and might represent more local factors at work creating conditions for substantial *Sphagnum* increase. For example, occult precipitation (fog) could be more frequent at Causeymire as a result of east coast haar conditions. This factor is important in maintaining blanket bog in Newfoundland (Price 1991).

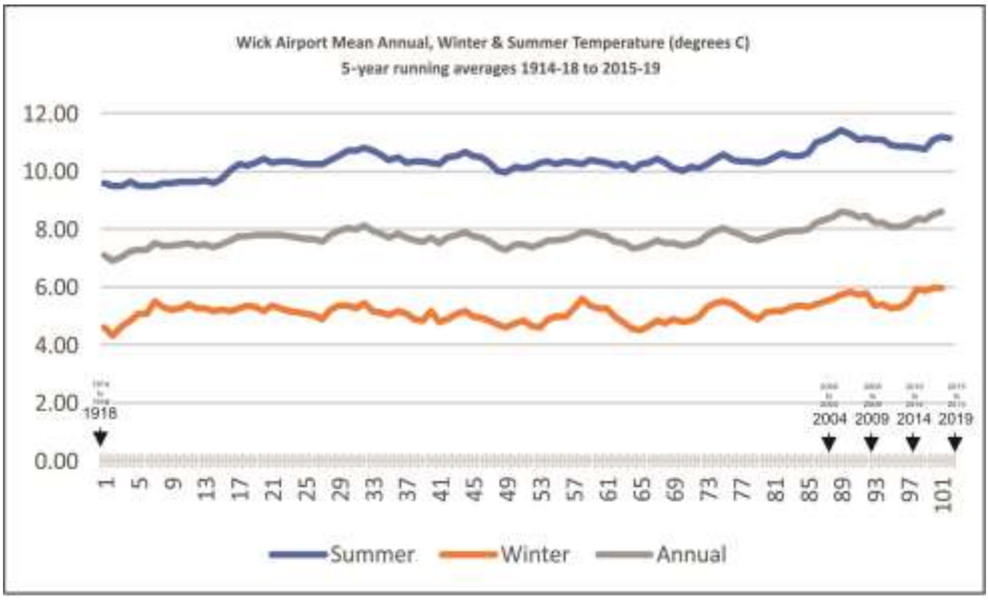
208 The Dorrery and Causeymire areas are, strictly, not comparable. Though similar in size, RSPB does not own or manage ground which is similar to variation at Causeymire (gentle slopes with a main mix of M17-M18-M19 mire, M25 *Molinia* and extensive areas of peat extraction). Moreover, RSPB does not hold land, apart from forested and deforested peatland, which is substantially damaged in parts, as at Causeymire.

209 The climate observations for Causeymire have been reviewed to cover long-term Wick Airport observations up to the end of summer 2019. Temperature trends are also included. Results for 5-year running averages (to smooth inter-year variability) are in Figure 15. Summer values cover April–September and winter January-March plus October-December.

210 Rainfall patterns are dominated by winter rainfall which contains oscillations from the late 1940s onwards. Most of the 2004-2019 monitoring period covers a phase of marked decreasing winter rainfall. Summer rainfall shows a slight increase over the phase.

211 A century of records at Wick shows warming of >1°C for annual, summer and winter graphs, with the period post-1970 showing the strongest rise. There was a slight fall in all temperature graphs for much of the 2004-2014 period, with warmer conditions 2014-2019. Winter temperatures were markedly lower between 2009 and 2014.

212 Cooler conditions 2004-2014 could have been marginally beneficial, judged by modelled average January and July temperatures published for the distributions of individual *Sphagnum* species (Hill *et al*. 2007). The inland and slightly higher location of Causeymire probably produces slightly colder conditions than shown by Wick data.



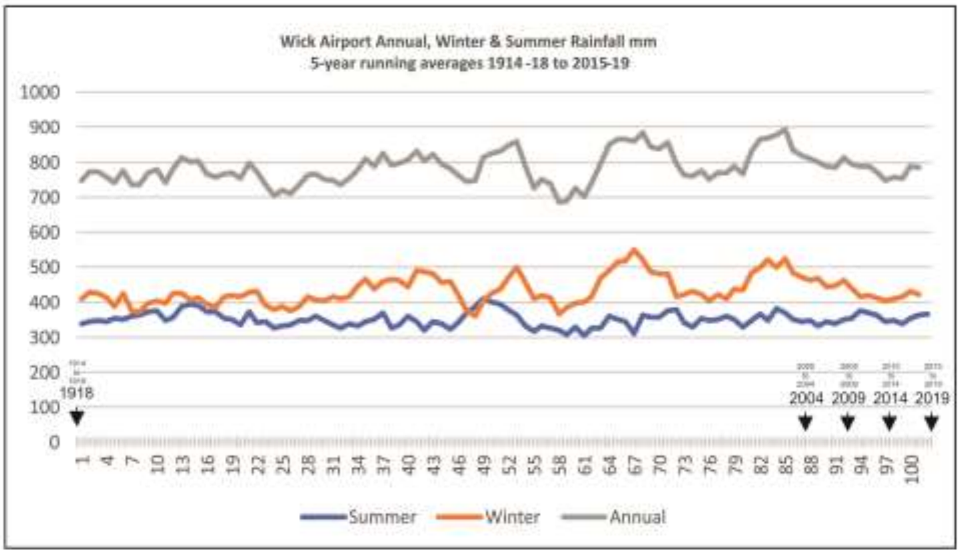


Figure 15 Long-term seasonal and annual temperature and rainfall trends at Wick

213 Lower rainfall at the time of maximum *Sphagnum* expansion is at first sight not favourable. The modelled average annual precipitation values published for the distributions of individual *Sphagnum* species (Hill *et al*. 2007) are much higher than rainfall values for Wick.

214 A different ecological model might operate. This would involve species zonation strongly tied to bog wetness and dynamic species adjustment (self-regulation) as surface wetness conditions changed. This could result in drier-ground species invading and expanding if the Causeymire bog surfaces experienced drier conditions.

215 That pattern agrees quite well with cane frequency intact bog results for *S. capillifolium* (which would increase on higher bog patches) and *S. papillosum* (which would expand on lower ground closer to the average bog watertable). Those increases are shown 2004 to 2019 for both species (Figure 5). There is also a corresponding fall for the wet ground (hollow and pool) species *S. cuspidatum* between 2004 and 2009, the period when the fastest *Sphagnum* expansion took place.

216 Wetter conditions (higher summer rainfall) might explain moderate decreased frequencies for *S. capillifolium* and *S. papillosum* between 2014 and 2019, plus a small expansion in *S. cuspidatum* (Figure 5).

217 These results suggest that regional climate change might be a strong driver of increased *Sphagnum*. However, there are other considerations which suggest climate is not key or things are more complicated. The following additional points, in relation to the possible self-adjusting change above, suggest that other factors might be involved or that the self-adjustment model is imperfect, or that the sampling methodology is imperfect:

- Some change might be driven by climate-related factors, such as increased nutrient inputs to ecosystems via aerial deposition. Bog species are adapted to very low nutritional inputs and increases in nitrogen are known to favour grasses and graminoids, over mosses and dwarf-shrubs. Separately, this has been investigated using the 2001 Macaulay Institute quadrat data. Quadrat locations were revisited and recorded in 2013, comparing those records with the 2001 set. The analysis suggested that increased nutrition had occurred and that nutrition change was stronger than wetness change. This work is part of separate research and is not discussed further.

- There is a slight anomaly in the observed sequences which might be self-adjusting - an increase in *S. cuspidatum* between 2009 and 2014 when rainfall data suggest the bog surface was drier. This is the opposite species response to drier conditions.

- Some other important intact bog species (Figures 4 and 5) fit the drying sequence 2004 to 2014, followed by wetting 2014 to 2019 (*Calluna vulgaris*, *Erica tetralix* Foliose lichens, Other Mosses) but others do not (*Eriophorum angustifolium, E. vaginatum, Molinia caerulea, Narthecium ossifragum, Racomitrium lanuginosum, Trichophorum germanicum*). Adding in *Sphagnum capillifolium* and *S. papillosum* (to good-fit species), half of the commonly-recorded species are good fits but the other half are poor.

- The species specified for recording could be expanded by some additional inclusions (e.g. Wavy Hair-grass *Deschampsia flexuosa*) or splitting aggregates (e.g. Foliose lichens into different *Cladonia* species, Other Mosses into *Hypnum jutlandicum, Hylocomium splendens, Pleurozium schreberi, Polytrichum commune,* Others). It is possible that patterns in the new inclusions would clarify the nature of self-regulation.

218 It is likely that regional climate change would have been noted in bog changes elsewhere in the Flow Country. Similar change elsewhere was not known to RSPB or SNH staff attending meetings to discuss bird and habitat monitoring in 2010 and 2015. The Flow Country has been a major area of research focus over the past decade and the absence of a known regional increase in *Sphagnum* extent carries weight in terms of hypothesis strength.

219 Overall, regional climate seems at best to be a partial driver of increased *Sphagnum.*

HYPOTHESIS 3: WIND FARM EFFECTS ON MICROCLIMATE

220 This hypothesis was originally framed as Velocity Deficit Effects in 2009 reporting and is expanded and modified here to cover possible effects on microclimate within and downwind of the turbine array. There has been further research since 2009.

221 A wind turbine array is designed to capture kinetic energy efficiently from the wind using optimal spacing, converting it into electrical power. In the case of Causeymire, the average wind speed (September 2004 to September 2009, RWE Npower Renewables data) at 10 m height for each of two permanent masts is approximately 20% less than the theoretical modelled 10 m height wind speeds for 1 km grid squares within the wind farm.

222 The reduction in wind speed is termed velocity deficit. There is also increased turbulence downwind, a so-called wake effect, which can disrupt the boundary layer microclimates established close to the ground. What effects do velocity deficit and/or the wake effect have, for example, on the water balance of the bog surface? Have these been sufficient to change the Causeymire water table, producing the marked pulse of *Sphagnum* growth?

223 Detailed studies of the effects of onshore wind farms on micrometeorology are rare. At the time of 2009 reporting there seemed to be none in the UK. Elsewhere, studies based on modelling have been undertaken, with little or no checking of results within or around wind farms.

224 For example, the effects of a massive future expansion of wind farms on a global scale were modelled by Keith *et al*. (2004), concluding that there would be local and large-scale (regional and continental) effects, some of which would be beneficial. These included a diversion of regional wind jets in the Northern Hemisphere causing polar cooling and low-latitude warming.

225 A study in the Great Plains region of the United States (Roy & Pacala, 2004) examined effects on local meteorology and concluded that turbulence downstream of a hypothetical wind farm was more important than velocity deficit, leading to a warming and drying of the surface air and reduced sensible heat flux. The net result was a small increase in evapotranspiration which would produce a slight drying effect. This was most intense in early morning in a continental climate.

226 Offshore wind farm research has produced the clearest actual studies of effects on wind speed, using synthetic aperture radar (SAR) to measure the roughness of the sea surface which is directly proportional to near-surface wind speed. Studies of satellite and airborne SAR data in the North Sea and Baltic, validated by an offshore anemometer mast, show 8-9% velocity deficit at the sea surface immediately downstream of a wind farm, with wind speed reductions continuing for a distance of 5 km under turbulent conditions, to 20 km or more with stable air (Christiansen & Hasager, 2005).

227 The first case for studying the interaction between micrometeorology and the water balance of peatlands, in relation to wind farms, was made around the time of 2014 reporting (Armstrong *et al*. 2014). This was followed by published research on these interactions based on studies at Black Law Windfarm (Armstrong *et al*. 2015; Armstrong *et al*. 2016).

228 The earlier Armstrong *et al*. (2014) study hypothesised, using a review of earlier windfarm-microclimate research, that there would be a velocity deficit downwind night and day, increased turbulence downwind, an unstable decline in near-surface temperature during the day and a stable temperature inversion at night. These conditions should then result in reduced evapotranspiration downwind during the day but the reverse at night.

229 That initial set of changes around one or more turbines was then extended to consider implications for plant productivity, soil carbon and greenhouse-gas emissions, via direct (plant-soil carbon cycling) and indirect effects (changes in plant and microbial communities), plus interactions.

230 The work on microclimate at Black Law (Armstrong *et al*. 2016) involved summer observations before, during and after a six-week shutdown of all turbines (12 June – 25 July 2012). At night air temperature during turbine operation was raised by 0.18 °C, with a rise too in absolute humidity by 0.03 g m^{-3}. There was increased variability in air, surface and soil temperature throughout the diurnal cycle. These changes varied strongly too in space, with change in air temperature and absolute humidity declining logarithmically with distance from the nearest turbine.

231 Microclimate effects on plant productivity, soil carbon and greenhouse-gas emissions were explored in Armstrong *et al.* (2015). For soils, these studies examined temperature, bulk density, watertable depth, peat depth, biomass (standing crop), percent soil carbon, soil nitrogen and carbon : nitrogen ratio variation over four seasons (spring, summer, autumn, winter), four 'site' clusters within the Blacklaw turbine array (A to D progressively located further east-northeast) and three plant functional (PFT) types: shrubs dominated by *Calluna vulgaris* and occurring on hummocks, sedges dominated by *Eriophorum angustifolium* on hummocks and mosses dominated by *Sphagnum* in hollows (but with no discrimination of species).

232 There is a likely error in the paper regarding PFT descriptions: *E. angustifolium* is almost certainly incorrect and should probably be *E. vaginatum*, a notable hummock-former. *E. angustifolium* in wetter blanket bog occurs mainly in hollows and pools and is not common on hummocks. This potential error has been passed to the authors.

233 Carbon cycling effects were examined using measurements or calculation of ecosystem respiration (R, based on dark chamber sampling), net ecosystem exchange (NEE, based on transparent chamber sampling), photosynthesis (P, calculated as NEE minus R), methane production (dark chamber sampling) and dissolved organic carbon (DOC) in soil water samples.

234 Results in Armstrong *et al.* (2015) are complex. They include a mix of clear differences in ecosystem carbon-cycling (between seasons, PFT types and inter-site variation in overall peat depth), modest interaction effects and many non-significant findings. The role of season and PFT is already well-known in the peatland literature on carbon cycling and little that is new is revealed. The role of peat depth variation at Blacklaw is unsurprising but should perhaps have been either minimised by peat probing in advance to locate clusters with minimal variation, or controlled by stratification (different depth classes) as part of a factorial design.

235 One noticeable feature not commented upon by the authors is the amount of blanket bog disturbance at Black Law. For example, there has been extensive forest clearance in the west and north.

236 Using Google Earth (centred at 55.77154 °N, 3.743533 °W) in relation to the turbine map (Fig. 1) in Armstrong *et al*. (2016), there is major regeneration of Lodgepole pine trees (at site A), ground restoration related to former mining (very close to site B), the presence of extensive old bog drainage and perhaps an old mine tramway (at site C) and very extensive ditch blocking (at site D). In the opinion of this author this heterogeneity reflects an unsuitable site for this kind of investigation. The heterogeneity is not reflected in article discussion and is not covered by study design.

237 It is surprising that a map of sample layout is not given in Armstrong *et al.* (2015) in relation to turbine footprint and relief. It is only given in Armstrong *et al.* (2016).

238 The most important element to stress about the 2015 study is that the effects of the windfarm *per se* as a potential modifier of carbon cycling are not examined in the paper. There is no non-windfarm control built into the research and there is no discussion of potential windfarm effects upon the impressive range of examined metrics.

239 This lack of discussion on possible windfarm effects is perhaps not surprising due to the lack of clear differences in results apart from known dominant controls (season, PFT), plus the inter-cluster differences in peat depth, the other dominant control which in turn reflects the role of excessive site heterogeneity.

240 Overall, these published results leave the hypotheses set in Armstrong *et al.* (2014), on windfarm impacts on carbon cycling, unanswered. This conclusion also applies to the role of windfarm impacts on the peatland watertable. At Black Law that is confounded by season and peat depth effects, plus (possibly) major drainage effects due to past and present site management (mining, forestry, land reclamation, blanket bog drainage).

