The state of Scotland's lowland raised bogs in 2012

Findings from a survey of 58 Scottish lowland raised bogs and analysis of change since 1994/1995

Esmée Fairbairn Foundation

Scottish Wildlife Trust

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2) Eric Coull, Paul Gallagher and Ian MacKenzie of the Scottish Wildlife Trust for their help and support in the preparation of this report.

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Cover photograph:

bog rosemary *Andromeda polifolia* at Cadgill Flow, Dumfries and Galloway.

Executive summary

1. A total of 58 Scottish lowland raised bog sites were surveyed during 2010/11 as part of the Scottish Wildlife Trust's Lowland Raised Bog Project. The aim of the project is to determine the current state of the sites and to analyse change in condition by comparison with surveys carried out in 1994/5. The project also identifies sites suitable for restoration and identifies landowners supportive of restoration aims.
2. The 58 sites surveyed cover a total area of 4,060 hectares, the median site size is 34 hectares and 67% of sites are less than 50 hectares in size.
3. The survey sites have been subject to significant historic peat cutting and loss of peatland to agriculture. 68% of the survey area is restorable deep peat (the 'restorable peatland area') and includes near natural and degraded open mire, deep peat with woodland cover and commercially worked bare peat. 32% of the survey area is non-restorable (archaic peat that is agriculturally improved or urbanised, and areas of non-peat where peat has been removed). Of the restorable peatland area, 38% is uncut primary mire and 62% is cutover secondary mire.
4. Artificial drainage ditches affect the peatland expanse of 56 sites (97% of the total) and all sites are affected by perimeter drainage ditches. Drainage ditches cause drying of the bog surface, degradation of raised bog vegetation and oxidation of the surface peat (carbon loss).
5. Woodland and scrub covers 45% of the area of the restorable peatland area and 74% of sites are affected by woodland and scrub. Woodland and scrub cover causes the surface of the bog to dry and the loss of raised bog vegetation through shading.
6. Active peat cutting on a semi-commercial or commercial scale affects 9% of sites. Of these, 3 sites are severely affected with greater than 50% of the mire expanse maintained as bare peat. No sites have evidence of recent small-scale domestic peat cutting.
7. The average primary mire (uncut) peat depth at the centre of the site is 4.7m and 77% of primary mire sites have a depth greater than 4.0m. The average secondary mire (cutover) peat depth is 2.3m.
8. *Sphagnum*-dominated areas occupy 11% of the restorable peatland area and it is here that peat accumulation, and therefore carbon sequestration, is likely to be taking place. Of the remaining 89% of the restorable peatland area, a high proportion is likely to be suffering from carbon loss as a result of drying and oxidation processes.
9. Based on site depth measurements, the total carbon stored across the survey area (excluding archaic peat) is estimated to be 10.1 Mt of carbon. An

extrapolation from the carbon stored in the surveyed sites gives an indicative carbon storage figure for all Scottish lowland raised bogs of 59.4 Mt of carbon. These figures are indicative and have a high level of uncertainty.

10. A comparison of site condition for the 1994/5 and 2010/11 surveys is based on plant indicator species, drainage, presence of woodland and burning / grazing damage on the restorable peatland area. 48% of sites show deterioration in condition, 36% of sites show an improvement in condition and 16% of sites show no change in condition. Of the 11 sites managed for conservation, 64% show improvement in condition.
11. A comparison of overall condition for the 1994/5 and 2010/11 surveys shows both improvement and deterioration. Overall improvement in condition is evidenced by an increase in sites with infilling drains, a decrease in sites affected by burning and a decrease in sites affected by severe grazing and trampling. Overall deterioration in condition is evidenced by a decrease in area of peatland classed as wet, deterioration in the quality of raised mire vegetation and an increase in woodland cover.
12. This mixed picture is consistent with less intense agricultural use and less intense management of sites ('benign neglect'). A clearer trend of deterioration in site condition becomes apparent if the sites managed for conservation are excluded.
13. Private landowners were asked about their attitudes to site restoration. Of those questioned, 39 out of 41 (95%) were either very supportive or broadly supportive of grant-aided restoration measures being carried out on their sites.
14. Restoration costs are estimated based on the restorable peatland area and include capital costs (e.g. removal of tree cover and installation of dams) and annual management costs (e.g. grazing and maintenance of dams). Capital costs are estimated to be £1,280 / ha and annual management costs are estimated to be £40 / ha / year. The cost of restoring 50 sites of typical size (34ha) is calculated. The total capital cost is £1,481,000 and the annual management cost is £46,000.
15. Scottish lowland raised bog sites show a high level of degradation and damage, and unmanaged sites show a net deterioration in condition over the last 15 years. Some improvement in condition as a result of less intensive use of sites ('benign neglect') is not sufficient to reverse the damaged condition of the Scottish lowland raised bog resource.
16. A programme of site restoration will have clear wildlife benefits whilst reducing carbon emissions and increasing the long-term storage of peat. Active restoration management is required to restore sites to favourable condition, increase their potential for peat accumulation and enhance their ability to adapt to climate change.

17. Restoration effort should focus on removal of woodland and scrub, installation of dams, use of livestock grazing to inhibit regeneration of woodland, and creation of hydrological buffer zones at the peatland margin.

Contents

1 Introduction

1.1 Background and Aims

The Scottish Wildlife Trust's peatland project involves the study of 58 lowland raised bog sites from across Scotland[1]. The sites were originally surveyed during 1994/5 and have been resurveyed during 2010/11 using the original methodology (with some additional requirements such as measurement of peat depth).

The main aim of the project is to determine the current state of Scottish lowland raised bogs by means of studying the sample of 58 sites. Furthermore, change in site condition is analysed by comparison with the original surveys, costs associated with bringing sites into favourable condition are estimated and landowners supportive of restoration measures are identified.

The outputs of the project include survey data entered into a Microsoft Access database, mapped data captured using ArcGIS digital mapping software and a final report.

1.2 Sites overview

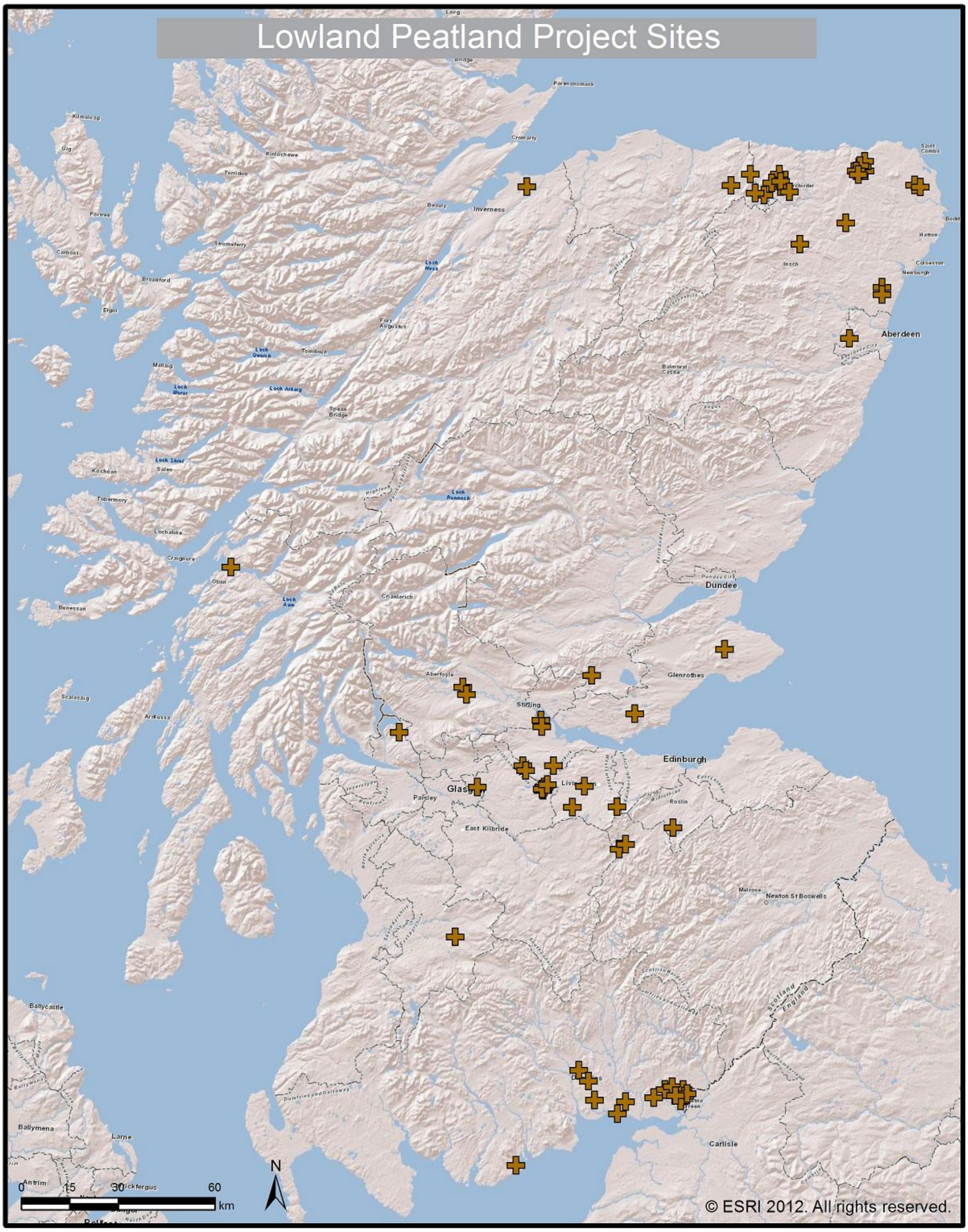
The 58 sampled Scottish lowland raised bog sites are spread over a wide geographical area covering 15 council areas although the majority of sites are located in Aberdeenshire, the central belt and Dumfries and Galloway (see Figure 1). The distribution of sampled sites largely reflects the distribution of all Scottish lowland raised bogs. The breakdown of sites by council area is shown in Table 1.