241 With this short consideration of windfarm – microclimate research in mind, particularly the hypothetical impacts in Armstrong *et al* (2014), the following review can be made of possible windfarm effects at Causeymire.

242 The main wind direction in this part of Caithness is a south-westerly air stream, with sufficient variability that there is no predominant sector. On an annual basis most winds are between WNW and SE, with maximum duration for SSE, closely followed by WSW. Winds between N and ESE are of very short duration. Summer winds are predominantly SSE but with long subordinate spells between WSW and NNW. This information is based on direction-only data provided in 2009 by RWE Innogy for research purposes and are not discussed in more detail.

243 Any medium-term effects of these wind streams, operating over several years, will affect habitats downwind from these directions. Results from Armstrong *et al.* (2016) suggest that temperatures and humidity will increase downwind of turbines, but they will fall logarithmically with distance. Complex patterns of temperature and humidity microclimates are likely to result related to the turbine layout, including the effects of several turbines in sequence downwind.

244 Other effects are likely (e.g. complex patterns of evapotranspiration and interactions with the bog watertable related to turbine layout) but these are not quantified in Armstrong *et al.* (2014) and were not examined in Black Law studies. It is uncertain if the diurnal differences, plus velocity deficit and turbulence, would represent, over the course of time, downwind drier or wetter peat surfaces, or downwind lower or higher watertables.

245 The scale of windfarm-imposed temperature change at Black Law under summer conditions was an increase of 0.18 °C. Applied at Causeymire, that is a warming uplift equivalent to the range of temperature change at Wick since 1990, and about 20% of a marked summer temperature increase 1980 to 1990 (Figure 15).

246 These are sizeable uplifts but they might be smaller because the turbine array at Causeymire only allows for 2 – 3 turbines-in-sequence, as opposed to seven (to site cluster C) at Black Law. The research in Armstrong *et al.* (2016) does not examine the cumulative downwind effect of in-line turbines on temperature.

247 In addition, the temperature uplift at Black Law was associated with winds (only at night) from south-southwest and southwest directions. The wider range of wind origins at Causeymire will probably 'dilute' any elevated temperature effect considerably.

248 To conclude, air temperature increases at Causeymire could be markedly lower than the Black Law result. This possibly much reduces the importance of increased temperature as a driver of habitat change and carbon cycle changes at Causeymire.

249 Earlier Causeymire reporting (Dargie 2015) considered that cover patterns for *Sphagnum* (and perhaps other attributes such as Other Mosses) were related in part to velocity deficits and/or turbulent wake effects.

250 The long-term (2004 to 2019) point and line segment results for several habitat variables have change patterns which seem to relate strongly to turbine spacing and distance downwind. These are as follows:

- Live *Calluna* % cover (Appendix 4): within a general increase 2004 – 2019, this species increases strongly over time downwind from W and WSW directions (but with little or no significant change in *Calluna* height), a pattern also seen in cane frequency maps where there is also an observable weaker WNW downwind increase (Appendix 4).
- *Erica tetralix* cane frequency (Appendix 4) shows areas of higher cover migrating 500 metres east within and east of the southern turbine array.
- *Eriophorum angustifolium* cane frequency (Appendix 4) shows only slight change in value over time but there are 500 metre shifts east and south in the locations of higher covers east of the southern turbine array. There is notable loss and reduction to the northwest of the southern turbine array, an area which has seen a strong expansion in *Sphagnum capillifolium* and this might be a decline due to competitive response.
- *Eriophorum vaginatum* in bog habitat has declined between 2004 and 2019, mostly since 2014 (Figure 4) and cane frequency results show this has occurred east of the southern turbine array and within the area of the northern turbines (Appendix 4). Strikingly, these areas of loss coincide with areas of major *Trichophorum germanicum* increase in cane frequencies (Appendix 4). This is perhaps the strongest evidence in all results of competitive displacement between two important sedge species and the locations of displacements are mainly downwind of turbines.
- There are losses and reductions in cane frequency for *Narthecium ossifragum* (Appendix 4) over time close to turbines in the southern array but this species is not common and its sporadic distribution in 2004 and 2019 creates higher-

frequency ‘island’ effects. This, at best, is possibly weak evidence of displacement eastwards.

- Other Mosses % cover (Appendix 4) shows a marked fall in cover eastwards, especially towards bog habitat. In addition, as part of a strong increase overall at Causeymire, it has spread eastwards over time within the southern turbine array. Cane frequency maps (Appendix 4) show the natural eastwards gradient decline in cover more clearly, including higher cover contours migrating roughly 500 metres eastwards within the southern array between 2004 and 2019.
- *Racomitrium lanuginosum* % cover (Appendix 5) and cane frequency (Appendix 4) show new locations and increase in cover east of the southern turbine array, upon intact bog.
- *Racomitrium lanuginosum* hummock frequency (Appendix 5) shows large increases in 2004 values and two large new areas east and south of the southern turbine array.
- All *Sphagnum* % cover (Appendix 4 and Appendix 5) increases strongly over time from lower values in the west to the highest quantities in the east and south. The strength of the increase seems more marked within and east of the southern turbine array as well as south of southern turbines and north of T7.
- Further *Sphagnum* detail is provided in cane frequency results for individual bog-moss species (Appendix 4). There are marked shifts in position over time, moving east and northeast, for *S. capillifolium.* The major expansion in the south mainly involves *S. papillosum,* with a local rise here too in *S. cuspidatum*. These increases seem associated with the southern eccentric raised bog. *S. papillosum* is also involved in higher bog-moss cover around the more northern of the dubh lochan area east of turbines. These species mappings also confirm that most *Sphagnum* cover and major change over time is associated with *S. capillifolium*, with *S. papillosum* important more locally in wetter bog conditions.

251 The map patterns summarised above allow a stronger interpretation of microclimate-induced habitat change at Causeymire than was possible in earlier reports. The following drivers might underly the changes observed:

- **Driver 1: Increasingly dry conditions over time** The strongest evidence of this is the expansion east of Other Mosses into the southern turbine array. Most species in this aggregate (*Hylocomium splendens, Pleurozium schreberi, Hypnum jutlandicum*) are indicators of drier surfaces in bog habitat. Other Mosses expansion as high cover is not confined to that area and there might be a regional drying effect, amplified by turbine microclimate effects. The expansion in *Calluna vulgaris* might also be driven by drying, but affecting its performance on bog habitats, further east than the Other Mosses increase. Further corroboration comes from the decline over time in *Narthecium ossifragum* (a wet ground indicator for bog conditions) and especially the expansion of *Racomitrium lanuginosum*. The latter species is a known indicator of drier bog conditions in published research on phases of Postglacial climate deterioration.
- **Driver 2: Self-adjusting competitive processes** Quite complex self-adjusting processes are known for bog vegetation, driven mainly by medium-term variation in the underlying watertable and the thickness of the aerated upper layer above, termed the acrotelm (Belyea & Clymo 2001).

- At its simplest self-adjustment involves expansion of wetter, lower habitats of the bog vegetation mosaic if the watertable rises and the reverse (higher habitat expansion) if the watertable falls. In the plant functional type PFT model of Armstrong et al. (2015), upper levels are characterised by *Calluna vulgaris* and *Eriophorum vaginatum* (not *E. angustifolium*, as stated in the paper), with *Sphagnum* bog-moss representing lower levels.
- Those PFT types are too simplistic for Causeymire bog surfaces and the following zonation from low to high levels is more accurate: *Sphagnum cuspidatum* hollows and small pools (with some *Eriophorum angustifolium* and *Narthecium ossifragum*) → *S. papillosum* lawns → *S. capillifolium* hummocks → a complex mosaic of *Calluna vulgaris* over *S. capillifolium* on hummocks plus tussocks of *Eriophorum vaginatum* or tufts of *Trichophorum germanicum* → *Racomitrium lanuginosum* hummocks as highest local relief.
- Drying at Causeymire has perhaps been expressed, via self-adjustment, as shifts from right (dry) to left (wet) in that sequence, with drier conditions increasing overall. The shifts might occur at a range of scales, over 10-20 metres and perhaps up to 500 metres, judging from some of the spatial shifts seen in map analysis.
- The above zonation covers the range of surface conditions present on intact bogs. Areas which are not intact and have been subject to historical drainage have a more limited range. They generally lack *S. papillosum* lawns and surfaces with *Trichophorum germanicum* and *Racomitrium* hummocks.
- The most extensive self-adjustment changes have involved 2004 ground with *Eriophorum vaginatum* dominant and patchy *Sphagnum capillifolium*, changing to *Trichophorum germanicum - S. capillifolium* co-dominant east of the southern turbine array and *E. vaginatum – S. capillifolium* co-dominant within that array. These three zonation elements occupy similar (high) levels in local zonations. Their partial separation into western and eastern re-combinations might represent a microclimate difference imposed by distance downwind from turbines, expressed only within the higher ground of local zonation.

252 Habitat change is not fully explained by these two drivers. There are anomalies and complications which cannot be accounted for, including the following:

- The separation has taken place roughly either side of a line dividing the Bad a Cheo higher plateau (with *T. germanicum – S. capillifolium*) and bog ground sloping gently to the west (with *E. vaginatum – S. capillifolium*). The difference in slope might be important in understanding separation, perhaps via watertable characteristics. No information is available regarding watertable variability.
- Surprisingly, there is very little UK ecological research which identifies differences in habitat preference between *E. vaginatum* and *T. germanicum*. Their UK distributions within blanket bog are very similar, producing wetness, acidity, nutrient, temperature and precipitation averages which hardly differ (Hill *et al*. 1999; Hill *et al* 2004). Each is associated with specific communities in the National Vegetation Classification (Rodwell 1991): M19 and M20 for *E. vaginatum* covering mainly upland blanket bog and M17 (for both species) which has a general western oceanic distribution at lower altitude, with higher rainfall. There is much overlap between these NVC types.

- Of the two, on the basis of NVC community distributions, *T. germanicum* might prefer wetter conditions with less variability in bog watertable. This distinction fits the separation seen at Causeymire with wetter conditions downwind and more distant from turbines, perhaps with a less variable watertable due to little slope.
- However, the very clear survey-on-survey expansion of *T. germanicum*, largely restricted to intact bog, does not explain why favourable ecology (wetter conditions on the Bad a Cheo plateau) had not allowed *T. germanicum* dominance prior to windfarm construction.
- The largest misfit for drier conditions since 2004 concerns *Sphagnum* quantity. Notable increases in *S. capillifolium* and *S. papillosum* between 2004 and 2019 suggest at first progressively wetter, not drier, conditions. Both species have habitat preferences which are close to *E. vaginatum* and *T. germanicum*.
- Using Ellenberg values for moisture (range 1 extremely dry to 12 permanently submerged under water), soil acidity (1 extreme acidity to 9 basic reaction, always on calcareous soils) and nutrition (1 extremely infertile sites to 9 extremely rich situations), the published UK scores of these simple habitat preference scales are: *E. vaginatum* (8, 2, 1), *S. capillifolium* (7, 2, 1or 2), *S. papillosum* (8, 1, 1), *T. germanicum* (8, 1, 1) (Hill *et al*. 1999; Hill *et al*. 2004; Hill *et al*. 2007).
- Expansion of *S. capillifolium*, with a slightly drier preference of 7, fits the drier conditions hypothesis but increased extent has occurred in areas of expansion and contraction for both *E. vaginatum* and *T. germanicum*. There is no simple zonation shift to drier conditions shown by changes in the distribution and quantity of all four species.
- These anomalies are important and reduce confidence in the hypothesis considering windfarm-induced modifications to microclimate, specifically drier conditions over time downwind, close to turbines.
- The hypothesis in 2019 is the reverse of that posed in reporting of 2009 and 2014 survey. That earlier work suggested wetter conditions since 2004 on the basis of just *Sphagnum* expansion. The multiple species changes observed in 2019 results suggest that earlier support for wetter conditions was incorrect, but at the same time does not itself fully support drier conditions with high confidence.

HYPOTHESIS 4: RECOVERY FROM A DAMAGED STATE

253 This RSPB proposal as a hypothesis (made in 2010) considered historic burning or over grazing to be responsible for a damaged state, with subsequent management, from 2004, allowing recovery of *Sphagnum* to values more typical of healthy blanket bog in the eastern Flows. The RSPB case included a reduction in Heather condition and height due to burning and Heather beetle damage, allowing *Sphagnum* to increase as a result of reduced shading by a Heather canopy.

254 The evidence for burning, over-grazing and a damaged state prior to windfarm construction was reviewed in reporting on 2009 results and considered implausible. The review considered 2004 and 2009 evidence for heavy grazing, Heather condition and the nature of *Sphagnum* cover increase. Causeymire evidence simply did not fit the RSPB case, with Heather cover increasing in bog conditions which experienced two

orders of magnitude of high-cover *Sphagnum* expansion (ground with >50% *Sphagnum* increasing from 2.2 ha to 292 ha in only five years)

255 This hypothesis is not strengthened by knowledge gained since 2009 reporting. Evidence of grazing suggests that there have been sharp falls in livestock units since 1996 (Figure 12b) and further reductions since. The timing of reduced grazing pressure does not fit observations on *Sphagnum* cover and the timing of increases. In particular, Macaulay Institute data on *Sphagnum* cover in 2001 (15.1%, average for 72 quadrats)) is very similar to the baseline cover in 2004 for the same part of the HMSA (14.7%, 57 point records) , with very rapid increases occurring thereafter in the following sequence 29.4% (2009) → 35.8% (2014) → 32.5% (2019). There is no substantive evidence for a major change in grazing at the same time as the start of a sharp increase in *Sphagnum* cover (2004/5).

256 As in 2009 reporting, this hypothesis is considered weak.

CONCLUSIONS ON SPHAGNUM EXPANSION

257 This review of available evidence in relation to four hypotheses can be summarised as follows:

- **Hypothesis 1 Reduced grazing pressure**: Increased *Sphagnum* does not coincide with the timing of lighter grazing pressure and areas with both higher and low grazing pressure overlap with high *Sphagnum* cover. This is poor correspondence and represents a weak hypothesis.
- **Hypothesis 2 Changing regional climate**: There is no evidence of a notable change in temperature at Wick between 2004 and 2015. However, winter rainfall shows a fairly consistent fall in that period, sufficient to maintain a drier peat surface for longer periods of time. Summer rainfall is much more important (particularly as a driver of carbon-cycling processes) but there is no trend 2004 – 2019. Overall, there is only slight evidence of recent change in regional climate and that is probably insufficient to affect *Sphagnum* growth. This too is a weak hypothesis.
- **Hypothesis 3 Wind farm effects on microclimate**: Published research from a windfarm established on Scottish peatland has recently demonstrated that turbines produce a maximum rise in summer night temperatures up to 0.18 °C and a slight increase in humidity, with a logarithmic rate of decline in difference downwind. The research did not examine all hypotheses stated in an earlier paper and studies on impact upon carbon-cycling at the research site found no windfarm effects. Carbon-cycling processes were affected strongly by season, plant functional type and site position within the windfarm, reflecting uncontrolled peat depth variation. The increased temperature effect is considered to be notably smaller at Causeymire due to a smaller array and a wider range of predominant winds. Patterns of change in monitored variables 2004 to 2019, displayed as maps, suggest quite strongly that there is a windfarm effect on several important species, particularly in relation to the southern turbine loop. There are quite complex increases, declines and spatial displacements. Taken together they suggest that peatland immediately downwind of turbines is drier, with self-regulated adjustment suggested as the mechanism producing changes in mapped patterns over time. There are anomalies in this hypothesis which need clarification. This is the strongest of all hypotheses but it would need considerable further research to

be confirmed. At best it can only be considered a possible explanation for major *Sphagnum* increase.

- **Hypothesis 4 Recovery from a damaged state**: This RSPB hypothesis was tested in reporting on 2009 monitoring. The explanations suggested for *Sphagnum* increase did not fit Causeymire information on multiple factors regarding potential damage (burning history, grazing pressure variation over time, Heather condition) when compared with information on the scale and location of *Sphagnum* increase for ground holding >50% *Sphagnum* cover (from 2.2 ha in 2004 to 297 ha in 2009, an increase of more than two orders of magnitude) and the sudden initial start of major increase in *Sphagnum* (after completion of windfarm construction). This poor correspondence with Causeymire information represents a weak hypothesis.

3.5 Habitat condition of turbine bases, hard standings and road verges

3.5.1 Background

258 The final stages of construction and the start of the operational phase in 2004 involved the initial restoration of four main types of ground:

- Backfilling of turbine bases;
- The addition of slab peat as a dressing to the surface of many hard standings;
- The laying and turfing of peat as road verges alongside the floating roads within the main turbine array, immediately along one side but delayed on the other until cable laying in a verge trench was complete;
- The clearance of a site compound located near to the A9 site entrance, retaining its stone cover as a surface similar to a hard standing.

259 After backfilling, turbine bases were left to undergo natural regeneration via habitat successions based on local plant sources. No systematic coverage of progress for the regeneration process was undertaken before May 2010.

260 The initial dressing of many hard standings with slab peat was noted in 2005 as largely unsuccessful due to drying and cracking. The original specification was for loose peat to be thoroughly mixed with coarse angular stone chippings, to form a stone-surfaced mulch which would gradually be colonised by acidic grassland and dry heath. That peat and stone mix was not supplied.

261 The non-parking areas of selected hard standings were dressed with fresh peat and then hydroseeded in mid-summer 2006. Survey in July 2006 showed that some hard standings had developed quite a high vegetation cover, with all cases having >5% cover having an average of 13.2% (Dargie 2007). Peat dressing was applied to hard standings with <5% vegetation cover (T1, T2, T9, T10). Hydroseeding used a mix of bog and heath species, including *Calluna vulgaris* and fragments of *Sphagnum* and lichen collected and prepared at Farr Wind Farm. This was applied to fresh dressed peat, as well as to other ground: some restored turbine bases and short sectors of roadside verge with low cover.

262 The initial four hard standings dressed in 2006 were recorded by photography in January 2007 and January 2008. No other systematic coverage of progress for the regeneration process has been undertaken. A first account was presented in the report on 2009/10 work, based on survey in May 2010. This is repeated here based on survey in September 2014 and August 2019.

263 No systematic coverage of progress for the regeneration process upon road verges or the former site compound has been undertaken. A first account was presented in the report on 2009/10 work, based on survey in May 2010. This is repeated here based on survey in September 2014 and August 2019.

3.5.2 Fieldwork in 2010, 2014 and 2019

264 The May 2010 survey work was planned for January that year but a bad winter prevented fieldwork until spring.

265 A rapid visual estimate survey was undertaken of all turbine bases, vegetated hard standings and selected road verges. Each turbine base was walked and estimates made of percent cover for key plant species (e.g. *Eriophorum vaginatum*) or species groups (*Sphagnum* species typical of very wet or aquatic conditions, *Sphagnum* species typical of wet to very damp conditions). Estimates of bare peat, stone and standing open water were also made. Any trampling damage by cattle was also recorded. A single photograph across a representative range of base conditions was taken. The range included dry raised ground close to the turbine tower, any depression holding water in winter, plus concave slopes above, as well as slopes around turbines located on plinths well above the adjacent peat.

266 The same approach of visual estimate survey was applied to vegetated hard standings.

267 Verges were sampled by driving to a visually representative location between a pair of turbines. A GPS grid reference was taken in the road centre. The road verge on each side of the road was then walked carefully for 15 metres, making visual estimates of percent cover for key plant species and species groups. Bare peat cover was also estimated, as well as the presence of any trampling by cattle. A photograph along the verge on each side of the road was also taken.

268 The turbine base – hard standing recording system was used at the former site compound.

269 The visual estimates work was repeated in September 2014 and August 2019. Cover records for turbine bases, hard standings and the former site compound are given in Appendix 6a. The 2014 visual estimates of cover for road verges are given in Appendix 6b. The photographic record for the above infrastructure is presented in Appendix 7. This is organised mainly by increasing turbine number (21 turbines, T1 through to T24, with turbines 11, 12 and 13 not constructed). Road verge photographs (e.g. the samples between T1 and T2) are inserted in the above sequence, with each verge pair on a single page to allow comparison.

3.5.3 Habitat condition of turbine bases

270 Habitat enhancement work on restored turbine bases has mainly used natural regeneration via habitat succession to allow vegetation development, together with some hydroseeding in 2006 for bases with vegetation cover <50%. Vegetation cover was very high (>70%) in January 2008 for most turbines except those with a depression around the turbine tower. Seasonal flooding or very damp conditions were occurring in these depressions and slowing down vegetation development, particularly at T20 and T24. The depressions arose as a result of local structural failure of the constructed floated road across deep peat. The road sank substantially, taking it well below the level of the adjacent peat bog surface. Base formation then seems to have been set at 1 – 2 metres below the adjacent bog level, to allow for lower levels of road and crane hard standings.

271 The average percent cover scores for turbine bases are given in Table 5. Photographs of turbine bases are in Appendix 7.

272 Vegetated ground made up about 91% of the average base in 2015 and 98% in 2019. Residual bare ground in 2019 was present as bare peat with scattered stone small areas of standing water.

273 The area of standing water is likely to be higher in winter when groundwater levels are at their highest. The several turbines sited in shallow basins below the level of the surrounding mire have vegetation consistently dominated by Common Cottongrass *Eriophorum angustifolium*. Some ground is similar to the National Vegetation Classification (NVC) type M3 *Eriophorum angustifolium* bog pool community. High covers of M3 vegetation mark areas with winter flooding. The NVC type often becomes dry in summer, as in these turbine base depressions. The extent of *E. angustifolium* has reduced since 2010 and it has probably been replaced by Soft Rush *Juncus effusus*. The latter species has expanded considerably since 2010 (from 15 to 23%).

274 Cattle trampling evidence is present now in almost all bases (only T10 and T24 did not have it in 2014 and again in 2019). Poached ground and occasional dung are occasional to frequent on most bases. No cattle were grazing on open ground at the time of survey and the closest herd was adjacent to the River Thurso.

275 As in 2010, poached peat soils were particularly visible for bases raised above the general level of the surrounding peatland beyond the original deep excavation (turbines 17 and 21). Hare's-tail Cottongrass *Eriophorum vaginatum* had established well here but stock poaching and dunging has allowed rush and grasses into the sward. Little *E. vaginatum* remained in 2019. Without cattle trampling and nutrient inputs it is possible that dry forms of blanket bog vegetation would develop in these raised base areas but this will not occur due to grazing.

276 Some of the bare peat cover in base depressions was maintained by cattle trampling damage but this effect was never severe in 2010, 2014 or 2019. A more subtle effect of cattle is the import of nutrients into these winter-wet depressions via dung and urine. The surrounding peatlands are very poor in nutrient levels and are mainly rain-fed. In addition, groundwater around bases will have changed chemistry due to bedrock and base concrete effects. It takes only modest additional nutrient additions to create conditions which favour acidic rush pasture and this is shown by the high average vegetation covers for Soft Rush *Juncus effusus* (23%, up from 15% in 2010) and the combination of grasses, sedges (particularly *Carex nigra*) and herbs (31%, up from 19%). *J. effusus* is a very effective colonist of disturbed areas, particularly poached ground.

277 The dampest ground rarely supports *Sphagnum* growth and this is probably the result of marginally high nutrient levels. There are *Sphagnum* occurrences where runoff from the surrounding bog supplies water sufficiently poor to support patches of *S. papillosum, S. capillifolium* and *S. tenellum*. Elsewhere the common wet ground pleurocarpous mosses are *Warnstorfia fluitans* and *Calliergonella cuspidata*, typical of more nutrient-rich conditions.

278 The main habitat condition benefit achieved so far is a high vegetation cover. The quality of vegetation developed to date is not outstanding and this is the result of a combination of varied elevations of turbine base construction (some too high, others too low) and its interaction with cattle grazing. A depression receiving cattle nutrients in dung and urine is a trap for nutrients.

279 Large areas of exposed peat with little vegetation cover remain present in the bases at T6 and T9. These seem to dry out strongly in summer but are very wet in winter, creating very difficult establishment conditions which are worsened by trampling effects.

280 The aim of base habitat restoration should be to establish and maintain vegetation types which are typical of nearby semi-natural conditions. Most bases are located within M17 blanket bog but this has not proved possible due to the topography of backfilled bases and cattle grazing.

Table 5 Average percent cover scores for turbine bases, 2010, 2014 and 2019 (Data source: Appendix 2a in Dargie (2015) and Appendix 6a in this report)

Species and species sets	Backfilled Bases May 2010	Backfilled Bases Sept 2014	Backfilled Bases Aug 2019	Vegetated Hard Standings May 2010	Vegetated Hard Standings Sept 2014	Vegetated Hard Standings Aug 2019
Acrocarpous moss %	5.7	6.9	2.3	6.6	8.3	6.6
Sphagnum cuspidatum, denticulatum, fallax %	0.6	3.1	9.2	0.0	0.0	0.0
Sphagnum capillifolium, papillosum %	1.2	2.0	0.8	0.0	0.0	1.4
Pleurocarpous moss %	5.9	10.6	11.1	4.1	5.6	8.6
Juncus effusus, other *J.* spp. %	14.6	20.3	23.1	3.3	2.9	2.6
Grasses, sedges, herbs %	18.5	20.0	30.5	34.2	38.5	33.0
Eriophorum vaginatum %	10.5	7.3	3.2	0.0	0.0	0.0
Eriophorum angustifolium %	19.4	17.7	12.8	0.0	0.0	0.0
Calluna vulgaris, Erica tetralix, Empetrum nigrum %	0.5	3.6	4.6	2.9	3.5	12.9
Bare peat %	17.9	5.4	1.1	26.7	17.4	11.7
Stone %	3.5	1.5	0.3	13.1	23.9	23.5
Open water %	1.8	1.6	1.0	0.0	0.0	0.0

3.5.4 Habitat condition of hard standings and former site compound

281 Dargie (2008) considered that a sample of hard standings was representative for the site. In 2008 vegetation cover ranged from 5 – 10% (recently peat-dressed) to 90% cover at T4. Excluding the recently-dressed cases, the average vegetation cover (January 2008) was between 30 and 40%, up from 13% in July 2006. Each hard standing was undergoing a rapid vegetation succession and over time percent cover was predicted to increase as a logistic (S-shaped) curve. Initial establishment (over 1 to 2 or 3 years) seemed slow and poor, followed by a rapid (near-exponential) phase of colonisation with cover usually more than doubling each year. This would then be followed by a slowing down as near-total vegetation cover (90% or more) was approached and the structure of a plant community developed as a result of more intense competition between key dominant species.

282 It was predicted here that all untreated vegetated hard standings at Causeymire would probably have at least 90% cover in 2009 (if monitored in January 2010). There was less certainty for turbine areas with slab peat treatment (2004) and freshly-dressed peat (2006), but some should have achieved 40% cover in 2009 (if monitored in January 2010).

283 The hydroseeding component of hard standing treatment in 2006 had not been very successful in 2014 and that remained the case in 2019. It has been particularly disappointing around turbines with freshly-dressed peat (at T1, T2, T9 and T10). The explanation is simple: grazing and trampling by both cattle and deer seem to have removed seedlings and destroyed the stable surface which is probably needed by other propagule material.

284 On the basis of results in 2008, the most rapid means of obtaining a high vegetation cover was to leave the stone surface untreated and allowing cattle feeding on that ground. However, it was predicted that the likely dominant vegetation would be acidic grassland, with or without a rush component. That has proved correct, although grasses only made up 39% of cover in 2014 and that had declined to 33% in 2019. A modest proportion of grass cover is now replaced by slowly expanding dwarf-shrub heath dominated by Heather (13% cover, up from 4% in 2014).

285 The composition and cover of vegetated hard standings is summarised in Table 7, with individual results in Appendix 2a. The predicted 90% cover made in 2008 has not been achieved. More than 40% of vegetated hard standing was still bare peat and stone in 2014 and vegetation cover has struggled to 65% in 2019.

286 Stone cover had increased substantially to 24% in 2014 because some hardstandings have been re-levelled and dressed with new stone, to allow major crane operations. That proportion remained as stone in 2019. The hard surface has minimised cattle effects and this probably explains a low cover for *Juncus effusus* (3%). the low dwarf shrub cover established (3-4% for *Calluna* and other dwarf shrubs in 2014, rising to 13% in 2019) is disappointing and is probably the result of cattle browsing and trampling, with nutrient levels from dung and urine favouring grasses and herbs.

287 Reporting since 2012 has recommended that no further enhancement of hard standings is attempted, to minimise site preparation for mobile crane operations. Natural regeneration should be used as the only means of habitat development for these surfaces.

3.5.5 Habitat condition of road verges

288 In 2008 habitat enhancement work on road verges was recorded as much more successful than hard standings. Most of the road verges had near 100% cover already, the result of employing turfing as the main technique in building and finishing roads at the very end of construction.

289 The only area in 2008 with a lower cover was on the top of dry rises formed by expressed peat for a sunken stretch of floated road between the T10 junction and T24 on the eastern side of the main circuit. This was hydroseeded in 2006 and there was reasonable Heather growth in 2008. Interestingly, this sector of the turbine array seems only lightly grazed and lack of heavier grazing has probably allowed Heather seedling establishment and growth.

290 The average scores for vegetation cover in 2010, 2014 and 2019 are given in Table 8. Individual verge results are given in full in Appendix 6b.

291 Verge habitat condition is determined by two factors:

- Adjacent habitat types (recorded in the field), which provide propagule sources for plant establishment. In some cases these were used to extract patches of turf to start restoration in 2004. Two main mire types were noted – M17 *Trichophorum germanicum – Eriophorum vaginatum* mire and the M25 *Molinia caerulea – Potentilla erecta* community. The M17 was recorded for 32 samples, with M25 in the remaining 10 samples. The M25 type frequently graded to M6 *Carex echinata – Sphagnum fallax/denticulatum* rush flush, which is the likely source of much of the *Juncus effusus* at Causeymire.
- Cattle trampling plus nutrient enrichment, which affects vegetation strongly as stock move around the site following tracks. Indeed, cattle generally walk on the softer, non-stony ground in preference to the stone track. Poaching damage was frequent in 2010, 2014 and 2019 (despite no cattle on site in preceding weeks). Ground without cattle trampling was rare in 2019 (between T9 and T10, T24 and T20), along the eastern road of the southern array.

292 Species composition relates to both adjacent habitat and cattle effects.

293 Verges adjacent to M17 mire had high average covers for *Eriophorum vaginatum* and *E. angustifolium* in 2010, compared to M25 samples. Both have declined markedly (13-26% to 4-5% cover). This is mainly due to a strong expansion of *Calluna* (6% in 2010 to 26% in 2019), suggesting that verge conditions are becoming drier, allowing it to replace the cottongrass species. There has also been a notable increase in Grasses-sedges-herbs (8% to 30% in 2019), again at the expense of typical M17 species. This latter increase is more likely to be due to grazing, rather than drying.

294 Conversely, samples beside M25-M6 habitat have high covers for *Juncus effusus* and the combination Grasses-sedges-herbs (which includes Purple moor-grass *Molinia caerulea*), both of which are much higher than their M17 averages. The grass-herb component has increased from 52% in 2010 to 62% in 2019, mainly at the expense of *J. effusus* which expanded strongly (17 to 27%) by 2014 but has since declined to 22%.

295 Cattle trampling is found in the majority of samples and initially promoted a higher cover (Table 8) for *Juncus effusus* but that had declined to 12% in 2019. Grasses-sedges-herbs have steadily increased 24 to 41% cover between 2010 and 2019, aided by

grazing. The decline in *Juncus effusus* and an increase in Heather (3 to 17% cover) suggest that drier conditions have developed on verges over the past decade.