Table 1. Sites surveyed during 2010/11 categorised by council area.

Council areas	Sites (number)
Aberdeenshire	20
Argyll and Bute	1
Borders	1
City of Glasgow	1
Dumfries and Galloway	12
East Ayrshire	1
Falkirk	5
Fife	1
Highland	1
Moray	3
Perth and Kinross	1
Fife	1
Stirling	2

[1] Sixty two sites were surveyed and four were excluded from the study. The excluded sites are Flanders Moss East and Longbridge Muir which are unrepresentative (large and highly managed), and Ingraston Moss and Gretna Flow that are entirely archaic peat.

West Dunbartonshire	1
West Lothian	7



Ian Mackenzie
Harbourside House
110 Commercial Street
Edinburgh, EH6 6NF
www.swt.org.uk

Legend

Survey Sites

Scottish Wildlife Trust

Figure 1. Distribution of sites surveyed during 2010/11.

Two of the survey sites are Sites of Special Scientific Interest (SSSIs) and Special Areas of Conservation (SACs), three are SSSIs only and one is a Local Nature Reserve (LNR) (Table 2).

Table 2. Site conservation designations.

Site name	SSSI	SAC	NNR	LNR
Arnhall Moss				x
Bankhead Moss	x			
Moss of Crombie	x			
Raeburn Flow	x	x		
Side Moss (Peeswit Moss)	x	x		
Tailend Moss	x			

The total survey area covered by the 58 sites is 4,060 hectares (40.6 km^2), based on the original boundaries determined in SNH's lowland raised bog inventory (LRBI) (Lindsay and Immirzi 1996). The average site area is 70 hectares, the median site area is 34 hectares and 67% of sites are less than 50 hectares in size.

The lowland raised bog inventory gives a total Scottish figure of 807 sites covering 27,892 hectares, with an average site area of 34.6 hectares. The area covered by all Scottish lowland raised bogs, excluding archaic sites, is 23,861 hectares.

The current survey of 58 sites represents 17% of the total Scottish resource by area excluding archaic sites.

A full list of sites by area is found in Appendix I.

2 Methodology

2.1 Survey method

The survey method has two main components – the aerial photograph interpretation (API) methodology and the field survey methodology.

In broad terms the API methodology uses aerial photographs to determine site compartment boundaries based on changes in vegetation type. Aerial photographs are also used to classify each site compartment using various criteria such as vegetation type and presence or absence of various types of damage. For example each compartment is assessed for the presence or absence of woodland, and sub-classified to the level of woodland type and whether the canopy is open or closed. The final stage involves field validation of both the chosen boundaries and the classification criteria, and both are amended where necessary.

The distinct field survey methodology was undertaken at the same time as the field validation of the API methodology and provided whole site and point location based data. Whole site data includes, for example, an assessment of burning and grazing damage, and point location based data includes, for example, vegetation quadrats and peat depth measurements. Field data was collected using a paper field form and was transferred at a later date to a database.

2.2 Differences between the 1994/5 and 2010/11 methods

One of the objectives of the current survey is to provide a comparison with the 1994/5 survey, and in order to facilitate this comparison the original methodology was largely repeated. There were also some additional requirements including the measurement of peat depth at each site. The 2010/11 survey, however, used the latest digital mapping and hand-held GPS technology which was not available at the time of the original survey – so in practice the implementation of the methodology changed quite substantially.

During the 1994/5 survey, pairs of unprocessed black and white photographs were viewed using a stereoscope and site compartment boundaries were drawn by hand onto transparent acetate sheets before being transferred to field maps. In the field, the surveyor's geographical location, and the location of site compartment boundaries, had to be estimated by reference to physical features that were illustrated on base Ordnance Survey (OS) maps.

In contrast, for the 2010/11 survey, geo-rectified colour aerial photographs were imported into ArcGIS mapping software, and site compartment boundaries were digitised and laid over digital base OS maps. Site compartment criteria were then assessed and the results recorded in a linked attribute table. The site compartments and base maps were viewed in the field on a hand-held GPS device that indicates position to an accuracy of within a few metres. The location of point data such as vegetation quadrats can also be recorded with the same level of accuracy. In order to allow a comparison to be made between the current survey and the original 1994/5 survey, the original paper maps were digitised and the assessment data entered into linked attribute tables.

The use of digital mapping and GPS technology during the current survey should have substantially improved the accuracy of the data derived from the API survey and the accuracy of the data collected in the field. Furthermore, the digitisation of the original hand drawn maps and the transfer of handwritten field forms and field notes to a database may have introduced additional errors into the 1994/5 data. The changes in the implementation of the methodology should be borne in mind when interpreting the results of the comparison of the 1994/5 and 2010/11 surveys.

Specific methodological issues and clarifications are addressed as necessary in 'Section 3 Survey results'.

Copies of the aerial photograph interpretation and field survey methodologies are available from the Scottish Wildlife Trust.

3 Survey results

3.1 Peatland resource

3.1.1 Current status

The total survey area is 4,060 hectares of which 68% is the 'restorable peatland area', 8% is archaic peat and 24% is non-peat (Figure 2)[2]. The restorable peatland area includes near natural and degraded open mire, mire with woodland cover and commercially worked bare peat. This is the area of lowland raised bog that has the potential to be restored to a favourable condition.

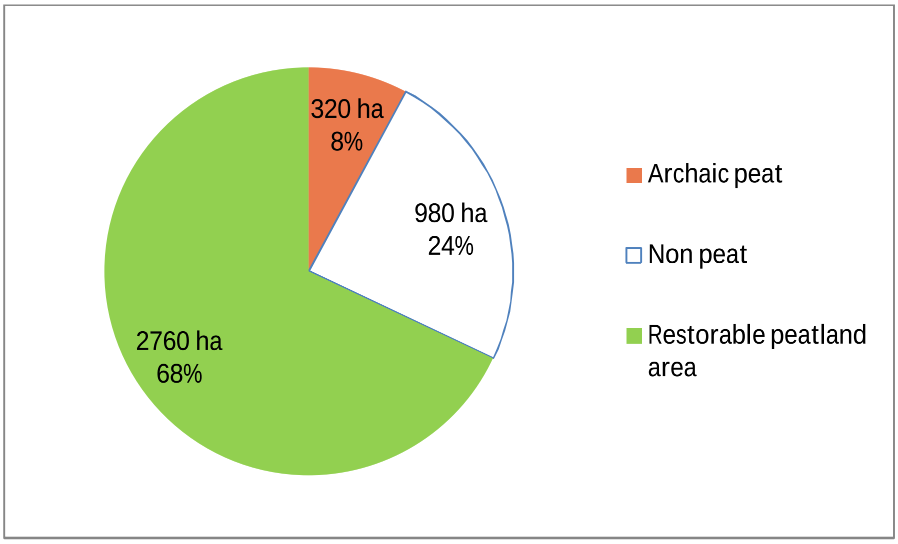


Figure 2. Total survey area categorised by peatland type.

Conversely, the 'non-restorable area' is the sum of the archaic peat and non-peat areas and covers 32% of the survey area. The non-restorable peatland area is archaic peat that is agriculturally improved or urbanised and non-peat is where peat has been removed or has disappeared (in practice non-peat also includes areas of mineral ground that have been included within the LRBI site boundary in error). Archaic peat was recorded at 19 sites covering 320 hectares. The non-restorable peatland area is unlikely to be suitable for restoration as lowland raised bog.

The restorable peatland area covers 2,760 hectares, of which 38% is uncut primary mire and 62% is cutover secondary mire (Figure 3). The majority secondary mire was historically cutover and has re-vegetated.

[2] Peatland is mapped where peat depth is greater than 30cm.

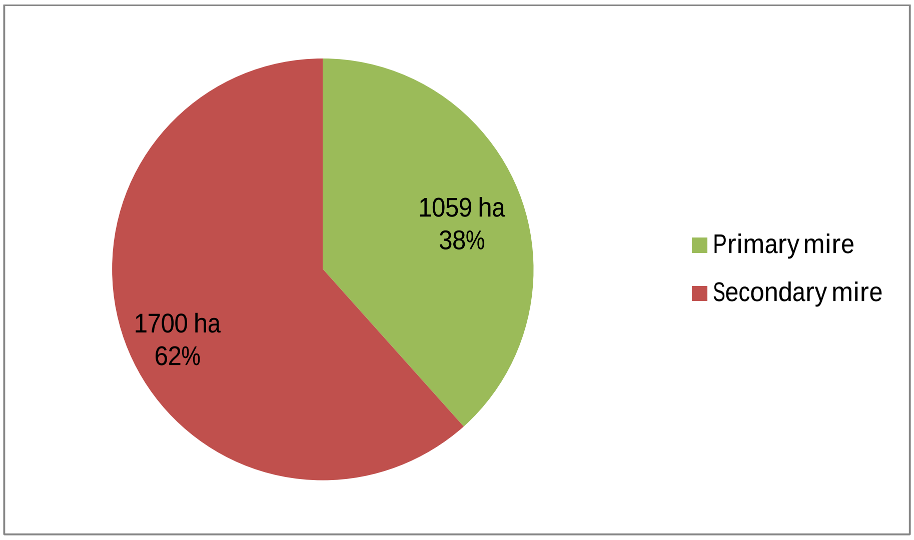


Figure 3. Restorable peatland area categorised by primary and secondary mire.