296 Non-trampled verges, all with M17 vegetation adjacent, had notably higher covers (48% cover) in 2010 for *Eriophorum vaginatum* and *Eriophorum angustifolium* but these have declined since (8% cover in 2019) and these species have been replaced mainly by *Calluna vulgaris* (51% cover in 2019), probably as a response to increased drying over time adjacent to the road.

297 Cattle and drying have modified an important feature of road verges along the inner road edge: a fringe of *Calluna vulgaris*. This developed initially as a result of indirect drainage and drying of the peat by the adjacent floating road. The fringe started as a narrow zone rarely more than 1 – 1.5 m in width which formed over a period of about 5 years (*Calluna* had only low cover in most turf used for verge construction except on the western side of the southern turbine array). *Calluna* is now spreading over a wider zone within the verge and is evidence of progressive drying over time away from the wind farm road.

298 There is a continued major debate in progress on the drying impacts of wind farms, particularly the role of roads. Opponents of wind farms consider that drying impacts spread for up to 100 m around infrastructure and in some cases, on drained steep slopes, for hundreds of metres (see examples in Nayak *et al.*, 2008, none of which have been confirmed by research within wind farms).

299 The examples of drying forming at Causeymire are real cases and observation so far suggests that substantial drying has only affected the verge width (which is rarely more than 7 m at Causeymire).

300 However, there might be more complex drying patterns within the wider bog expanse, possibly driven by a drier microclimate downwind of turbines (see section 3.3.2). This has involved a major unexplained increase in *Sphagnum* (mainly *S. capillifolium*) and is very different drying effects on verges.

301 The quality of the *Calluna* fringe was poor in 2010 due to very extensive Heather beetle damage and a winter with much snow. Heather condition was better in 2014 and 2019, with quite strong Heather growth and little recent damage.

Table 8 Average percent cover scores for sampled road verges: 2010, 2014 and 2019 (Data sources: Dargie (2015) and Appendix 6b in this report)

Species and species groups	Adjacent to M17 (n=32) May 2010	Adjacent to M17 (n=32) Sep 2014	Adjacent to M17 (n=32) Aug 2019	Adjacent to M25 (n=10) May 2010	Adjacent to M25 (n=10) Sep 2014	Adjacent to M25 (n=10) Aug 2019	Trampled (n=32) May 2010	Trampled (n=34) Sep 2014	Trampled (n=38) Aug 2019	Non-trampled (n=10) May 2010	Non-trampled (n=8) Sep 2014	Non-trampled (n=4) Aug 2019
Trichophorum germanicum	0.6	1.0	0.8	0.1	0.1	0.01	0.4	0.8	0.6	0.9	0.6	0.0
Eriophorum vaginatum	25.7	17.7	5.0	2.0	0.8	0.0	18.9	13.5	3.8	23.8	14.6	3.8
Eriophorum angustifolium	12.9	8.9	4.1	1.2	0.6	0.0	5.8	5.4	3.0	24.0	13.6	4.3
Calluna vulgaris	6.1	18.3	26.1	1.6	2.3	0.2	2.7	9.2	16.7	12.5	37.1	51.0
Juncus effusus	4.8	8.0	7.7	17.1	27.2	22.1	10.1	15.6	12.3	0.2	0.1	0.3
Erica tetralix, Empetrum nigrum	2.4	3.6	1.9	0.0	0.5	0.0	1.2	2.4	1.3	3.7	4.9	3.0
Pleurocarpous moss	12.9	14.4	17.6	16.3	13.7	15.2	15.6	14.6	16.1	7.5	12.9	25.5
Grasses, sedges, herbs	8.2	17.0	29.6	51.6	51.3	61.7	23.9	30.4	41.1	1.5	3.1	1.0
Polytrichum moss	1.5	1.4	1.2	0.1	0.0	0.0	0.5	0.8	0.8	3.2	2.3	2.3
Sphagnum moss	1.0	3.5	3.6	0.0	0.5	0.0	0.8	2.5	2.5	0.8	3.9	5.3
Lichens	0.6	0.4	0.9	0.0	0.1	0.0	0.6	0.3	0.4	0.0	0.4	3.0
Acrocarpous moss	5.6	3.1	0.5	1.6	1.0	0.2	3.8	2.0	0.5	7.3	5.1	0.0
Bare peat and stone	17.7	2.6	1.1	8.4	2.0	0.6	15.7	2.7	1.0	14.6	1.5	0.8

4 Conclusions

302 Monitoring has focussed on several subjects: a northern Habitat Enhancement Area; drain blocking to protect large bog wetlands east of turbines plus impacts on blanket bog surface drainage around turbines and tracks; reducing grazing pressure over a wide area around the windfarm; tracking habitat condition over a large area around the windfarm footprint plus turbine bases, hard standings and road verges.

303 **Habitat Enhancement Area (HEA)** This was a small (7.7 ha) electric-fenced field in the north of the HMSA where remedial measures aimed to provide Heather 50 cm tall which might attract breeding raptors. The site was well away from the risk of turbine collision. In addition to largely excluding deer, a poorly-growing conifer plantation was removed from the HEA and fertiliser applied to higher dry ground in an attempt to increase Heather height. A 10 cm rise in height was achieved between 2004 and 2014 (21 to 31 cm, 50% increase), notably more than Heather height on equivalent habitat elsewhere (19 cm, little change over time). Discussion of 2014 reporting agreed that a 50 cm target could not be achieved, mainly due to the wet condition of the much-disturbed blanket bog. The target was too ambitious. There have been other notable habitat benefits in the HEA, including the elimination of bare peat by 2019 and a fourteen-fold increase in the percent cover of *Sphagnum* since 2004 (3% to 43%). Tree removal probably contributed to the large increase in *Sphagnum* cover between 2004 and 2019. Overall, HEA condition is much better in 2019, compared to 2004.

304 **Drain blocking and track drainage** Selective drain blocking was completed in 2004, to prevent headward erosion extending east towards very fine dubh lochan and bog pool systems east of turbines. This has been particularly successful in the area of Turbine 6, re-wetting former pools which seem to have been part of a damaged (drained) eccentric raised bog, a rare bog-type in Britain. Restoration at Causeymire is probably the first documented case for an eccentric bog in Britain and this is a major benefit which deserves wider publicity.

305 Up to 2014, drain blocking was considered a successful enhancement, based on visual checking of blocked drain integrity. Survey in 2014 of a wider drainage network installed in the 1950s found evidence for widespread drying of ditch conditions close to windfarm roads. This was due to faulty culverts.

306 In addition, impacts from one sector of the windfarm floated road and new ditches installed to drain two turbine bases have resulted in complete loss of *Sphagnum* from pre-windfarm ditches. These were choked with *Sphagnum* in a walkover survey undertaken in 2004. This is disappointing but effects were localised. Impacts in the operational phase were not anticipated in the Causeymire EIA.

307 **Reduced habitat grazing pressure** The main method of habitat enhancement proposed in the EIA was a reduction of grazing. This was implemented successfully, first by reducing and then, from 2009, eliminating sheep grazing. Cattle numbers have been maintained or increased to control the height of tall vegetation in fen and wet grassland habitats. Deer numbers are controlled via stalking.

308 Cattle grazing impacts are largely confined to fen habitat, marshy grassland and the verges of windfarm tracks. There is field evidence for an increase in grazing pressure from deer between 2004 and 2019. Overall, there has been marked reduction in grazing, particularly for the most sensitive and important habitat, blanket bog. Much bare peat is

the result of excessive grazing and that has fallen dramatically since 2004 and is now rare except in areas of former commercial peat extraction.

309 **Overall habitat condition and change** The RSPB monitoring method shows large improvements in the extent of several indicators of good bog condition and breeding bird habitat, particularly increased cover for Heather and Bog-moss *Sphagnum*. There is considerable overlap in the locations of the increases, suggesting they have occurred together over much of the bog within, around and distant from the windfarm. The increase in *Sphagnum* is particularly large on both drained and undrained blanket bog.

310 Using the 2019 monitoring area of 946 ha and average percent *Sphagnum* cover, extent has increased remarkably from an initial 2004 baseline figure of 11% (115 ha), rising to 48% (452 ha) in 2019. The 337 ha of recent *Sphagnum* establishment is concentrated in drained and undrained blanket bog which now have covers of 55% and 74% respectively.

311 *Sphagnum* cover values are strongly skewed. Median percent cover values are a more accurate measure for estimating extent and the equivalent figures are a 2004 baseline of 8% (75 ha), reaching 46% (434 ha) in 2019. This estimates *Sphagnum* cover increase as 359 ha. In 2019 drained and undrained bog had 54% and 81% cover respectively using median values.

312 The *Sphagnum* cover increase is a major positive benefit which seems to have started with windfarm construction, increasing over a decade to 2014, with only a slight further rise in 2019. The 2019 extent might represent stability for current environmental and management conditions.

313 The *Sphagnum* increase is not easily explained. This is unfortunate, on account of the scale of *Sphagnum* increase (which seems very large) and the dominant current paradigm which portrays wind farms as major drying agents when established on deep peat (i.e. *Sphagnum* extent should decline within a bog hosting a wind farm).

314 It is possible that the increase in *Sphagnum* is related to windfarm microclimate change downwind from turbines but this conclusion is speculative. Early monitoring in 2004, 2005, 2006, 2007 and 2009 show that *Sphagnum* increase began immediately following windfarm construction, continuing at a near-exponential rate within bog habitat. The *Sphagnum* cover in 2004 was very similar to results collected in 2001 for the Causeymire Wind Farm EIA.

315 The *Sphagnum* cover on bog habitat at Causeymire is now probably higher than that cover on many other parts of the Flow Country. It has developed following site enhancement measures and is the outstanding result of site management. It was not anticipated in the EIA or in preparing enhancement proposals.

316 Trends in a large set of other monitored attributes became clearer over time, in part due to a long time interval for observation and in part due to additional analysis which was partitioned by habitat and drainage. Blanket bog, fen and former peat extraction areas were shown to respond differently to changes in grazing management.

317 **Turbine bases, hard standings and track verges** The habitat condition of turbine bases, hard standings and road verges was recorded in 2010, 2014 and 2019 using bespoke systematic techniques. A high vegetation cover developed in bases and along verges. Cattle grazing and nutrient impacts have been important in affecting species composition in bases and on verges. In addition, verge results also show that drier

conditions have developed, allowing a high Heather cover following declines in the cover of Multi-headed and Hare's-tail Cottongrasses.

318 **Overview of enhancement and EIA assessment** Monitoring results show clearly that management based on enhancement measures has resulted in much-improved site condition, particularly for bog habitat, the main objective of EIA proposals and more detailed specifications made in 2004.

319 This development is located in ground which is much-modified by a range of activities. Grazing management has operated probably more than a century, with very high sheep numbers between the 1960s and mid-1990s. As part of that grazing, fen and bog habitats have been extensively drained, leaving the Bad a Cheo blanket bog plateau as the only large bog sector remaining intact. Afforestation has affected a sizeable part of the HMSA and a large tract of former wet peatland at Dale Moss has been deep-drained and surface-milled for commercial peat extraction and then left to regenerate naturally without restoration.

320 A key measure of pre-windfarm site condition is given by *Sphagnum* extent. Analysis for this report revealed that 2001 Macaulay Institute samples for the Causeymire Wind Farm EIA had a low average cover of 15.1% for both blanket bog and fen habitat. That is little different from windfarm monitoring in 2004 (14.7%) for the same area and habitats as Macaulay work.

321 As a measure of improved condition, monitoring for the same area as Macaulay work shows the following sequence over time: 14.7% (2004) → 29.4% (2009) → 35.8% (2014) → 32.5% (2019). A high *Sphagnum* cover suggests much more active bog and fen habitats (i.e. increased rates of peat formation).

322 Breeding bird habitat condition should have improved at Causeymire if bog and fen environments have improved condition, as suggested by multiple RSPB indicators.

323 Predictions on windfarm impacts on ecology and surface hydrology in the Causeymire EIA have in general been validated, apart from some restricted road and turbine drainage effects which have developed in the operational phase. Recent published work assessing the content of peatland windfarm EIAs in Scotland is disputed on the basis of exaggeration, using Causeymire findings.

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Appendix 1: RSPB methodology for blanket bog habitat monitoring

HABITAT MONITORING METHODOLOGY 2002-11-06

Aims

The aims of this survey are to:

- provide mapped spatial data on the condition of the habitats and plant communities on the Peatland Reserves to aid interpretation of bird data and to inform management decisions.
- provide baseline monitoring of habitat condition to measure change over time to inform long term management.

<u>Methods</u>

Straight line transects parallel to North-South gridlines will be walked. These lines will normally lie 250m west and 250m east of the 1km national gridlines.

Walk around water bodies or dangerously soft ground but stay as close as possible to the transect line. Restarting on same transect line once around obstacle.

Use a GPS to check location of transect starting point, samples points and to record start and finish of features as indicated by "(GPS)" on Transect Recording Sheet. You should use a normal compass to identify direction of transect line in the normal fashion by picking a feature around 100m away and walking in as straight a line as possible towards it. The GPS compass function varies too much to be of use.

Do not pick driest/easiest route but walk straight. This is essential to prevent introducing observer bias into the results. Try to keep as even a pace as possible so that where footfalls occur they are random. Where footfalls would be on dangerous ground e.g. water, soft peat, then if possible judge where right footfalls would have occurred for recording purposes and deviate around dangerous section, returning to predicted line a.s.a.p. and ignoring footfalls involved in the deviation. Otherwise we will end up over sampling edges of pools/lochs/soft ground margins.

You will be provided with the following equipment:

One GPS unit, with a set of spare batteries
One compass
One 1.5 m rod (12 mm dowelling) marked in 1cm sections
One Sward stick disc to fit above rod
Two 1m long rods (12 mm dowelling)
One tally counter
One WeatherWriter
Belt Transect and Point Sample Record Sheets (normal and waterproof paper)
Pencils

The recording will be done in two sections:

1. Belt Transect

The transect line is divided into 100m sections which run through each cell and which are identified by the Northing **at the North end** of the 100m. Information is recorded on the Belt Transect Recording Sheet during the walk and includes information on the frequency with which your right foot falls touch specific items and the frequency with which other items occur within 0.5 m either side of the transect line. Records are also kept using the GPS of the starting and end grid reference of features such as micro-erosion, deer tracks and sections of the transect not walked because of presence of lochs etc.

2. Point Samples

These sample points occur at the end of each 100m transect and a range of data at a detailed level are recorded including vegetation height, % cover data from a 2m diameter circle, structural measurements of the vegetation and frequency along a 1m rod in 10cm sections. **The frequency data is only recorded every 200m** (at the following Northings: xx000, xx200, xx400, xx600, xx800). These are all recorded on the Point Sample Recording Sheet.