The restorable peatland area, comprising the sum of uncut primary mire and cutover secondary mire, is the base area used for analysis in this study (current state of the resource, analysis of change, restoration costs, carbon storage etc). The extent of the restorable peatland area by site is shown in Appendix I.

3.1.2 Analysis of results

The stated area of archaic peat may be an under-estimate because of the difficulty in identifying archaic peat in the field. Determining the extent of archaic peat was problematical where vegetation, such as a grassland sward, provided unbroken cover over the soil or peat substrate. For example, in cases where there was a narrow band of archaic peat, with an indeterminate boundary, at the edge of the peatland expanse, a target note was made rather than an attempt to map its extent. Furthermore, areas of developed land, housing and private gardens, which were not accessed, were classified as 'non peat' by default where there was no positive evidence of archaic peat, and this may have increased under-recording of this category.

The restorable peatland area was mapped taking into account a number of factors including site morphology, vegetation type and the presence of old peat workings, and the mapping accuracy of the combined area is likely to be high. The differentiation of primary and secondary mire is less certain because, for example, evidence of old peat workings may have faded over time as peat has slumped and drains have become infilled. Wooded areas may also prove problematical because the tree cover can obscure morphological features. By default woodland on deep peat was classified as primary or secondary mire rather than archaic.

3.2 Ground conditions

3.2.1 Methodological issues

The methodology does not provide a clear definition of 'wet' and 'dry' ground conditions; however during the 1994/5 survey a vegetation proxy was used (*pers.*

comm. Jonathan Hughes, Scottish Wildlife Trust). A compartment was classified as 'wet' where *Sphagnum* species were constant (at a low cover or otherwise) and the microtope type T2 or wetter (i.e. T1, A1 etc) provided at least 20% of ground cover. For compartments where mesotrophic conditions prevailed, a compartment was defined as 'wet' where fen and swamp species were dominant, regardless of the ground cover of *Sphagnum* or other bryophytes.

The analysis of change between 1994/5 and the current survey is based on 47 sites for which there is adequate data. Seven sites are excluded that have no PSAF (land-use type) classification from the 1994/5 survey (curiously these include all 5 SSSIs) and therefore no distinction can be made between the peatland area, archaic peat and non-peat areas. A further four sites are excluded that have an incomplete set of ground condition data from 1994/5 survey.

3.2.2 Current status

Ground conditions, classified as wet or dry, were mapped and recorded at a site compartment level. Ground conditions were analysed over the restorable peatland area which includes open mire, areas of woodland and scrub and commercially worked bare peat. The restorable peatland area covers 2,760 hectares.

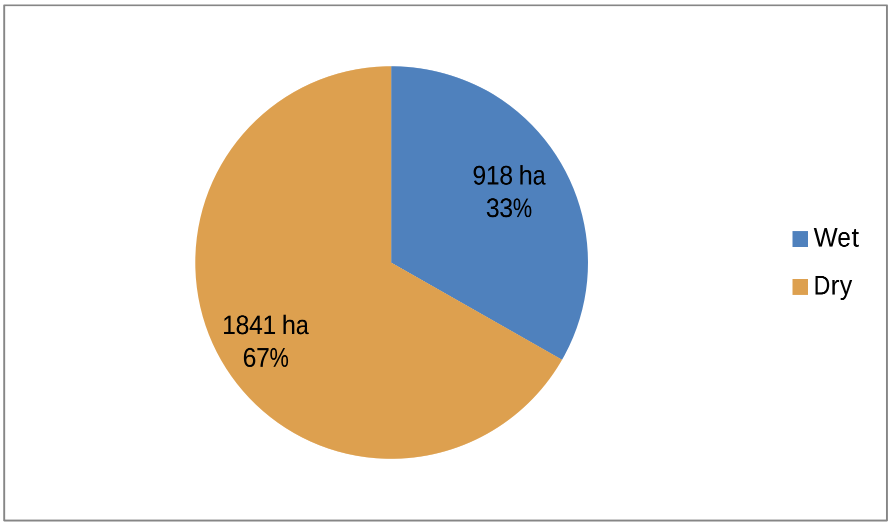


Figure 4. Peatland area (hectares) categorised as wet or dry for all sites.

The results in Figure 4 show that 33% of the peatland area is classified as wet and 67% is dry. This data is derived from the complete 58 sites surveyed.

Table 3. Sites categorised by proportion of site area that is recorded as wet.

Proportion of site wet (%)	Sites (no.)	Sites (%)
<30	26	45
30 to 60	12	21
>60	20	34
Total sites	**58**	**100**

Analysis of ground conditions on a site by site basis for all sites is provided in Table 3. This shows that 45% of sites have less than 30% of their surface area categorised as wet, 21% of sites have between 30% and 60% of their area wet and 34% of sites have greater than 60% of their area wet.

3.2.3 Comparison with 1994/5 survey

The results of the analysis of change between 1994/5 and the current survey are shown in Figure 5 below.

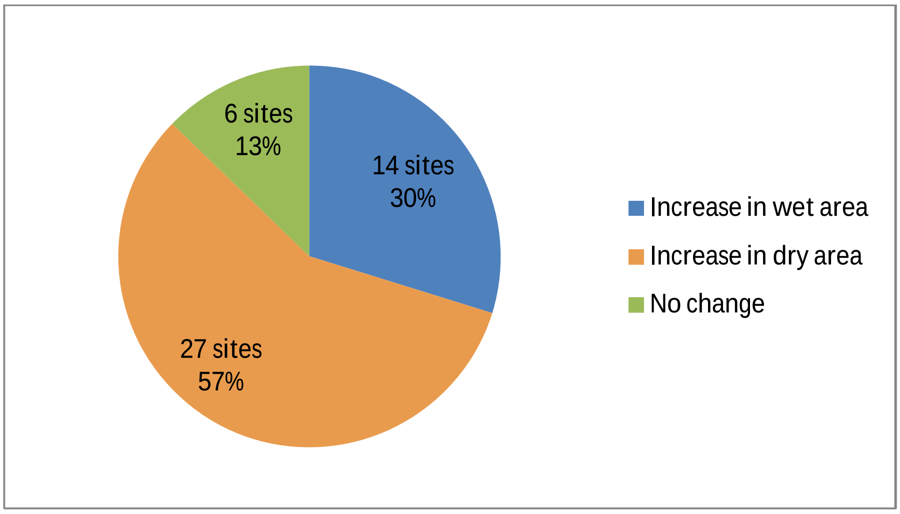


Figure 5. Number of sites with a >5% increase in wet or dry areas (47 sites) from 1994/5 to 2010/11.

The results show that 57% of sites have an increase in the proportion of the site that is dry, 30% of sites show an increase in the proportion of the site that is wet and 13% of sites show no change.

Data were also aggregated to provide figures for total dry and wet peatland area for all 47 sites. Figures are provided for the 1994/5 and the 2010/11 surveys (Figure 6 below).

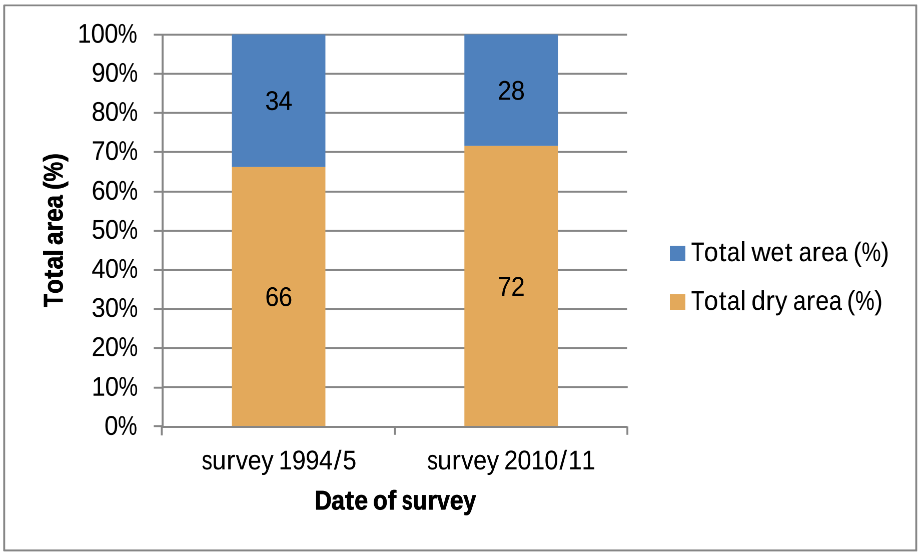


Figure 6. Restorable peatland area for 47 sites categorised as wet or dry – 1994/5 and 2010/11 surveys compared.

The results show that the dry area increased from 66% to 72% of the total restorable peatland area and that the wet area decreased from 34% to 28%.

3.2.4 Analysis of results

The assessment of ground condition uses the presence of *Sphagnum* cover to determine the distinction between the wet and dry categories. In practice this means that vegetation classed as dry includes very degraded M18 raised mire that has little if any *Sphagnum* species cover, dry heath, bare peat, the drier *Molinia caerulea* grasslands and much of the closed woodland and scrub cover. These much degraded areas have no acrotelm and there will be no active peat formation – and they can be considered haplotelmic (Lindsay 2010). It is a reflection of the very modified and degraded nature of the sites surveyed that 67% of the peatland survey area is categorised as dry.

Vegetation classed as wet largely comprises the better quality areas of M18 raised mire in addition to smaller areas of fen, swamp and wet woodland. The areas classified as wet include areas dominated by *Sphagnum* species, where peat accretion is likely to be occurring, but also more degraded raised bog vegetation. At many sites which have both primary and secondary mire, it tends to be the lower cutover areas that are the wettest and most *Sphagnum*-rich, whilst the higher uncut areas are drier with more degraded vegetation.

Photo 1. Dry ground conditions and exposed tree roots indicating peat shrinkage at the edge of the peatland expanse. Creca Moss, Dumfries and Galloway.

The analysis of change between 1994/5 and the present survey shows an increase in dry ground conditions both in the total peatland area classified as dry and in the net number of sites showing an increase in dry peatland area. However, this analysis should be treated with a good deal of caution. In addition to the methodological difficulties and differences outlined in 'Section 2 Methodology', there is some uncertainty with the definition of ground conditions used in the original survey field assessment. Furthermore, the sample size was reduced to 47 sites (because of the lack of data for some sites) and there is a high degree of variability on a site by site comparison (only 6 sites showed no change in condition). Nevertheless the results do appear to indicate a drying trend across the surveyed sites.

3.3 Open mire vegetation

3.3.1 Methodological Issues

Open mire vegetation was recorded in a variety of ways including site species lists, vegetation quadrats, and dominant ground layer vegetation type at the site compartment level. The latter category gives the most systematic and complete data set and this can be aggregated by area at a whole site level. The ground layer vegetation type was classed as '*Sphagnum*-dominated', 'bryophyte-dominated' (i.e. not including *Sphagnum* species), bare ground or as two categories co-dominant. A record was also made of compartments that were dominated by herbs (indicating mesotrophic conditions).

Quadrat data were analysed to determine the presence or absence of positive indicator species to give some indication of the quality of the raised mire vegetation at each site. This assessment is adapted from the Scottish Natural Heritage (SNH) guidance on lowland raised bog site condition assessment (JNCC 2004) and the species used are constant and preferential species from the M18 raised mire NVC community (Rodwell 1991). This assessment also forms part of the site condition assessment (see section '5 Site condition assessment'), including a comparison of condition between the 1994/5 survey and the present survey.

The following three criteria were tested for each site, and a point scored if fulfilled:

(i) Three species out of *Calluna vulgaris*, *Erica tetralix*, *Eriophorum angustifolium*, *Eriophorum vaginatum* and *Trichophorum cespitosum* present in >30% of quadrats.
(ii) One species out of *Andromeda polifolia*, *Drosera rotundifolia*, *Empetrum nigrum*, *Narthecium ossifragum* and *Vaccinium oxycoccus* present in >30% of quadrats.
(iii) Two species out of *Sphagnum capillifolium*, *Sphagnum magellanicum*, *Sphagnum papillosum* and *Sphagnum tenellum* present in >30% of quadrats.

A site which scores 0 has the poorest quality raised mire vegetation and a site that scores 3 has the best quality vegetation.

3.3.2 Current status

The results for open mire vegetation type by area are in Figure 6 below.

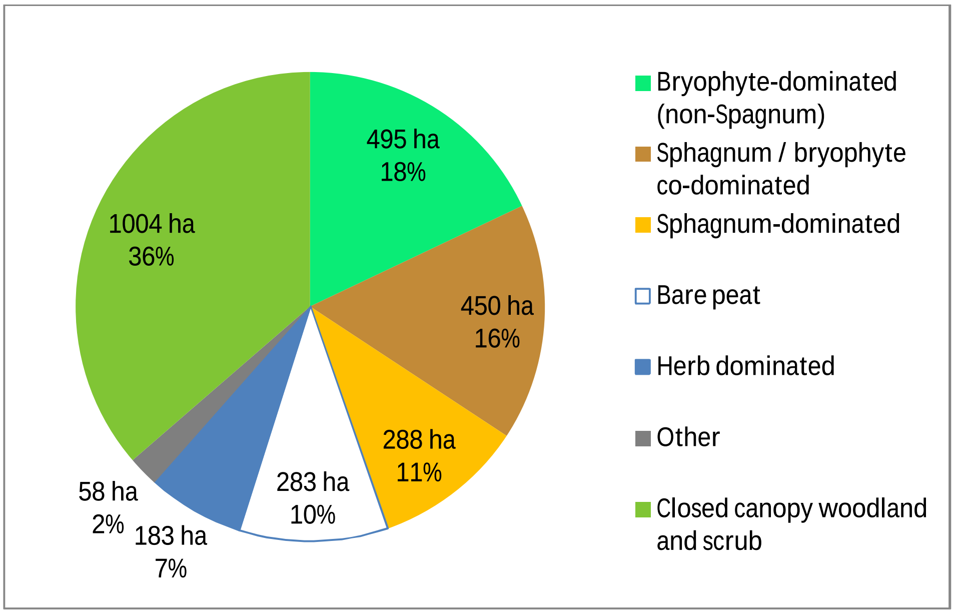


Figure 7. Open mire vegetation category by area for all sites.

Vegetation categories were only recorded for open mire areas (including under open scrub and woodland) but for the sake of completeness Figure 7 also includes the area of closed canopy woodland and scrub, herb dominated areas and bare peat. The pie chart therefore represents the complete restorable peatland area for 58 sites (2,760 hectares).

The ground layer vegetation types providing the highest cover are 'Bryophyte-dominated (non-*Sphagnum*)' which covers 18% of the area, '*Sphagnum*-bryophyte co-dominated' which covers 16% and '*Sphagnum*-dominated' which covers 11% of the restorable peatland area (see Appendix I). Closed canopy woodland and scrub account for 36% of the restorable peatland area.

Quadrat data were analysed to determine the presence or absence of positive indicator species to give some indication of the quality of the raised mire vegetation at each site. During the survey 325 vegetation quadrats were recorded which gives an average or 5.2 per site. The results are shown in Table 4.

Table 4. Positive indicator species scores by site.

Score (per site)	Sites (no.)	Sites (% of total)
0	16	28
1	22	38
2	11	19
3	9	16
Total	**58**	**100**

The two lowest score categories (0 and 1 point), representing poor quality raised bog vegetation, account for 66% of sites, and the two highest score categories (2 and 3 points), representing good quality vegetation, account for 35% of sites.

3.3.3 Comparison with 1994/5 survey

Positive indicator species were also used to provide a comparison between the 1994/5 and the 2010/11 surveys, following the scoring protocol outlined in Section 3.3.1 above. During the 1994/5 survey 268 vegetation quadrats were recorded which gives an average of 4.3 per site. The results are shown in Figure 8 below.

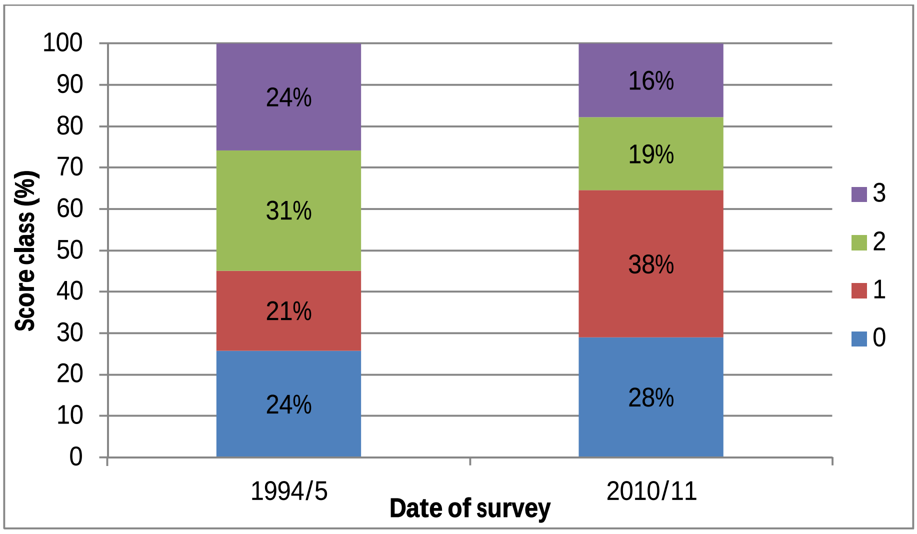


Figure 8. Positive indicator species scores by site – 1994/5 and 2010/11 surveys compared.

Sites which score 0 or 1, representing poor quality raised bog vegetation, accounted for 45% of the total during the 1994/5 survey rising to 66% of the total during the 2010/11 survey. Conversely sites which score 2 and 3, representing good quality raised bog vegetation, accounted for 55% of sites during the 1994/5 survey falling to 35% during the 2010/11 survey.