Data Recording

1. **Belt Transect Recording Sheet**

Fields to enter on Belt Transect Recording Sheet:

Day and Date –	Enter as separate figures in top line
Recorder –	Enter initials of surveyor
Grid Square –	Give 4 fig grid reference for the 1km square, e.g. NC8841
Cloud % –	Record % cloud cover at start
Transect –	Define transect by 5 figure Easting, e.g. 88250
Starting Grid Reference –	Record the point where transect surveying started for day which will normally be at a previous sample point but could be at the edge of a compartment or the edge of a loch etc.
Direction on Transect –	Record direction being walked in (North or South)
Northing –	Identify the transect by the 5 figure Northing **at the North end** of the 100m transect

The next section records using five-bar-gates what the perimeter of your right foot falls on unless otherwise specified:

No. of right footfalls –	Use the tally counter to record each time your right foot touches the ground
***Sphagnum* –**	Right foot touches *Sphagnum*
Bare peat –	Right foot touches bare peat
Deer/sheep prints –	Clearly identifiable deer or sheep footprints which lie within 50cm of the edge of the right foot: do not count prints – if there are some prints within 50cm of your foot, add one bar only
***Racomitrium* –**	Where right foot touches any *Racomitrium* moss
Exposed substrate/rock –	Where bare rock or other hard mineral surface is touched by foot including gravel mixed with bare peat where more than 50% gravel
Bracken stems –	Bracken stems (alive) which fall within 10cm of edge of foot

Within 0.5 metre either side of the transect – which is judged visually using rods to check where not sure, record the following:

***Racomitrium* hummocks > 20cm –**	**Count** number of *Racomitrium* hummocks with minimum dimension over 20cm
Micro erosion bare peat (GPS) –	Use GPS to record 5 figures Northing for start and finish of micro erosion of bog surface where the connected "runnels" have under 25% *Sphagnum* cover. Micro erosion is identifiable by there being a series of interconnected shallow channels or reticulations across the bog surface which are normally no more than30cm deep. The key difference with long linear shallow pool systems which may be dried out is that most pools will not have an obvious exit point for water. Also most linear pools run along the contours whereas the channels in micro erosion run down-slope.
Micro erosion > 25% *Sphagnum* (GPS) –	Same but where over 25% *Sphagnum* cover in bottoms of runnels
'Mud bottomed' pools < 2m wide –	Pools less than 20cm deep, under 2m wide and which have less than 50% *Sphagnum* cover
Pools < 2m wide, > 50% *Sphagnum* –	Pools of any depth under 2m wide with *Sphagnum* cover over 50%
Pools < 2m wide, < 50% *Sphagnum* –	Pools of any depth which are under 2m wide and have less than 50% *Sphagnum* cover
Lochans > 2m wide, < 50m long –	Pools under 50m longest dimension but over 2m wide. Larger pools and pool systems will be mapped as below.
Non-navigable pools (GPS) –	Where pools are larger than above dimensions or where you enter a pool system where it is impossible to follow a straight-line course use the GPS to record the Northing at the start and end of the pools.
Lochans > 50m max dimension (GPS) –	Treat as for non-navigable pools
Flushes (GPS) –	Record Northing for start/end of flushes using GPS

Streams (GPS) –	Record Northing for start/end of streams using GPS
Bare peat areas > 5m max dimn –	Bare peat areas over 5m in longest dimension
Bare rock/scree > 5m max dimn –	Bare rock/scree/substrate over 5m in longest dimension
Hagging, bare peat faces > 30cm –	Count number of exposed peat faces over 30cm tall
Deer tracks (GPS) –	Record the Northing of the centre of the deer/sheep track using GPS
Peat digging new (GPS) –	Record Northing for start/end of active cuttings
Peat digging old (GPS) –	Record Northing for start/end of old cuttings
Droppings: Count as separate groups only where over 50cm apart.	
Red grouse droppings –	Count all distinct groups of grouse droppings
Deer droppings –	Count all distinct groups of deer droppings
Sheep droppings –	Count all distinct groups of sheep droppings
Deer/sheep droppings –	Count all distinct groups of droppings which are not separable into deer or sheep
Hare droppings –	Count all distinct groups of hare droppings
Trees: record all native spp to the left of the slash and all conifers to the right	
Trees < dwarf shrubs (native/conifer) –	Count all trees/seedlings less than dwarf shrub height
Trees > dwarf shrubs but < 1m (n/c) –	Count all trees higher than dwarf shrubs but under 1m tall
Trees > 1m (native/conifer) –	Count all trees over 1m tall
Others	Here other records can be made using codes on List A attached or additional ones if thought relevant. Simply write down two or three letter code and record number seen. For lizards only record adults.

2. Point Sample Recording Sheet

On this sheet the point where the sample is to be taken lies at the North end of the 100m transect line. There is room on the sheet for 10 sample points with a column each.

Locating Sample Point –
As you near the end of the 100m transect (gauge from number of footfalls recorded on tally counter) walk on the transect bearing until the GPS Northing reads 'xxx99'. Stop, turn around and drop the disc of the sward stick over your shoulder. Take the centre of the disc where it lands as the centre of your recording circle and frequency stick. Stick one of the 1m canes into the ground at this location whilst testing soil type and depth. Lay other 1m cane radially to help visualise a 1m radius circle to estimate % cover information.

<u>Fields to enter on Point Sample Record Sheet:</u>

Observer –	Enter initials of surveyor
Day and Month –	Enter as separate figures in top line
Km Square –	Give 4 fig grid reference for the 1km square, e.g. NC8841
GR Eastings –	Enter 5 figure Easting which defines the point
GR Northings –	Enter 5 figure Northing which defines the point
Plant Community (Code) –	Pick from list on List A. Needed to help interpret results.
Light Bright/Dull (B/D) –	Enter B or D to allow checking if lighting affects recordability
Vegetation Height (cm) –	Record the maximum height of the relevant species within the 2m circle. For dwarf shrubs, record the 2-letter code for the tallest shrub species in brackets beside measurement (*e.g.*, CV for *Calluna vulgaris*, MG for *Myrica gale*, ET for *Erica tetralix*).
Percentage Cover Data –	Record estimated percentage cover within the 2m circle for listed species
No. of deer/sheep prints –	Record no. of deer/sheep prints within the 2m diameter circle

Structure of Vegetation –
Use the 1.5 m cane with 1cm black/white tape markings to record structure. First, hold the cane out at arms length to the side with head turned away to avoid subjective placement. Hold cane vertical and record the following list in 1cm divisions. Then repeat the process

with the cane at arms length straight in front. Try not to move the base of the cane when adding the disc to the cane for sward height measurement and lower it gently onto vegetation. For the sward height measurement, read off the height at the top of the tube (this will be adjusted later).

Maximum Height –	Maximum vegetation height within 5 cm of rod
Obscured Height –	Height to which bands on rod completely obscured (first band from bottom, any part of which is visible)
Part Obscured Height –	Height to which bands on rod **continuously** partly obscured (first band which is completely visible)
Max Obscured Height –	Maximum height at which any segment of the rod is obscured
Sward stick Height –	Height at which sward disc sits when lowered **gently**

Frequency Scores –
Using your compass to ensure objective placement lay 1m rod with 10cm sections perpendicular to transect against the central rod of sample point. You may have to thread rod through vegetation to prevent compressing it with rod. Count the number out of 10 (sections) where the rod passes over or under one of the relevant listed plants/features and enter the figure out of 10 in the relevant row. Other species occurring in List A attached to be added under “Other Features” at bottom.
If sample points fall on water bodies, simply record 10 in the “water over peat/mineral” box. Similarly if in dangerous wet bare peat just record 10 under bare peat.

Soil Type/Depth –
At centre of sample point use one of the 1m canes to push into soil and record as MS (mineral soil) if won’t penetrate soil of dry and not black. If penetrates over 50cm record DP for deep peat, otherwise record as SP (shallow peat) and record depth in brackets (up to 80cm).

List A	Species/Management Codes:
For Transect sheet:	
Black Burn	BKB
Grey Burn	GYB
Green Burn	GNB
Fox scat	FS
Adder	AD
Lizard adult	LZ
Sphagnum imbricatum	SI
Sphagnum fuscum	SF
Betula nana	BN
For Point Count Sheet:	
Arctostaphylos uva-ursi	AU
Erica cinerea	EC
Myrica gale	MG
Vaccinium spp.	VA
Empetrum nigrum	EM
Rubus chamaemorus	RC
Pteridium aquilinum	PT
Carex spp	SE
Juncus effuses/conglomeratus	JE
Juncus squarrosus	JS
Nardus stricta	NS
Grasses other than *Nardus* or *Molinia*	GRASS
Mosses other than *Racomitrium or Sphagnum*	MO
Pleurozia purpurea	PL
Galium saxatile	GS
Potentilla erecta	PE
Pedicularis sylvatica/palustris	PS
Pinguicula vulgaris	PV
Drosera spp	DR
Huperzia	HU
Plant Community Codes:	
Dry Heath	**D1**
Wet Heath	**D2**
Montane Heath	D4
Blanket Bog	**E1**
Flushes and Springs	**E2**
Marginal/inundation Communities	**F2**
Woodland	A1
Felled Woodland	A4
Acidic Grassland	**B1**
Improved Grassland	B4
Marshy Grassland	B5
Bracken stand	C1

Appendix 2 Point Quadrat Results

Each year of sampling using the 2019 sample area covers 189 point locations. The matrix below shows the 189 sample numbers split between drainage (two) and habitat (four) categories. Two habitat types have no undrained equivalent, making six groups. Numbers in brackets represent the number of samples with full records (i.e. frequency scores were recorded).

	Bog	Fen/Marshy Grassland	Habitat Enhancement Area (HEA)	Old Peat Extraction	Totals
Drained	31 (19)	34 (15)	17 (12)	18 (9)	100 (55)
Not drained (Intact)	62 (30)	27 (15)			89 (45)
Totals	93 (49)	61 (30)	17 (12)	18 (9)	189 (100)

Pivot table analysis was applied to the above drainage and habitat subsets, calculating the following averages from records made at 100 metre intervals on belt transects: 2004 (baseline), 2009 (Year 5), 2014 (Year 10) and 2019 (Year 15, final sampling), plus all years combined (as long-term values). These averages are presented here as two sets (A and B).

A) Visual estimate records made in circular (1m radius) quadrat at each point
   1 Bare peat (percent cover)
   2 Live Heather *Calluna vulgaris* (percent cover)
   3 Height (cm) of tallest Heather *Calluna vulgaris*
   4 Number of cattle prints present
   5 Number of deer or sheep prints present
   6 Litter/graminoid (percent cover)
   7 Height of tallest non-woody vegetation
   8 Other moss (i.e. not *Sphagnum* moss) (percent cover)
   9 *Sphagnum* moss (percent cover)
   10 Average vegetation height (cm) using two sward stick records

B) Presence in 10 cm sectors of 1 m long stick (0 = absent, maximum score 10) for the following attributes (mainly plant species), recorded at points with an even-numbered 100 metre OS grid northing (i.e. 000, 200, 400, 600, 800)

   1 Bare peat
   2 Live Heather *Calluna vulgaris*
   3 Dead Heather *Calluna vulgaris*
   4 Four-leaved heath *Erica tetralix*
   5 Multi-headed cottongrass Eriophorum angustifolium
   6 Hare's-tail cottongrass *Eriophorum vaginatum*
   7 Foliose lichens (*Cladonia* species belonging to *Cladina* group)
   8 Grazed vegetation
   9 Purple moor-grass *Molinia caerulea*
   10 Bog asphodel *Narthecium ossifragum*
   11 Other mosses (not *Racomitrium* or *Sphagnum*)
   12 Woolly-hair moss *Racomitrium lanuginosum*
   13 All Bog-moss *Sphagnum*
   14 *Sphagnum capillifolium* or *S. subnitens*

15 *Sphagnum cuspidatum*
16 *Sphagnum fallax* (formerly *S. recurvum*)
17 *Sphagnum fuscum*
18 *Sphagnum magellanicum* (recently renamed, probably S. medium at Causeymire)
19 *Sphagnum palustre*
20 *Sphagnum papillosum*
21 *Sphagnum tenellum*
22 Deer-grass *Trichophorum germanicum* (formerly *T. cespitosum* and *Scirpus cespitosus*)

Bare Peat % cover	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.85	0.43	5.49	21.67	5.54
Not Drained	0.97	0.04			0.69
Subset/Overall	1.26	0.26	5.49	21.67	3.26
Bare Peat % cover	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.03	0.06	13.38	25.11	7.31
Not Drained	0.16	0.07			0.13
Subset/Overall	0.78	0.06	13.38	25.11	3.93
Bare Peat % cover	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.35	1.18	6.88	29.33	7.58
Not Drained	2.13	0.07			1.51
Subset/Overall	2.20	0.69	6.88	29.33	4.72
Bare Peat % cover	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.71	0.44	2.18	19.72	4.91
Not Drained	0.73	0.00			0.51
Subset/Overall	1.39	0.25	2.18	19.72	2.84
Bare Peat % cover	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.29	0.06	0.00	12.50	2.36
Not Drained	0.87	0.00			0.61
Subset/Overall	0.68	0.03	0.00	12.50	1.53

Live *Calluna* % cover	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	10.81	1.49	22.43	26.81	12.44
Not Drained	12.97	2.77			9.87
Subset/Overall	12.25	2.05	22.43	26.81	11.23
Live *Calluna* % cover	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	5.90	2.49	21.13	23.06	10.23
Not Drained	7.65	2.89			6.20
Subset/Overall	7.06	2.66	21.13	23.06	8.33
Live *Calluna* % cover	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	7.39	0.21	25.41	25.83	11.33
Not Drained	12.58	2.19			9.43
Subset/Overall	10.85	1.08	25.41	25.83	10.43
Live *Calluna* % cover	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	12.16	1.94	20.47	33.89	14.01
Not Drained	13.02	5.44			10.72
Subset/Overall	12.73	3.49	20.47	33.89	12.46
Live *Calluna* % cover	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	17.77	1.29	22.65	24.44	14.20
Not Drained	18.63	0.56			13.15
Subset/Overall	18.34	0.97	22.65	24.44	13.70

Calluna height (cm)	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	19.00	3.60	29.30	34.14	18.18
Not Drained	19.27	5.94			15.22
Subset/Overall	19.18	4.63	29.30	34.14	16.78
Calluna height (cm)	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	17.32	5.51	23.69	30.28	16.54
Not Drained	20.02	6.81			16.01
Subset/Overall	19.12	6.08	23.69	30.28	16.29
Calluna height (cm)	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	13.77	1.24	28.65	34.50	15.77
Not Drained	16.76	5.00			13.19
Subset/Overall	15.76	2.90	28.65	34.50	14.56
Calluna height (cm)	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	19.03	4.74	31.94	37.50	19.69
Not Drained	17.71	6.19			14.21
Subset/Overall	18.15	5.38	31.94	37.50	17.11
Calluna height (cm)	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	25.87	2.85	32.59	34.28	20.70
Not Drained	22.58	5.74			17.47
Subset/Overall	23.68	4.13	32.59	34.28	19.18

Cattle prints per quadrat	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.01	0.08	0.00	0.00	0.03
Not Drained	0.04	0.00			0.03
Subset/Overall	0.03	0.04	0.00	0.00	0.03
Cattle prints per quadrat	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00
Cattle prints per quadrat	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00
Cattle prints per quadrat	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.03	0.24	0.00	0.00	0.09
Not Drained	0.13	0.00			0.09
Subset/Overall	0.10	0.13	0.00	0.00	0.09
Cattle prints per quadrat	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.09	0.00	0.00	0.03
Not Drained	0.02	0.00			0.01
Subset/Overall	0.01	0.05	0.00	0.00	0.02

Deer Prints per quadrat	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.51	0.47	0.09	0.86	0.49
Not Drained	0.59	0.37			0.53
Subset/Overall	0.56	0.42	0.09	0.86	0.51
Deer Prints per quadrat	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.23	0.00	0.19	0.67	0.22
Not Drained	0.29	0.04			0.21
Subset/Overall	0.27	0.02	0.19	0.67	0.22
Deer Prints per quadrat	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.90	1.18	0.18	2.06	1.08
Not Drained	0.65	0.26			0.53
Subset/Overall	0.73	0.77	0.18	2.06	0.82
Deer Prints per quadrat	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.48	0.41	0.00	0.72	0.42
Not Drained	0.71	1.15			0.84
Subset/Overall	0.63	0.74	0.00	0.72	0.62
Deer Prints per quadrat	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.42	0.29	0.00	0.00	0.23
Not Drained	0.73	0.04			0.52
Subset/Overall	0.62	0.18	0.00	0.00	0.37

Litter/Graminoid % cover	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	23.98	35.00	11.54	10.19	23.19
Not Drained	22.14	29.79			24.46
Subset/Overall	22.75	32.70	11.54	10.19	23.79
Litter/Graminoid % cover	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	7.84	15.71	7.56	6.44	10.30
Not Drained	9.68	15.96			11.58
Subset/Overall	9.06	15.82	7.56	6.44	10.90
Litter/Graminoid % cover	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	5.29	10.74	4.76	2.89	6.62
Not Drained	5.50	9.30			6.65
Subset/Overall	5.43	10.10	4.76	2.89	6.63
Litter/Graminoid % cover	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	9.10	25.00	8.00	5.61	13.69
Not Drained	9.66	17.78			12.12
Subset/Overall	9.47	21.80	8.00	5.61	12.95
Litter/Graminoid % cover	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	73.71	89.12	25.59	25.83	62.15
Not Drained	63.71	76.11			67.47
Subset/Overall	67.04	83.36	25.59	25.83	64.66

Non-woody vegetation height (cm)	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	46.04	76.32	51.12	34.93	55.26
Not Drained	43.94	71.32			52.24
Subset/Overall	44.64	74.12	51.12	34.93	53.84
Non-woody vegetation height (cm)	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	47.39	69.46	48.00	35.22	53.02
Not Drained	46.42	70.78			53.81
Subset/Overall	46.74	70.03	48.00	35.22	53.39
Non-woody vegetation height (cm)	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	48.58	78.79	57.59	38.67	58.60
Not Drained	43.89	75.85			53.58
Subset/Overall	45.45	77.49	57.59	38.67	56.24
Non-woody vegetation height (cm)	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	53.71	84.91	56.71	40.89	62.52
Not Drained	48.89	79.33			58.12
Subset/Overall	50.49	82.44	56.71	40.89	60.45
Non-woody vegetation height (cm)	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	34.48	72.32	42.00	24.94	46.91
Not Drained	36.55	59.33			43.46
Subset/Overall	35.86	66.57	42.00	24.94	45.29

Other Moss % cover	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	28.90	34.02	45.81	40.42	35.56
Not Drained	24.25	38.47			28.56
Subset/Overall	25.80	35.98	45.81	40.42	32.27
Other Moss % cover	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	25.16	27.86	24.94	43.44	29.36
Not Drained	28.06	32.96			29.55
Subset/Overall	27.10	30.08	24.94	43.44	29.45
Other Moss % cover	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	38.39	29.82	45.59	31.78	35.51
Not Drained	30.71	42.52			34.29
Subset/Overall	33.27	35.44	45.59	31.78	34.94
Other Moss % cover	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	19.26	36.53	54.41	38.94	34.65
Not Drained	19.40	45.37			27.28
Subset/Overall	19.35	40.44	54.41	38.94	31.18
Other Moss % cover	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	32.81	42.06	57.06	47.50	42.72
Not Drained	18.82	33.04			23.13
Subset/Overall	23.48	38.07	57.06	47.50	33.50

Sphagnum moss % cover	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	42.84	6.06	25.78	17.46	22.82
Not Drained	53.16	15.83			41.83
Subset/Overall	49.72	10.37	25.78	17.46	31.77
Sphagnum moss % cover	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	20.55	4.71	9.19	9.56	11.21
Not Drained	27.69	6.85			21.37
Subset/Overall	25.31	5.65	9.19	9.56	15.99
Sphagnum moss % cover	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	42.74	6.09	23.24	15.28	22.02
Not Drained	54.63	13.33			42.10
Subset/Overall	50.67	9.30	23.24	15.28	31.48
Sphagnum moss % cover	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	60.97	8.09	32.65	19.11	30.64
Not Drained	65.56	18.70			51.35
Subset/Overall	64.03	12.79	32.65	19.11	40.39
Sphagnum moss % cover	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	47.10	5.38	37.06	25.89	27.39
Not Drained	64.74	24.44			52.52
Subset/Overall	58.86	13.82	37.06	25.89	39.22

Sward Stick: Average height (cm)	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	16.47	26.50	18.60	17.40	20.43
Not Drained	15.43	24.16			18.08
Subset/Overall	15.78	25.47	18.60	17.40	19.32
Sward Stick: Average height (cm)	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	15.50	21.30	15.84	16.27	17.72
Not Drained	15.45	20.70			17.04
Subset/Overall	15.47	21.04	15.84	16.27	17.40
Sward Stick: Average height (cm)	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	17.40	26.72	20.00	17.94	21.11
Not Drained	15.42	22.50			17.57
Subset/Overall	16.08	24.85	20.00	17.94	19.44
Sward Stick: Average height (cm)	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	16.71	26.26	19.76	16.42	20.43
Not Drained	16.02	24.59			18.62
Subset/Overall	16.25	25.52	19.76	16.42	19.57
Sward Stick: Average height (cm)	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	16.27	31.88	18.65	18.97	22.47
Not Drained	14.84	28.83			19.08
Subset/Overall	15.32	30.53	18.65	18.97	20.88

Frequency Data Averages

Bare Peat	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.27	0.05	0.76	2.49	0.67
Not Drained	0.18	0.02			0.12
Subset/Overall	0.21	0.03	0.76	2.49	0.43
Bare Peat	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.05	0.00	1.73	2.13	0.69
Not Drained	0.00	0.06			0.02
Subset/Overall	0.02	0.03	1.73	2.13	0.38
Bare Peat	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.62	0.16	1.70	5.60	1.62
Not Drained	0.57	0.00			0.43
Subset/Overall	0.58	0.10	1.70	5.60	1.05
Bare Peat	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.55	0.00	0.09	1.75	0.49
Not Drained	0.04	0.00			0.02
Subset/Overall	0.27	0.00	0.09	1.75	0.29
Bare Peat	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00

Live *Calluna vulgaris*	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.72	0.73	4.51	5.49	3.36
Not Drained	4.39	0.56			3.12
Subset/Overall	4.12	0.65	4.51	5.49	3.26
Live *Calluna vulgaris*	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.45	1.77	2.45	4.00	2.52
Not Drained	3.07	0.75			2.26
Subset/Overall	2.81	1.21	2.45	4.00	2.40
Live *Calluna vulgaris*	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.85	0.32	5.40	5.20	2.87
Not Drained	4.17	0.08			3.13
Subset/Overall	3.81	0.23	5.40	5.20	2.99
Live *Calluna vulgaris*	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	5.09	0.64	5.27	7.50	4.35
Not Drained	5.65	1.33			4.07
Subset/Overall	5.40	1.00	5.27	7.50	4.23
Live *Calluna vulgaris*	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.14	0.43	4.82	5.33	3.66
Not Drained	4.89	0.00			3.11
Subset/Overall	4.57	0.20	4.82	5.33	3.43

Dead *Calluna vulgaris*	All Years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.92	0.17	1.12	2.03	0.94
Not Drained	1.46	0.37			1.10
Subset/Overall	1.25	0.27	1.12	2.03	1.01
Dead *Calluna vulgaris*	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.73	0.15	0.00	1.63	0.57
Not Drained	0.97	0.81			0.91
Subset/Overall	0.87	0.52	0.00	1.63	0.73
Dead *Calluna vulgaris*	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.08	0.26	0.60	1.90	1.35
Not Drained	2.94	0.50			2.32
Subset/Overall	2.98	0.35	0.60	1.90	1.81
Dead *Calluna vulgaris*	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.55	0.21	2.36	2.63	1.13
Not Drained	1.54	0.20			1.05
Subset/Overall	1.08	0.21	2.36	2.63	1.09
Dead *Calluna vulgaris*	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.19	0.00	1.35	2.00	0.74
Not Drained	0.07	0.00			0.05
Subset/Overall	0.12	0.00	1.35	2.00	0.45

Erica tetralix	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.60	0.72	2.98	2.51	2.86
Not Drained	3.93	1.76			3.21
Subset/Overall	4.20	1.24	2.98	2.51	3.02
Erica tetralix	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.32	0.31	2.55	3.63	2.89
Not Drained	2.97	1.56			2.48
Subset/Overall	3.54	1.00	2.55	3.63	2.70
Erica tetralix	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.92	1.00	1.70	1.10	1.88
Not Drained	4.14	0.83			3.30
Subset/Overall	4.08	0.94	1.70	1.10	2.56
Erica tetralix	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	5.36	0.86	4.27	4.50	3.87
Not Drained	4.69	2.53			3.90
Subset/Overall	5.00	1.72	4.27	4.50	3.89
Erica tetralix	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.52	0.57	3.18	1.33	2.77
Not Drained	4.00	1.94			3.25
Subset/Overall	4.22	1.30	3.18	1.33	2.97

Eriophorum angustifolium	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.05	0.72	3.53	2.89	2.50
Not Drained	3.25	1.27			2.60
Subset/Overall	3.17	0.99	3.53	2.89	2.54
Eriophorum angustifolium	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.14	1.00	1.64	1.75	1.70
Not Drained	2.70	0.94			2.09
Subset/Overall	2.46	0.97	1.64	1.75	1.88
Eriophorum angustifolium	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.46	1.00	2.90	2.40	2.25
Not Drained	3.97	1.33			3.30
Subset/Overall	3.83	1.13	2.90	2.40	2.75
Eriophorum angustifolium	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.18	0.50	3.36	5.88	3.33
Not Drained	3.88	2.20			3.27
Subset/Overall	4.02	1.38	3.36	5.88	3.30
Eriophorum angustifolium	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.57	0.29	5.24	1.78	2.67
Not Drained	2.36	0.69			1.75
Subset/Overall	2.45	0.50	5.24	1.78	2.29

Eriophorum vaginatum	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	6.14	1.10	3.86	3.06	3.79
Not Drained	5.58	1.95			4.38
Subset/Overall	5.80	1.52	3.86	3.06	4.05
Eriophorum vaginatum	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	6.55	1.77	2.73	4.63	4.33
Not Drained	5.73	2.13			4.48
Subset/Overall	6.08	1.97	2.73	4.63	4.40
Eriophorum vaginatum	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	6.62	1.26	4.60	3.50	3.67
Not Drained	6.57	2.17			5.45
Subset/Overall	6.58	1.61	4.60	3.50	4.52
Eriophorum vaginatum	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	6.45	1.00	4.09	1.50	3.87
Not Drained	6.27	2.40			4.85
Subset/Overall	6.35	1.72	4.09	1.50	4.29
Eriophorum vaginatum	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	5.10	0.36	4.00	2.56	3.33
Not Drained	3.54	1.19			2.68
Subset/Overall	4.20	0.80	4.00	2.56	3.06

Foliose lichens (*Cladonia*, *Cladina* group)	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.74	0.07	0.84	0.83	0.59
Not Drained	2.03	0.08			1.39
Subset/Overall	1.52	0.08	0.84	0.83	0.95
Foliose lichens (*Cladonia*, *Cladina* group)	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.36	0.00	0.36	1.00	0.37
Not Drained	1.60	0.25			1.13
Subset/Overall	1.08	0.14	0.36	1.00	0.72
Foliose lichens (*Cladonia*, *Cladina* group)	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.08	0.21	0.90	0.80	0.67
Not Drained	2.17	0.08			1.64
Subset/Overall	1.88	0.16	0.90	0.80	1.13
Foliose lichens (*Cladonia*, *Cladina* group)	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.91	0.00	1.36	1.13	0.80
Not Drained	2.62	0.00			1.66
Subset/Overall	1.83	0.00	1.36	1.13	1.17
Foliose lichens (*Cladonia*, *Cladina* group)	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.76	0.00	0.76	0.44	0.54
Not Drained	1.79	0.00			1.14
Subset/Overall	1.35	0.00	0.76	0.44	0.79

Grazed Vegetation	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.09	1.00	0.16	0.03	0.34
Not Drained	0.15	0.61			0.30
Subset/Overall	0.13	0.81	0.16	0.03	0.33
Grazed Vegetation	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.31	0.27	0.00	0.13
Not Drained	0.10	0.19			0.13
Subset/Overall	0.06	0.24	0.27	0.00	0.13
Grazed Vegetation	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.08	1.26	0.20	0.10	0.54
Not Drained	0.23	1.08			0.45
Subset/Overall	0.19	1.19	0.20	0.10	0.49
Grazed Vegetation	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.27	1.71	0.18	0.00	0.58
Not Drained	0.27	1.20			0.61
Subset/Overall	0.27	1.45	0.18	0.00	0.59
Grazed Vegetation	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.57	0.06	0.00	0.15
Not Drained	0.00	0.13			0.05
Subset/Overall	0.00	0.33	0.06	0.00	0.10

Molinia caerulea	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.85	5.00	0.63	0.00	1.79
Not Drained	0.85	3.88			1.85
Subset/Overall	0.85	4.45	0.63	0.00	1.82
Molinia caerulea	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.41	4.08	0.82	0.00	1.31
Not Drained	0.67	3.56			1.67
Subset/Overall	0.56	3.79	0.82	0.00	1.48
Molinia caerulea	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.31	3.32	0.20	0.00	1.33
Not Drained	0.66	4.33			1.60
Subset/Overall	0.56	3.71	0.20	0.00	1.45
Molinia caerulea	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.77	7.00	1.82	0.00	2.45
Not Drained	1.35	4.40			2.46
Subset/Overall	1.08	5.66	1.82	0.00	2.46
Molinia caerulea	Column Labels				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.71	6.14	0.00	0.00	2.00
Not Drained	0.82	3.38			1.75
Subset/Overall	1.20	4.67	0.00	0.00	1.90

Narthecium ossifragum	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.53	0.03	0.55	0.80	0.44
Not Drained	0.87	0.00			0.58
Subset/Overall	0.73	0.02	0.55	0.80	0.50
Narthecium ossifragum	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.23	0.08	0.91	1.25	0.48
Not Drained	0.53	0.00			0.35
Subset/Overall	0.40	0.03	0.91	1.25	0.42
Narthecium ossifragum	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.08	0.05	0.80	0.00	0.44
Not Drained	1.34	0.00			1.00
Subset/Overall	1.27	0.03	0.80	0.00	0.71
Narthecium ossifragum	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.64	0.00	0.45	2.25	0.67
Not Drained	1.15	0.00			0.73
Subset/Overall	0.92	0.00	0.45	2.25	0.70
Narthecium ossifragum	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.38	0.00	0.24	0.00	0.20
Not Drained	0.36	0.00			0.23
Subset/Overall	0.37	0.00	0.24	0.00	0.21

Other Mosses (not *Racomitrium* or *Sphagnum*)	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.87	5.20	5.96	4.60	4.81
Not Drained	3.61	5.61			4.28
Subset/Overall	3.72	5.40	5.96	4.60	4.57
Other Mosses (not *Racomitrium* or *Sphagnum*)	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.55	4.46	4.36	5.38	3.80
Not Drained	2.73	3.81			3.11
Subset/Overall	2.65	4.10	4.36	5.38	3.48
Other Mosses (not *Racomitrium* or *Sphagnum*)	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.46	5.00	6.40	2.90	4.48
Not Drained	5.46	7.25			5.91
Subset/Overall	4.92	5.87	6.40	2.90	5.16
Other Mosses (not *Racomitrium* or *Sphagnum*)	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.45	5.79	5.73	6.63	5.36
Not Drained	3.62	6.33			4.61
Subset/Overall	4.00	6.07	5.73	6.63	5.04
Other Mosses (not *Racomitrium* or *Sphagnum*)	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.90	5.57	6.88	4.00	5.48
Not Drained	2.25	5.50			3.43
Subset/Overall	3.39	5.53	6.88	4.00	4.62

Racomitrium lanuginosum	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.21	0.00	0.02	0.23	0.11
Not Drained	0.34	0.00			0.23
Subset/Overall	0.29	0.00	0.02	0.23	0.17
Racomitrium lanuginosum	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.05	0.00	0.00	0.13	0.04
Not Drained	0.33	0.00			0.22
Subset/Overall	0.21	0.00	0.00	0.13	0.12
Racomitrium lanuginosum	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.38	0.00	0.00	0.10	0.12
Not Drained	0.17	0.00			0.13
Subset/Overall	0.23	0.00	0.00	0.10	0.12
Racomitrium lanuginosum	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.18	0.00	0.09	0.38	0.15
Not Drained	0.50	0.00			0.32
Subset/Overall	0.35	0.00	0.09	0.38	0.22
Racomitrium lanuginosum	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.29	0.00	0.00	0.33	0.15
Not Drained	0.43	0.00			0.27
Subset/Overall	0.37	0.00	0.00	0.33	0.20