3.3.4 Analysis of results

The analysis of open mire vegetation types for the 2010/11 survey shows that 11% of the restorable peatland area has a ground layer dominated by *Sphagnum* – species. These will incorporate the micro-topographic features – lawns and hummocks of *Sphagnum* species – that have the most potential for peat accumulation (Lindsay 2010) and therefore it will be within this 11% area that any carbon sequestration will be taking place. Conversely, a high proportion of the remaining 89% of the restorable peatland area is likely to be suffering from carbon loss as a result of drying and oxidation processes.

The ground vegetation categories '*Sphagnum*-dominated', '*Sphagnum* / bryophyte co-dominated' and 'herb-dominated' most closely align with the 'wet' class used under the ground condition category (see 'Section 3.3 Ground conditions'). The aggregated total of these ground vegetation categories is 34% of the restorable peatland area which is close to the 33% figure for 'wet' ground conditions. It is also notable that closed canopy woodland and scrub (36% of the peatland area) provides a high proportion of the area that is classed as 'dry' under the ground conditions category (67% of the peatland area).

The assessment of the quality of vegetation based on positive indicator species has a rather arbitrary scoring threshold (indicator species must be present in at least 30% of quadrats) and it is therefore primarily of use in the ranking of sites. A further problem is that quadrats are positioned within the five best quality open mire compartments for each site, and so a high score could indicate either that the whole site has good quality raised bog vegetation, or that only a localised section of that site is of good quality.

The opportunities for analysing change using the original 1994/5 survey are limited. The original quadrat data are not associated with grid references, and if these were available (for example on the original field survey forms) their accuracy would be poor because the surveys were carried out prior to the use of hand-held GPS. Therefore no attempt could be made to repeat quadrats at the original locations and therefore no direct comparison can be made of quadrat data. Comparison of the original and current species lists is also problematical because these are whole site lists (no distinction is made between open mire, archaic peat, areas not on peat etc), the recorded species do not have cover or frequency scores, and the original lists appear less complete than those recorded during 2010/11.

The use of ground and field layer vegetation type recorded at a site compartment level to analyse change appeared more promising initially, however study of the 1994/5 data shows that these data are inconsistent and incomplete. For example, analysis of compartments categorised as '*Sphagnum*-dominated' appears to show that the area has more than doubled from 1994/5 to 2010/11 (from 388 hectares to 818 hectares). Examination of the site records, however, shows that there is often a mismatch between vegetation descriptions and the recording of ground cover modifiers for the 1994/5 survey. The problem with the original data may be the result of transferring hand-drawn maps and hand-written notes into a digital map format.

A comparison of the current and previous surveys is made using positive indicator species. The results show a surprisingly marked decrease in the number of sites with the best quality vegetation (scoring 2 and 3) in 2010/11 compared to the original survey. The methodology requires quadrats to be located randomly within the best quality compartments however the precise selection of location is open to interpretation. For this reason the results of the comparison should be treated with caution.

3.4 Damage

3.4.1 Trees and scrub

3.4.1.1 Methodological issues

Woodland and scrub are categorised by tree type (broadleaved, conifer or mixed) and by canopy type (open or closed). The identification and mapping of woodland and scrub features by aerial photograph interpretation is normally straightforward, however ground truthing is important to determine whether areas of woodland have been felled or whether recent scrub or tree regeneration has occurred.

Trees and scrub are defined as open canopy where space can be seen around most individual trees or shrubs on an aerial photograph or in the field. Trees can be up to

24m apart on average within this category, whilst trees or shrubs that are more widely spaced are classed as scattered trees on open mire.

3.4.1.2 Current status

Figure 9 shows area of scrub and woodland across the restorable peatland area for all sites (2,760 hectares in total). Closed and open canopy woodland covers 35% and 4% of the area respectively, and closed and open canopy scrub covers 1% and 5% of the area respectively. Overall 36% of the total peatland area supports closed canopy woodland and scrub, 9% supports open woodland and scrub and the remaining 55% of the area is open mire.

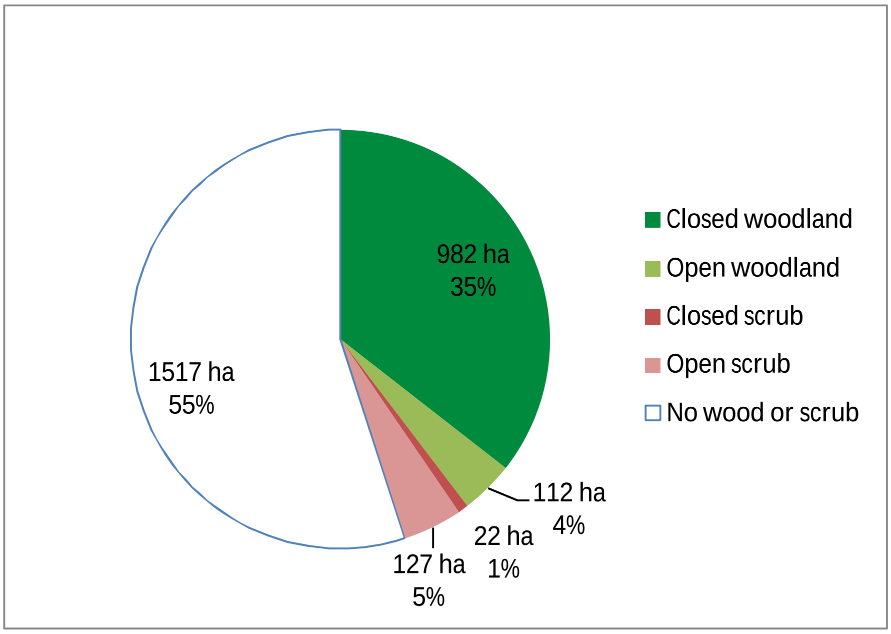


Figure 9. Restorable peatland area categorised by open and closed canopy woodland and scrub type for all sites.

Closed canopy woodland is present on 43 sites (78% of the total) and covers 982 hectares of the restorable peatland area. Figure 10 shows that closed canopy woodland comprises 57% conifers, 37% broadleaves and 6% mixed woodland by area.

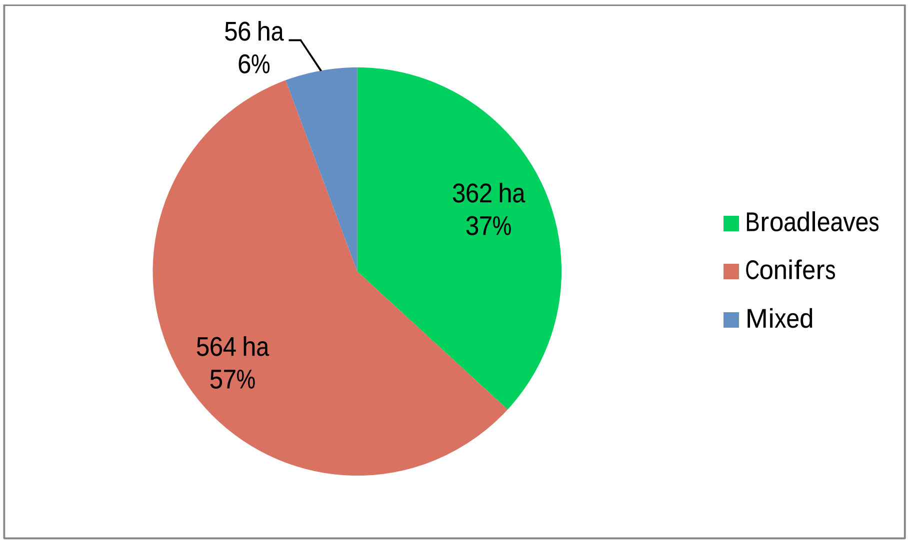


Figure 10. Closed canopy woodland categorised by broad woodland type.

Analysis of closed woodland on a site by site basis shows that 32 sites have closed-canopy woodland cover below 30% of the site area, 13 sites have cover between 30% and 60% and 13 sites have cover greater than 60% (Table 5). Closed canopy woodland area by site is shown in Appendix I.

Table 5. Sites categorised by proportion of site area that is recorded as closed canopy woodland.

Proportion of site closed woodland (%)	Sites (no.)	Sites (%)
<30	32	55.2
30 to 60	13	22.4
>60	13	22.4
Total sites	**58**	**100**

Overall most of the compartments recorded as closed canopy conifers are plantations and the majority of broadleaved woodland is self-sown birch. The areas of open woodland and scrub tend to be self-sown birch, but with a significant proportion of self-sown scots pine – particularly if a scots pine plantation is present nearby.

3.4.1.3 Comparison with 1994/5

Woodland categories including open / closed canopy and woodland type were compared against the 1994/5 survey and the results are shown in Figure 11.

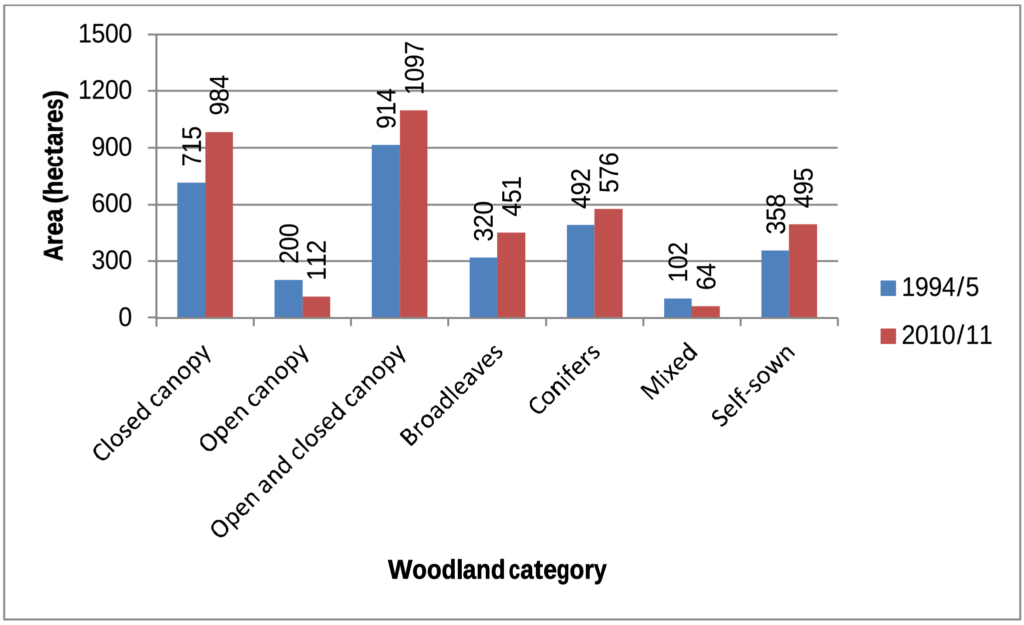


Figure 11. Restorable peatland area categorised by woodland type – 1994/5 and 2010/11 surveys compared for all sites.

The woodland type categories of 'broadleaves', 'conifers', 'mixed' and 'self-sown' shown in Figure 11 are combined totals for open and closed canopy woodland. Seven sites have no PSAF (land-use type) data from the 1994/5 survey and these were compared to the equivalent 2010/11 survey sites on a whole site area basis (including areas of archaic peat and no peat).

The results show that between the 1994/5 survey and the current survey closed canopy woodland has shown a net increase of 269 hectares (38%) which is mainly an increase in the area of self-sown broadleaves and, to a lesser extent, conifer plantation.

3.4.1.4 Analysis of results

Woodland and scrub features were readily identified during the initial aerial photograph interpretation stage of the project and therefore the mapped boundaries and the associated area data for these features are likely to be accurate, at least for the 2010/11 data.

The results show that almost half of the restorable peatland area supports open and closed canopy woodland and scrub, and three-quarters of sites have closed canopy woodland recorded across the mire expanse. Trees and scrub impact on the condition of a raised bog by causing the surface of the bog to dry and loss of bog vegetation through shading. Consequently, trees and scrub are one of the major negative impacts across the survey area.

The analysis of change between 1994/5 and 2010/11 shows a general trend of increasing broadleaved woodland and conifer plantation. The sites surveyed also show a trend of reduced intensity of land use management, and the increase in self-sown woodland may be a result of less livestock grazing and burning management (see Section 3.5.3 'Bare peat, erosion, burning and animal impacts').

Some caution should be observed when considering the comparison because of omissions and inconsistencies in other data sets from the 1994/5 survey. In the case of woodland and scrub there is no positive indication that this land-use category is absent from a particular compartment (the relevant field in the ArcGIS attribute table is left blank which could be the result of an error of omission) and therefore it is difficult to judge the quality of the data. It is possible that the observed increase in woodland compared to 1994/5 is partly the result of under-recording during the original survey.

3.4.2 Artificial drainage

3.4.2.1 Methodological issues

At a compartment level, where present, drains are categorised as narrow, moderate, wide or irregular-spaced. Narrow-spaced drains have parallel spacing between 5m and 10m (or equivalent density if not parallel), moderate-spaced drains are 10m to 50m apart, and wide-spaced drains are 50m to 100m apart. Irregular-spaced drains have a similar density to wide-spaced drains but are more fragmented and irregular. A site perimeter drain that is concurrent with the border of a compartment polygon is not captured by that compartment to allow a distinction to be made between drains that are present across the peatland expanse and those at the perimeter.

Data on drainage were also recorded on a whole site basis and the presence of different drainage types by site was analysed to compare the 1994/5 with 2010/11 surveys. If a field had been left blank in the database from the 1995 survey it was assumed that this was an error by omission rather than an indication that drains were absent for that particular site. The sites with blank field data were therefore excluded and the analysis considers 49 sites out of a total of 58.

3.4.2.2 Current status

Data on artificial drains and ditches were mapped and recorded on a site compartment level in addition to their status being recorded on a whole site basis.

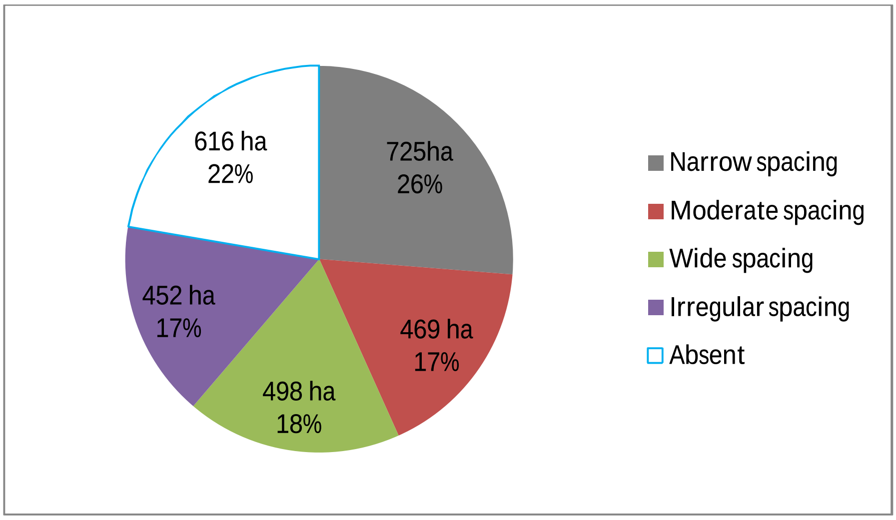


Figure 12. Restorable peatland area categorised by drainage density for all sites.

The results of artificial drainage type by area across the restorable peatland area (58 sites, 2,760 hectares) are shown in Figure 12.

The results show that the majority of the total peatland area (78%) is affected by artificial drainage. Analysis of drainage on a site by site basis shows that 97% of sites are affected by drains across the peatland expanse. Only Mossdale and Greenrae Flow have none, although both sites have a scouring drain or drains around at least part of the peatland expanse. At Mossdale an infilling drain bisecting the site was recorded in the 1994/5 survey and it is likely that this had become further infilled and difficult to detect by the time of the 2010/11 survey.

At the whole site level drains across the peat expanse and at the perimeter were classed as scouring, infilling and/or dammed and the presence of an artificial perimeter ditch at the peatland edge is also recorded (Table 6).

Table 6. Drainage category by site for peatland expanse and peatland margin (all sites).

Drainage category	Peatland expanse (no. sites)	Peatland expanse (% sites)	Margin (no. sites)	Margin (% sites)
Absent	2	3	0	0
Dammed only	1	2	1	2
Dammed and infilling	4	7	0	0
Infilling only	31	53	1	2
Scouring only	8	14	49	84
Scouring and infilling	12	21	7	12
Total sites	**58**	**100**	**58**	**100**

The results show for the peatland expanse there are 53% of sites that have artificial drains that are 'infilling only' with vegetation whilst 81% of sites have at least a proportion of drains that are 'infilling only'. 'Scouring only' drains are found at 14% of sites, and 36% of sites have at least a proportion of drains that are scouring. At the margin of the peatland expanse 84% of sites have 'scouring only' drains and 12% have scouring and infilling drains. All sites surveyed have a perimeter ditch or ditches around at least a part of the peatland expanse.

3.4.2.3 Comparison with the 1994/5 survey

Comparison of the drainage category on a whole site basis for the 1994/5 and 2010/11 surveys is shown in Table 7.

Table 7. Drainage category by site for the peatland expanse for 49 sites – 1994/5 and 2010/11 surveys compared.

Drainage category	1994/5 (no. Sites)	1994/5 (% Sites)	2010/11 (no. Sites)	2010/11 (% Sites)
Dammed only	0	0	1	2
Dammed and infilling	0	0	3	6
Infilling only	25	51	28	57
Scouring only	19	39	8	16
Scouring and infilling	5	10	9	18
Total sites	**49**	**100**	**49**	**100**

The results show that the proportion of sites with 'infilling only' drains increased from 51% to 57% of sites between 1994/5 and 2010/11, and sites with 'scouring only' drains declined from 39% to 16%. Furthermore, the proportion of sites with dammed drains present increased from zero to 14% over the same period.

3.4.2.4 Analysis of results

Analysis of drainage data shows that perimeter drainage ditches affect all of the sites surveyed, and that drains across the peatland expanse affect all but two sites. On an area basis, only 22% of the restorable peatland area is free from drains and this comprises largely primary mire. These figures highlight the extent to which the surveyed lowland raised mires have been modified and agriculturally improved, and this is likely to be true of the whole Scottish resource. Artificial drainage in the form of surface ditches may be the most important factor affecting raised bog site hydrology (Morgan-Jones et al 2005) and it is likely to be one of the major factors that have caused damage to the sites surveyed.