All *Sphagnum*	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.76	0.57	3.31	2.40	2.93
Not Drained	5.33	1.86			4.18
Subset/Overall	5.10	1.21	3.31	2.40	3.49
All *Sphagnum*	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.73	0.00	1.27	2.63	1.35
Not Drained	3.17	0.63			2.28
Subset/Overall	2.56	0.34	1.27	2.63	1.78
All *Sphagnum*	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	6.15	1.16	2.30	1.60	2.71
Not Drained	5.23	2.00			4.40
Subset/Overall	5.48	1.48	2.30	1.60	3.52
All *Sphagnum*	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	6.55	0.57	3.91	3.88	4.11
Not Drained	6.96	2.40			5.29
Subset/Overall	6.77	1.52	3.91	3.88	4.61
All *Sphagnum*	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	5.19	0.29	4.82	1.78	3.46
Not Drained	6.25	2.50			4.89
Subset/Overall	5.80	1.47	4.82	1.78	4.06

Sphagnum capillifolium or *subnitens*	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.64	0.30	1.84	1.83	2.05
Not Drained	4.17	0.66			3.01
Subset/Overall	3.96	0.48	1.84	1.83	2.48
Sphagnum capillifolium or *subnitens*	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.09	0.00	0.45	1.38	0.74
Not Drained	2.33	0.19			1.59
Subset/Overall	1.81	0.10	0.45	1.38	1.13
Sphagnum capillifolium or *subnitens*	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.85	0.95	1.40	1.60	2.13
Not Drained	4.40	0.83			3.49
Subset/Overall	4.52	0.90	1.40	1.60	2.78
Sphagnum capillifolium or *subnitens*	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.95	0.00	2.09	3.13	2.85
Not Drained	5.58	0.40			3.68
Subset/Overall	5.29	0.21	2.09	3.13	3.21
Sphagnum capillifolium or *subnitens*	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.19	0.00	2.82	1.33	2.43
Not Drained	4.54	1.25			3.34
Subset/Overall	4.39	0.67	2.82	1.33	2.81

Sphagnum cuspidatum	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.12	0.00	0.94	0.34	0.30
Not Drained	0.18	0.00			0.12
Subset/Overall	0.16	0.00	0.94	0.34	0.22
Sphagnum cuspidatum	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.27	0.00	0.00	1.00	0.26
Not Drained	0.33	0.00			0.22
Subset/Overall	0.31	0.00	0.00	1.00	0.24
Sphagnum cuspidatum	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	1.40	0.00	0.27
Not Drained	0.06	0.00			0.04
Subset/Overall	0.04	0.00	1.40	0.00	0.16
Sphagnum cuspidatum	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.82	0.00	0.16
Not Drained	0.12	0.00			0.07
Subset/Overall	0.06	0.00	0.82	0.00	0.13
Sphagnum cuspidatum	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.14	0.00	1.35	0.44	0.49
Not Drained	0.25	0.00			0.16
Subset/Overall	0.20	0.00	1.35	0.44	0.35

Sphagnum fallax	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.12	0.03	0.47	0.09	0.17
Not Drained	0.02	0.36			0.13
Subset/Overall	0.06	0.19	0.47	0.09	0.15
Sphagnum fallax	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.18	0.00	0.00	0.00	0.07
Not Drained	0.03	0.00			0.02
Subset/Overall	0.10	0.00	0.00	0.00	0.05
Sphagnum fallax	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.03	0.00			0.02
Subset/Overall	0.02	0.00	0.00	0.00	0.01
Sphagnum fallax	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.14	0.00	0.55	0.38	0.22
Not Drained	0.00	1.13			0.41
Subset/Overall	0.06	0.59	0.55	0.38	0.30
Sphagnum fallax	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.10	0.14	1.00	0.00	0.34
Not Drained	0.00	0.25			0.09
Subset/Overall	0.04	0.20	1.00	0.00	0.24

Sphagnum magellanicum	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.04	0.00			0.03
Subset/Overall	0.03	0.00	0.00	0.00	0.01
Sphagnum magellanicum	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00
Sphagnum magellanicum	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00
Sphagnum magellanicum	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00
Sphagnum magellanicum	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.18	0.00			0.11
Subset/Overall	0.10	0.00	0.00	0.00	0.05

Sphagnum palustre	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00
Sphagnum palustre	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00
Sphagnum palustre	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00
Sphagnum palustre	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00
Sphagnum palustre	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.14	0.00	0.00	0.03
Not Drained	0.00	0.31			0.11
Subset/Overall	0.00	0.23	0.00	0.00	0.07

Sphagnum papillosum	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.29	0.07	0.35	0.49	0.63
Not Drained	1.45	0.36			1.08
Subset/Overall	1.39	0.21	0.35	0.49	0.83
Sphagnum papillosum	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.50	0.00	0.45	0.38	0.35
Not Drained	0.67	0.06			0.46
Subset/Overall	0.60	0.03	0.45	0.38	0.40
Sphagnum papillosum	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.31	0.21	0.00	0.30	0.71
Not Drained	1.31	1.17			1.28
Subset/Overall	1.58	0.58	0.00	0.30	0.98
Sphagnum papillosum	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.73	0.00	0.73	1.38	1.04
Not Drained	2.12	0.20			1.41
Subset/Overall	1.94	0.10	0.73	1.38	1.20
Sphagnum papillosum	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.05	0.00	0.24	0.00	0.43
Not Drained	1.82	0.19			1.23
Subset/Overall	1.49	0.10	0.24	0.00	0.76

Sphagnum tenellum	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.37	0.00	0.29	0.14	0.22
Not Drained	0.50	0.19			0.40
Subset/Overall	0.45	0.09	0.29	0.14	0.30
Sphagnum tenellum	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.69			0.24
Subset/Overall	0.00	0.38	0.00	0.00	0.11
Sphagnum tenellum	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.10	0.00	0.02
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.10	0.00	0.01
Sphagnum tenellum	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.23	0.00			0.15
Subset/Overall	0.13	0.00	0.00	0.00	0.06
Sphagnum tenellum	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.38	0.00	0.76	0.56	0.77
Not Drained	1.93	0.00			1.23
Subset/Overall	1.69	0.00	0.76	0.56	0.96

Trichophorum germanicum	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.01	0.03	0.37	0.34	0.85
Not Drained	2.05	0.12			1.41
Subset/Overall	2.04	0.08	0.37	0.34	1.10
Trichophorum germanicum	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.55	0.00	0.45	0.00	0.31
Not Drained	0.70	0.00			0.46
Subset/Overall	0.63	0.00	0.45	0.00	0.38
Trichophorum germanicum	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.62	0.11	0.10	0.00	0.46
Not Drained	1.49	0.00			1.11
Subset/Overall	1.52	0.06	0.10	0.00	0.77
Trichophorum germanicum	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.36	0.00	0.73	1.13	1.25
Not Drained	2.15	0.47			1.54
Subset/Overall	2.25	0.24	0.73	1.13	1.38
Trichophorum germanicum	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.43	0.00	0.24	0.33	1.30
Not Drained	4.11	0.00			2.61
Subset/Overall	3.82	0.00	0.24	0.33	1.85

Appendix 3 Line transect results

Each year of sampling using the 2019 sample area covers 173 line segments upon belt transects. The matrix below shows the line segment number split between drainage (two) and habitat (four) categories. Two habitat types have no undrained equivalent, making six groups.

	Bog	Fen/Marshy Grassland	Habitat Enhancement Area	Old Peat Extraction	Totals
Drained	50	33	10	19	112
Not drained (Intact)	49	12			61
Totals	99	45	10	19	173

Pivot table analysis based on the above six drainage and habitat subsets was used to calculate the following averages from line transect pacing results for 2004 (baseline), 2009 (Year 5), 2014 (Year 10) and 2019 (Year 15, final sampling), plus all years combined (as long-term values):

1. Bare peat – results probably approximate percent cover of this surface type
2. Cattle dung – results probably approximate percent frequency
3. Cattle prints - results probably approximate percent frequency
4. Deer droppings - results probably approximate percent frequency
5. Deer and sheep prints - results probably approximate percent frequency
6. Grouse droppings - results probably approximate percent frequency
7. Mud bottomed pools - results probably approximate percent frequency
8. Pools with *Sphagnum* moss cover >50% - results probably approximate percent frequency
9. Pools with *Sphagnum* moss cover <50% - results probably approximate percent frequency
10. *Racomitrium* moss - results probably approximate percent cover of this surface type
11. *Racomitrium* moss hummocks - results probably approximate percent frequency
12. *Sphagnum* moss - results probably approximate percent cover of this surface type

Bare Peat	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.72	0.29	8.91	29.20	7.05
Not Drained	1.11	0.09			0.91
Subset/Overall	1.92	0.23	8.91	29.20	4.88
Bare Peat	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.92	0.46	21.42	32.80	9.37
Not Drained	0.43	0.00			0.35
Subset/Overall	2.20	0.34	21.42	32.80	6.19
Bare Peat	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.40	0.29	10.77	34.66	8.45
Not Drained	0.80	0.00			0.65
Subset/Overall	2.12	0.22	10.77	34.66	5.70
Bare Peat	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.56	0.39	1.46	26.27	5.84
Not Drained	0.79	0.37			0.70
Subset/Overall	1.68	0.38	1.46	26.27	4.03
Bare Peat	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.99	0.00	2.00	23.08	4.54
Not Drained	2.40	0.00			1.93
Subset/Overall	1.69	0.00	2.00	23.08	3.62

Cattle Dung	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.02	0.18	0.04	0.00	0.06
Not Drained	0.13	0.09			0.12
Subset/Overall	0.08	0.15	0.04	0.00	0.09
Cattle Dung	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.16	0.00	0.01
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.16	0.00	0.01
Cattle Dung	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.44	0.00	0.00	0.13
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.32	0.00	0.00	0.08
Cattle Dung	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.14	0.00	0.00	0.04
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.10	0.00	0.00	0.03
Cattle Dung	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.08	0.13	0.00	0.00	0.07
Not Drained	0.53	0.35			0.50
Subset/Overall	0.31	0.19	0.00	0.00	0.22

Cattle Prints	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.55	2.97	0.23	0.00	1.59
Not Drained	0.76	1.14			0.83
Subset/Overall	1.16	2.48	0.23	0.00	1.32
Cattle Prints	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.07	0.00	0.00	0.00	0.03
Not Drained	0.00	0.00			0.00
Subset/Overall	0.04	0.00	0.00	0.00	0.02
Cattle Prints	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.90	2.98	0.91	0.00	1.81
Not Drained	0.22	1.69			0.51
Subset/Overall	1.07	2.63	0.91	0.00	1.35
Cattle Prints	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.97	1.41	0.00	0.00	1.74
Not Drained	1.66	0.46			1.42
Subset/Overall	2.32	1.16	0.00	0.00	1.63
Cattle Prints	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.25	7.49	0.00	0.00	2.77
Not Drained	1.15	2.43			1.40
Subset/Overall	1.20	6.14	0.00	0.00	2.29

Deer Droppings	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.99	0.46	1.16	4.82	1.50
Not Drained	0.38	0.54			0.42
Subset/Overall	0.69	0.48	1.16	4.82	1.12
Deer Droppings	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.64	0.56	1.80	10.80	2.45
Not Drained	0.15	0.98			0.31
Subset/Overall	0.40	0.67	1.80	10.80	1.69
Deer Droppings	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.89	0.77	1.55	6.93	2.38
Not Drained	0.78	0.36			0.70
Subset/Overall	1.34	0.66	1.55	6.93	1.79
Deer Droppings	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.40	0.17	0.87	1.55	0.57
Not Drained	0.29	0.11			0.25
Subset/Overall	0.34	0.15	0.87	1.55	0.46
Deer Droppings	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.03	0.35	0.40	0.00	0.60
Not Drained	0.32	0.73			0.40
Subset/Overall	0.68	0.45	0.40	0.00	0.53

Deer & Sheep Prints	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.37	4.14	7.37	8.67	5.30
Not Drained	4.98	5.23			5.03
Subset/Overall	4.67	4.43	7.37	8.67	5.20
Deer & Sheep Prints	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	1.51	1.23	1.08	5.87	2.13
Not Drained	1.53	1.34			1.49
Subset/Overall	1.52	1.26	1.08	5.87	1.90
Deer & Sheep Prints	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	4.63	2.52	0.00	17.51	5.78
Not Drained	4.31	1.58			3.78
Subset/Overall	4.47	2.27	0.00	17.51	5.07
Deer & Sheep Prints	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	3.34	3.05	9.36	10.02	4.92
Not Drained	3.53	2.78			3.39
Subset/Overall	3.43	2.98	9.36	10.02	4.38
Deer & Sheep Prints	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	7.99	9.76	19.05	1.27	8.36
Not Drained	10.55	15.22			11.47
Subset/Overall	9.26	11.21	19.05	1.27	9.45

Grouse Droppings	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.30	0.03	1.83	3.53	0.91
Not Drained	0.36	0.03			0.30
Subset/Overall	0.33	0.03	1.83	3.53	0.69
Grouse Droppings	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.16	0.14	0.62	8.05	1.53
Not Drained	0.07	0.00			0.05
Subset/Overall	0.11	0.10	0.62	8.05	1.01
Grouse Droppings	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.50	0.00	0.00	3.11	0.75
Not Drained	0.22	0.00			0.18
Subset/Overall	0.36	0.00	0.00	3.11	0.55
Grouse Droppings	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.23	0.00	2.41	0.81	0.45
Not Drained	0.52	0.12			0.44
Subset/Overall	0.37	0.03	2.41	0.81	0.45
Grouse Droppings	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.33	0.00	4.31	2.13	0.89
Not Drained	0.64	0.00			0.51
Subset/Overall	0.48	0.00	4.31	2.13	0.76

Mudpools	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.03	0.01	0.08	1.25	0.24
Not Drained	0.04	0.07			0.05
Subset/Overall	0.04	0.03	0.08	1.25	0.17
Mudpools	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.13	0.04	0.10	0.00	0.08
Not Drained	0.00	0.14			0.03
Subset/Overall	0.07	0.07	0.10	0.00	0.06
Mudpools	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.24	0.00	0.02
Not Drained	0.17	0.00			0.13
Subset/Overall	0.08	0.00	0.24	0.00	0.06
Mudpools	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	5.02	0.85
Not Drained	0.00	0.14			0.03
Subset/Overall	0.00	0.04	0.00	5.02	0.56
Mudpools	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.00	0.00			0.00
Subset/Overall	0.00	0.00	0.00	0.00	0.00

Pools *Sphagnum* >50%	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.72	0.00	0.14	0.55	0.43
Not Drained	2.59	0.07			2.10
Subset/Overall	1.64	0.02	0.14	0.55	1.01
Pools *Sphagnum* >50%	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	2.27	0.00	0.03	0.00	1.01
Not Drained	4.32	0.00			3.47
Subset/Overall	3.28	0.00	0.03	0.00	1.88
Pools *Sphagnum* >50%	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	1.97	0.00			1.58
Subset/Overall	0.97	0.00	0.00	0.00	0.56
Pools *Sphagnum* >50%	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.03	0.00	0.15	0.56	0.12
Not Drained	0.36	0.29			0.34
Subset/Overall	0.19	0.08	0.15	0.56	0.20
Pools *Sphagnum* >50%	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.57	0.00	0.40	1.62	0.56
Not Drained	3.72	0.00			2.99
Subset/Overall	2.13	0.00	0.40	1.62	1.42