An attempt was made to compare the results of the total peatland area categorised by drainage type for the 1994/5 and the 2010/11 surveys. However analysis of the data showed that for the 1994/5 survey, complete data was only available for 28 sites (less than 50% of the total) and that these data showed some inconsistencies. For this reason it was judged that no meaningful comparison could be made.

The comparison of drainage categories on a whole site basis (for the peatland expanse) shows a decrease in sites which have scouring drains present, an increase in sites with infilling drains and an increase in dammed ditches. These results are consistent with the subjective observation made during the 2010/11 survey that artificial drains within the mire expanse are rarely being maintained and that few new drains are being excavated.

3.4.3 Bare peat, erosion, burning and animal impacts

3.4.3.1 Methodological issues

Micro-erosion is recorded at a site compartment level and it is defined in the field survey methodology as small scale interconnecting channels on a primary mire surface where the natural *Sphagnum* cover is becoming 'micro-broken' (Scottish Wildlife Trust 2010). This definition was extended to include fine-scale erosion caused by animal poaching, or other physical factors, across the peatland expanse in order to reflect the degraded nature of the sites surveyed (where in most cases *Sphagnum* species did not dominate vegetation cover).

Damage from burning was recorded at a whole site basis and was categorised as either 'recent' or 'historic'. The historic category was used for sites where the burn event appeared to have taken place more than two years ago as evidenced by charring of tree trunks, fence posts and the largest heather stems. Recent burning is likely to be seen as charring of finer vegetation, the ground layer and / or the peat surface. Damage from animals, both livestock and wild animals, was also recorded at a whole site level including grazing, trampling and dunging enrichment. Each type of damage was categorised as either 'insignificant', 'moderate' or 'heavy' and only one category was assigned to each site (i.e. the worst damage category present was assigned).

3.4.3.2 Current status

The damage data mapped and recorded at a site compartment level are the presence of bare peat and micro-erosion on the peatland surface (Figure 13). This data is derived from all sites surveyed during 2010/11.

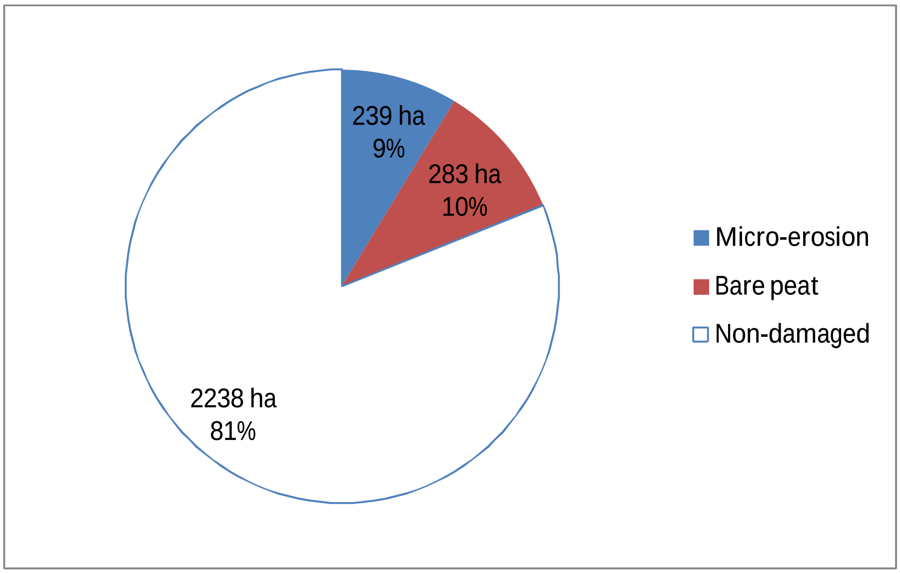


Figure 13. Peatland area categorised by damage category for all sites.

Bare peat and micro-erosion affects 19% of the restorable peatland area. The majority of recorded micro-erosion appears to be the result of livestock poaching.

A further erosion damage category not included in Figure 13 is gully erosion which was only recorded on three sites. The combined area subject to gully erosion is 14.4 hectares which is equivalent to 0.3% of the total restorable peatland area. A number of other sites had vegetated gullies that were not actively eroding, and these locations were target noted.

The bare peat category was recorded across five sites and in each case related to bare peat exposed by active commercial or semi-commercial peat cutting operations (Table 8). Areas that comprised a mosaic of vegetation and bare peat will have been captured by the 'micro-erosion' or 'gully erosion' categories or, if the result of regenerating vegetation or another factor, then target noted.

Table 8. Peatland area classed as bare peat for all sites.

Site name	Area (ha)
Craigmaud Moss	4
Creca Moss	28
Foggy Moss	1
Letham Moss	129
St Fergus Moss	121
Total	**283**

Photo 2. Commercial peat cutting at St Fergus Moss, Aberdeenshire.

Large-scale peat cutting operations occur at Creca Moss, Letham Moss and St Fergus Moss where 60% to 80% of the total surface area of each site is bare peat. The operations at Foggy Moss and Craigmaud Moss are semi-commercial in scale and bare peat accounts for 7% and 25% of their surface areas respectively.

Damage caused by animal grazing, trampling and dunging enrichment, as well as evidence of recent and historical burning, was also recorded on a whole site basis (Table 9).

Table 9. Presence of burning and animal damage for all sites.

Damage category	Present (no. sites)	Present (% sites)
Burning – recent and historic	13	22
Grazing - heavy	4	7
Trampling - heavy	1	2
Enrichment - heavy	2	3

In all cases the burning was classified as 'localised'. It was often difficult to determine whether each burn event was the result of vandalism or active management by the landowner, and it is likely that the recorded burns were a mix of the two. The presence of burning evidence was recorded at 13 sites (22% of the total), ten of which were categorised as 'recent' burns, and the remaining three were 'historic'.

The data on animal damage only includes grazing, trampling and enrichment damage categorised as 'heavy'. These were all classified as 'localised'. These categories of damage accounted for a small proportion of total sites ranging between 2% and 7% of total sites. Damage from animals makes no distinction between the impact from livestock or wild animals such as deer, however all instances of 'heavy' damage appeared to be the result of livestock, most commonly cattle.

Photo 3. Charred tree trunks indicating historic burning damage at Blar nam Fiadh, Highland region.

3.4.3.3 Comparison with 1994/5 survey

In order to make a comparison between the 1994/5 and the current survey an analysis is made of damage caused by animals and burning on a whole site basis (Figure 14).

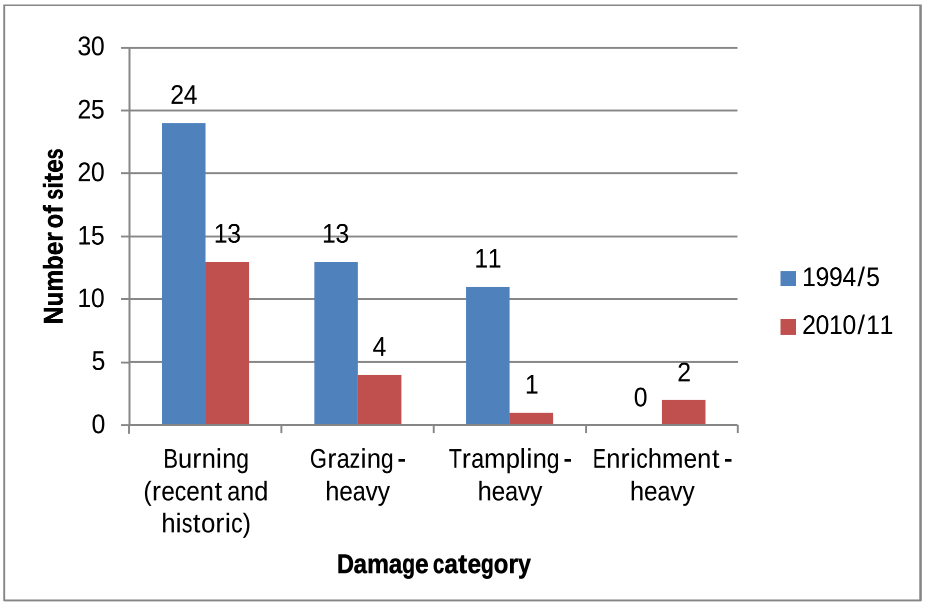


Figure 14. Presence of burning damage for all sites and animal damage for 60 sites – comparison of the 1994/5 and 2010/11 surveys.

The data for burning damage is based on all sites surveyed, whilst the data for animal damage is based on 56 sites (two sites from 1994/5 had no data available).

The results show a marked reduction in sites affected by burning, heavy grazing and heavy trampling damage between 1994/5 and 2010/11. Sites damaged by burning declined from 41% to 22% of the total, sites damaged by heavy grazing declined from 22% to 7% of the total and sites damaged by heavy trampling declined from 18% to 2% of the total. In contrast, the sites affected by heavy dunging enrichment show a small increase from 0% to 4%.

3.4.3.4 Analysis of results

The damage considered in this section, namely bare peat, micro-erosion, burning and the affects of animals, each have a fairly limited impact across the survey area. Each individual impact affects less than 10% of the total peatland area, or less than 10% of sites, with the exception of burning that affects 22% of sites. The impact of animal grazing and trampling would have appeared more widespread if 'moderate' impacts were also included in the presented data. However, moderate grazing and trampling may be beneficial in inhibiting regeneration of woodland and scrub at some sites, and so it is excluded as a damage category.