Pools *Sphagnum* <50%	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.09	0.00	2.38	0.23	0.29
Not Drained	0.33	0.00			0.26
Subset/Overall	0.21	0.00	2.38	0.23	0.28
Pools *Sphagnum* <50%	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.25	0.00	3.13	0.00	0.39
Not Drained	0.07	0.00			0.05
Subset/Overall	0.16	0.00	3.13	0.00	0.27
Pools *Sphagnum* <50%	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.03	0.00	0.00	0.00	0.01
Not Drained	0.25	0.00			0.20
Subset/Overall	0.14	0.00	0.00	0.00	0.08
Pools *Sphagnum* <50%	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.06	0.00	4.77	0.91	0.61
Not Drained	0.73	0.00			0.59
Subset/Overall	0.39	0.00	4.77	0.91	0.60
Pools *Sphagnum* <50%	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	1.60	0.00	0.14
Not Drained	0.25	0.00			0.20
Subset/Overall	0.13	0.00	1.60	0.00	0.16

Racomitrium moss	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.20	0.00	0.07	2.17	0.46
Not Drained	0.66	0.00			0.53
Subset/Overall	0.43	0.00	0.07	2.17	0.49
Racomitrium moss	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.00	0.00	0.00	0.00	0.00
Not Drained	0.15	0.00			0.12
Subset/Overall	0.08	0.00	0.00	0.00	0.04
Racomitrium moss	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.29	0.00	0.30	4.88	0.99
Not Drained	0.63	0.00			0.51
Subset/Overall	0.46	0.00	0.30	4.88	0.82
Racomitrium moss	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.32	0.00	0.00	3.82	0.79
Not Drained	0.88	0.00			0.70
Subset/Overall	0.59	0.00	0.00	3.82	0.76
Racomitrium moss	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.18	0.00	0.00	0.00	0.08
Not Drained	0.99	0.00			0.80
Subset/Overall	0.58	0.00	0.00	0.00	0.33

Racomitrium hummocks	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.31	0.00	0.00	0.00	0.14
Not Drained	0.92	0.00			0.74
Subset/Overall	0.62	0.00	0.00	0.00	0.35
Racomitrium hummocks	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.15	0.00	0.00	0.00	0.07
Not Drained	0.18	0.00			0.15
Subset/Overall	0.17	0.00	0.00	0.00	0.10
Racomitrium hummocks	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.03	0.00	0.00	0.00	0.01
Not Drained	0.36	0.00			0.29
Subset/Overall	0.20	0.00	0.00	0.00	0.11
Racomitrium hummocks	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.08	0.00	0.00	0.00	0.04
Not Drained	0.37	0.00			0.30
Subset/Overall	0.23	0.00	0.00	0.00	0.13
Racomitrium hummocks	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	0.99	0.00	0.00	0.00	0.44
Not Drained	2.77	0.00			2.23
Subset/Overall	1.87	0.00	0.00	0.00	1.07

Sphagnum moss	All years				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	41.82	10.52	28.02	19.70	27.61
Not Drained	59.12	16.05			50.65
Subset/Overall	50.38	12.00	28.02	19.70	35.74
Sphagnum moss	2004				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	14.29	2.51	3.05	2.90	7.89
Not Drained	23.69	5.53			20.12
Subset/Overall	18.94	3.32	3.05	2.90	12.20
Sphagnum moss	2009				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	44.56	11.74	26.79	17.86	28.77
Not Drained	62.37	12.93			52.64
Subset/Overall	53.37	12.06	26.79	17.86	37.19
Sphagnum moss	2014				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	53.66	10.97	39.03	26.83	35.22
Not Drained	76.12	20.18			65.11
Subset/Overall	64.77	13.43	39.03	26.83	45.76
Sphagnum moss	2019				
Drainage	Bog	Fen/MG	HEA	Old Peat Extraction	Subset/Overall
Drained	54.78	16.86	43.21	31.22	38.58
Not Drained	74.30	25.57			64.71
Subset/Overall	64.44	19.19	43.21	31.22	47.79

Appendix 4 Map comparisons: point data

Appendix 5 Map comparisons: line data

Appendix 6a 2019 data on turbine base and hard standing condition

APPENDIX 6a: PERCENT VEG/OTHER COVER OF BASES AND HARDSTANDINGS

Codes: Acro Acrocarpous moss; Scdf *Sphagnum cuspidatum-denticulatum-fallax*; Scp *Sphagnum capillifolium-papillosum*; Pleu Pleurocarpous moss; Je *Juncus effusus*; GSH Grasses, sedges and herbs; Ev *Eriophorum vaginatum*; Ea *Eriophorum angustifolium*; CvEtEn *Calluna vulgaris-Erica tetralix-Empetrum nigru*m; BP Bare Peat, ST Stone; OW Open Water; Cattle Trampled (Y=Yes, N=No)

Turbine	Feature	Acro	Scdf	Scp	Pleu	Je	GSH	Ev	Ea	CvEtEn	BP	ST	OW		CT
1	Backfilled base	1	35	0	5	15	20	3	15	3	0	1	2		Y
2	Backfilled base	1	8	0	3	30	5	0	50	3	0	0	0		Y
3	Backfilled base	0	0	0	10	20	68	0	2	0	0	0	0		Y
4	Backfilled base	1	0	0	3	35	60	0	0	0	0	1	0		Y
5	Backfilled base	0	0	0	24	40	25	0	10	1	0	0	0		Y
6	Backfilled base	1	5	0	5	20	20	0	37	5	5	1	1		Y
7	Backfilled base	1	30	4	0	4	10	5	42	3	0	0	1		Y
8	Backfilled base	2	5	5	25	14	33	0	10	5	0	1	0		Y
9	Backfilled base	15	18	1	0	8	10	15	15	3	10	0	5		Y
10	Backfilled base	5	15	5	2	2	5	1	43	15	2	0	5		N
14	Backfilled base	0	10	1	25	10	37	10	5	2	0	0	0		Y
15	Backfilled base	1	0	0	10	45	40	0	3	1	0	0	0		Y
16	Backfilled base	0	0	0	10	62	26	1	1	0	0	0	0		Y
17	Backfilled base	0	0	0	20	10	56	10	1	3	0	0	0		Y
18	Backfilled base	4	15	0	20	45	11	2	2	1	0	0	0		Y
19	Backfilled base	10	3	1	17	5	30	5	5	20	3	0	1		Y
20	Backfilled base	0	30	0	5	10	47	0	2	5	0	0	1		Y
21	Backfilled base	0	0	0	10	30	57	1	0	2	0	0	0		Y
22	Backfilled base	0	0	0	10	55	28	0	0	4	2	1	0		Y
23	Backfilled base	2	15	0	10	10	27	15	5	15	0	1	0		Y
24	Backfilled base	5	5	0	20	15	25	0	20	5	0	0	5		N
Other	Former Compound	15	0	30	10	0	45	0	0	0	0	0	0		Y
1	Hardstanding	4	0	0	4	0	20	0	0	40	30	2	0		Y
2	Hardstanding	0	0	0	0	0	7	0	0	0	0	93	0		N
3	Hardstanding	0	0	0	0	15	60	0	0	0	0	25	0		Y
4	Hardstanding	3	0	0	0	1	95	0	0	0	0	1	0		Y
5	Hardstanding	10	0	0	35	5	32	0	0	3	0	15	0		Y
6	Hardstanding	5	0	0	22	0	25	0	0	45	0	3	0		Y
7	Hardstanding	0	0	0	0	0	10	0	0	0	0	90	0		Y
8	Hardstanding	2	0	0	10	25	55	0	0	3	0	5	0		Y
9	Hardstanding	2	0	0	0	0	15	0	0	1	0	82	0		Y
10	Hardstanding	5	0	0	5	0	10	0	0	15	60	5	0		N
14	Hardstanding	5	0	0	0	0	20	0	0	0	0	75	0		Y
15	Hardstanding	0	0	0	20	8	70	0	0	1	0	1	0		Y
16	Hardstanding	10	0	0	5	0	25	0	0	0	0	60	0		Y
17	Hardstanding	0	0	0	15	1	79	0	0	3	0	2	0		Y
18	Hardstanding	25	0	0	0	0	20	0	0	20	20	15	0		Y
19	Hardstanding	25	0	0	17	0	15	0	0	25	3	15	0		Y
20	Hardstanding	10	0	0	25	0	10	0	0	30	20	5	0		Y
21	Hardstanding	5	0	0	18	0	15	0	0	60	0	2	0		Y
22	Hardstanding	8	0	0	0	0	29	0	0	2	60	1	0		Y
23	Hardstanding	10	0	0	0	0	16	0	0	10	60	4	0		Y
24	Hardstanding	0	0	0	2	1	52	0	0	25	5	15	0		Y

Appendix 6b 2019 data on road verge condition

Codes: X Easting; Y Northing; Road Side (N=North, S=South; W=West; E=East); Adjacent Habitat (M17 *Trichophorum germanicum-Eriophorum vaginatum* mire; M25 *Molinia caerulea-Potentilla erecta* mire); Tg *Trichophorum germanicum*; Ev *Eriophorum vaginatum*; Ea *Eriophorum angustifolium*; Cv *Calluna vulgaris*; Je *Juncus effusus*; EtEn *Erica tetralix-Empetrum nigrum;* Pleuros Pleurocarpous moss; Grass Grasses, sedges and herbs; Polyt *Polytrichum* moss; Sphag *Sphagnum* moss; Lich Lichens; Acros Acrocarpous moss; BP Bare Peat; Cattle Trampled (Y=Yes, N=No), Burning - None (no burning adjacent to a road in 2019)

Verge Position	X	Y	Road Side	Adjacent Habitat	Tg	Ev	Ea	Cv	Je	EtEn	Pleuros	Grass	Polyt	Sphag	Lich	Acros	BP	Cattle Trampled	Burning
T1 to T2	316546	950461	N	M17	0	5	3	10	10	5	30	20	0	15	2	0	0	Y	None
T1 to T2	316546	950461	S	M17	0	1	1	1	20	0	31	40	1	5	0	0	0	Y	None
Compound to T3	316586	950594	N	M25/M6	0	0	0	0	65	0	10	24	0	0	0	1	0	Y	None
Compound to T3	316586	950594	S	M25/M6	0	0	0	0	20	0	15	65	0	0	0	0	0	Y	None
T3 to T4	316459	950836	N	M25/M6	0	0	0	0	20	0	5	75	0	0	0	0	0	Y	None
T3 to T4	316459	950836	S	M25/M6	0	0	0	0	50	0	2	45	0	0	0	0	3	Y	None
T4 to T5	316213	950823	N	M17	0	0	0	0	50	0	2	48	0	0	0	0	0	Y	None
T4 to T5	316213	950823	S	M17	0	0	0	0	55	0	10	35	0	0	0	0	0	Y	None
T5 to T6	315881	950596	N	M17	0	0	0	5	30	5	20	37	0	1	1	1	0	Y	None
T5 to T6	315881	950596	S	M17	0	0	2	5	30	1	30	5	11	15	1	0	0	Y	None
T5 to T7	315871	950766	N	M17	1	2	3	1	5	2	2	79	0	0	0	0	5	Y	None
T5 to T7	315871	950766	S	M17	1	5	7	0	2	0	4	80	0	0	0	0	1	Y	None
T7 to T8	315525	950761	N	M17	0	10	3	3	4	1	2	73	0	0	0	1	3	Y	None
T7 to T8	315525	950761	S	M17	0	10	0	1	30	1	25	32	0	0	0	0	1	Y	None
T8 to T9	315489	950403	W	M17	0	5	5	52	0	5	15	2	0	14	2	0	0	Y	None
T8 to T9	315489	950403	E	M17	0	7	7	50	0	5	17	0	0	10	1	1	2	Y	None
T9 to T10	315539	950167	W	M17	0	5	2	70	0	4	8	0	0	5	5	0	1	N	None
T9 to T10	315539	950167	E	M17	0	10	5	39	0	5	25	0	0	15	1	0	0	N	None
T8 to T14	315218	950626	N	M25	0	0	0	0	15	0	30	54	0	0	0	0	1	Y	None
T8 to T14	315218	950626	S	M25	0	0	0	0	20	0	15	64	0	0	0	0	1	Y	None

Codes: X Easting; Y Northing; Road Side (N=North, S=South; W=West; E=East); Adjacent Habitat (M17 *Trichophorum germanicum-Eriophorum vaginatum* mire; M25 *Molinia caerulea-Potentilla erecta* mire); Tg *Trichophorum germanicum*; Ev *Eriophorum vaginatum*; Ea *Eriophorum angustifolium*; Cv *Calluna vulgaris*; Je *Juncus effusus*; EtEn *Erica tetralix-Empetrum nigrum;* Pleuros Pleurocarpous moss; Grass Grasses, sedges and herbs; Polyt *Polytrichum* moss; Sphag *Sphagnum* moss; Lich Lichens; Acros Acrocarpous moss; BP Bare Peat; Cattle Trampled (Y=Yes, N=No), Burning - None (no burning adjacent to a road in 2019)

Verge Position	X	Y	Road Side	Adjacent Habitat	Tg	Ev	Ea	Cv	Je	EtEn	Pleuros	Grass	Polyt	Sphag	Lich	Acros	BP	Cattle Trampled	Burning
T14 to T15	315102	950355	W	M25	0	0	0	0	10	0	20	69	0	0	0	1	0	Y	None
T14 to T15	315102	950355	E	M25	0	0	0	0	15	0	0	84	0	0	0	0	1	Y	None
T15 to T16	314899	950192	N	M25	0	0	0	0	4	0	30	66	0	0	0	0	0	Y	None
T15 to T16	314899	950192	S	M25	0	0	0	2	2	0	25	71	0	0	0	0	0	Y	None
T16 to T17	315096	949976	W	M17	0	2	1	0	1	0	15	81	0	0	0	0	0	Y	None
T16 to T17	315096	949976	E	M17	0	5	1	1	0	0	30	61	0	0	0	0	2	Y	None
T17 to T18	315284	949833	N	M17	0	10	5	8	1	4	12	59	0	1	0	0	0	Y	None
T17 to T18	315284	949833	S	M17	0	0	3	15	0	0	15	66	0	0	0	0	1	Y	None
T17 to T19	315302	949562	W	M17	15	5	5	55	0	1	17	1	0	0	1	0	0	Y	None
T17 to T19	315302	949562	E	M17	5	5	15	37	0	5	17	1	0	5	2	3	5	Y	None
T19 to T21	315461	949260	W	M17	0	1	5	59	0	1	16	5	1	1	1	5	5	Y	None
T19 to T21	315461	949260	E	M17	1	0	10	71	0	1	5	0	0	5	1	1	5	Y	None
T21 to T22	315608	948925	W	M17	0	10	0	1	1	0	15	73	0	0	0	0	0	Y	None
T21 to T22	315608	948925	E	M17	0	10	0	10	0	3	25	50	0	2	0	0	0	Y	None
T22 to T23	315859	948736	N	M17	0	30	0	36	0	2	15	15	0	1	0	0	1	Y	None
T22 to T23	315859	948736	S	M17	0	15	0	4	0	1	30	50	0	0	0	0	0	Y	None
T23 to T24	315946	948929	W	M17	0	0	5	75	0	1	14	0	1	4	0	0	0	Y	None
T23 to T24	315946	948929	E	M17	1	0	20	50	0	4	6	2	0	15	0	2	0	Y	None
T24 to T20	315816	949258	W	M17	0	0	5	50	1	1	36	1	2	0	3	0	1	N	None
T24 to T20	315816	949258	E	M17	0	0	5	45	0	2	33	3	7	1	3	0	1	N	None
T20 to T10	315658	949675	W	M17	0	5	10	40	1	1	20	13	5	0	2	2	1	Y	None
T20 to T10	315658	949675	E	M17	0	1	2	42	5	1	20	15	10	0	2	1	1	Y	None

Appendix 7 2019 photos: turbine base, hard standings and road verges