The comparison of damage impacts between the 1994/5 and 2010/11 surveys indicates a marked decline in damage from burning, animal grazing and animal trampling. These results appear to be consistent with the subjective observation of a reduction in active management and agricultural use of the surveyed sites between 1994/5 and the 2010/11. The reduction in livestock impacts may be the result of a cessation in grazing, a reduction in grazing intensity or a reduction in length of time grazed. It is also likely to be related to the reduction in burning impacts, in particular the managed burns that are carried out to increase an area's suitability for grazing (for example by reducing the dominance of sub-shrubs). The reduction in livestock grazing and active burning management may also, arguably, be a contributory factor in the increase in the recorded area of self-sown woodland between 1994/5 and 2010/11.

4 Peat depth and carbon storage

4.1 Peat depth

4.1.1 Methodological issues

The measurement of peat depth was an additional requirement for the 2010/11 survey; no measurements were carried out during 1994/5.

Peat depth sampling was undertaken using a set of ten steel rods measuring 1m in length and 10mm in diameter that were joined by means of a threaded connector (providing a maximum sampling depth of 10m). The leading end of the first rod was designed with a pointed tip and a threaded handle could be attached to the trailing end of the final rod.

In practice there was a limit to the depth that could be measured by a single operator using this equipment in the field and this related to the bulk density of the peat being sampled. The maximum sampling depth for typical wet areas of primary and secondary mire was between 5m and 7m whilst the maximum depth for areas of dry and compacted peat could be significantly less (one dense area of archaic peat could only be measured to a depth of 1m). Secondary mire on which well established woodland had been self-sown or planted could also provide a higher level of resistance and could restrict depth measurements to 3m or 4m.

The minimum requirement for each site was one depth measurement on primary mire (at the highest point of the dome in the centre of the site), one depth measurement on secondary mire (at a representative cut-over area) and one depth measurement near to the edge of the peatland expanse. In practice, if a site comprised only primary or secondary mire, or if secondary mire were only present at the edge of the mire, two samples fulfilled this requirement, but additional measurements were usually taken.

4.1.2 Results

Peat depth samples were taken from 55 sites out of a total of 58. Permission was refused at three sites, two of which were owned by peat extraction companies who cited commercial sensitivity for their refusal.

Primary mire peat depth samples were taken at 42 sites and the recorded depth ranged from 0.7m to 7.0m (if more than one primary depth measurement was made at a site the values were averaged). The average depth of primary mire for the 42 sites is 4.7m. However, this is an under-estimate of the true value because at 20 sites the measurements are a minimum figure only (i.e. the resistance of the peat was too great to allow the depth probe to reach the bottom of the profile). A summary of results categorised by range of depth is shown in Table 10.

Table 10. Summary of primary mire peat depth results categorised by range of depth.

Peat depth (m)	Sites (no.)	Sites (%)
0 to 2.4	6	14
2.5 to 4.9	13	31
5.0 to 7.5	23	55
Total	**42**	**100**

The results show that for primary mire 55% of sites fall into the 5.0m to 7.0m peat depth category, 31% fall into the 2.5m to 4.9m category and remaining 14% are less than 2.5m. Thirty two sites (76% of the total) have an average depth over 4.0m.

Secondary mire depth samples were taken at 44 sites and the average depth measurement per site ranged from 0.5m to 6.0m. These figures include one measurement that is a minimum figure only, where the bottom of the peat profile was not reached, and this was 6.0m. The average measured depth for the 44 sites is 2.2m.

4.2 Carbon storage

4.2.1 Methodological issues

A literature review of peatlands as a store of carbon, and a critical synthesis of related research, has been recently published by Lindsay (2010). The report proposes 'standard' peat carbon density related to mire condition, and these are used as the basis for the carbon storage figures calculated in the current study. These values relate mainly to blanket bog, where most research has been focused, however it is assumed that they remain relevant to the calculation of carbon stored by raised bogs.

The main factors determining the carbon content of peat are mineral matter content, proportion of organic matter, water content and bulk density. In practice the most variable factor is bulk density which is directly proportional to the amount of carbon stored in a unit volume of peat. Consequently, the major difficulty in calculating the carbon stored in raised bogs is determining sensible values for bulk density. A related question is how bulk density varies with depth and there are contradictory studies that show both an increase and decrease in density with greater depth.

Lindsay notes that measured bulk density values are almost exclusively taken from the top 1m of peat for both blanket and raised bog systems. There are two reasons for this; firstly, the UK's carbon database only includes the carbon stored in the top 1m of peat in its inventory, and secondly there are practical difficulties associated with taking measurements at a greater depth. There is some evidence to suggest that drained degraded peatland will have a compacted surface layer above the water table with a relatively high bulk density, whilst at a greater depth below the water table the peat will be effectively supported by water and have a lower bulk density. Nevertheless, for the purposes of this study it is assumed that bulk density is uniform throughout the raised bog peat profile.

The bulk density and carbon content of standard near-natural catotelm peat is quoted by Lindsay to be 0.1gcm^{-1} and 52kgCm^{-3} of peat respectively. At the other end of the scale Lindsay cites figures from Burton and Hodgson (1987) giving an average bulk density for English and Welsh lowland peats of 0.35gcm^{-3}, and it is speculated that these peats are mainly lowland raised bogs that have been drained. For the purposes of this study it is assumed that the best quality sites in terms of ground conditions have an average bulk density equivalent to the near-natural catotelm peat (0.1gcm^{-1} and 52kgCm^{-3} of peat) and that the poorest quality sites have average bulk density values three times greater (0.3gcm^{-3} 156kgCm^{-3} of peat). More specifically those sites with >60% of their surface area classed as wet are assumed to have an average carbon content of 52kgCm^{-3} of peat, those that are 30%-60% wet are assumed to have an average carbon content of 104kgCm^{-3} of peat, and those that are <30% wet are assumed to have an average carbon content of 156kgCm^{-3} of peat.

The results for the surveyed sites are extrapolated to provide a figure for all Scottish lowland raised bogs based on the peatland area data from SNH's Lowland Raised Bog Inventory. Those sites in the inventory that are principally archaic peat are excluded from the calculations and it is assumed that the whole Scottish resource has, on average, the same ratio of restorable peatland area to non-restorable peatland area as the surveyed sites. Furthermore they are assumed to have the same ratio of ground condition classes.

Other assumptions not covered above are stated in Section 4.2.2 'Results' below.

4.2.2 Results

The summary of results for carbon stored in the surveyed sites and in all Scottish lowland raised bogs is shown below (Table 11).

Table 11. Carbon stored in surveyed sites and all Scottish lowland raised bogs.

Survey area - restorable peatland area (ha)	2,760
Scottish resource - excluding archaic peat sites (ha)	23,861
Conversion factor (proportion of site that is restorable)	0.68
Survey area (MtC)	**10.1**
Scottish resource (MtC)	**59.4**

The assumptions relating to bulk density, in particular, are uncertain and the results for carbon stored in the survey sites and all Scottish sites should be treated with caution.

Additional calculation notes:

1. Volume of peat for each site surveyed is based on actual measurements of depth where available.
2. Where no peat depths were taken, primary and secondary peat depths are assumed to be the average for all measured sites.
3. For uncut primary mire, the measured peat depth at the centre of the site is assumed to be the average peat depth across the primary mire.
4. For cutover secondary mire, the measured representative peat depth is assumed to be the average peat depth across the secondary mire.

5. Stored carbon is only calculated for the restorable peatland area (archaic peat is excluded from the calculations).

It is estimated that the carbon stored in the 58 surveyed sites is 10.1MtC. An extrapolation to all Scottish raised bog sites for indicative purposes gives a figure of 59.4MtC.

Carbon storage figures broken down by site are presented in Appendix IV.

4.2.3 Analysis of results

The model underlying the calculation of stored carbon has a high level of uncertainty and the carbon estimates, particularly the estimate for all Scottish lowland raised bogs, should be treated with caution. The two areas of greatest potential error relate to the bulk density assumptions and the assumptions made on peat depth.

With regards to peat depth, limited peat depth samples were taken at each site and the assumption that the measurement of depth at the centre of primary mire is an average depth across the site may lead to an over-estimate of peat volume. A further source of error is the depth measurements taken from deep peat where, for a significant number of sites, the bulk density and resistance of the peat was too high to allow the peat depth tool to reach the bottom of the peat profile. This may have lead to an under-estimate of the volume of peat at these sites.

The calculated figures for the whole Scottish resource are, nevertheless, within the same order of magnitude as other published work. For example ECOSSE (2007) estimates that 123.6MtC is stored in Scottish 'basin peat', based on an area of 83,770 hectares and an average peat depth of 2.9m. Notwithstanding the high quoted value for the area of basin peat (83,770 hectares against 27,892 hectares from SNH's LRBI), and assuming basin peat is equivalent to lowland raised bog, after adjusting the figures to a unit area basis, the ECOSSE value for stored carbon is about 30% lower than the figure calculated in the current study. A report by the James Hutton Institute and partners for the IUCN and the Scottish Wildlife Trust estimates that a total of 71MtC is stored by Scottish lowland raised mires (*pers. comm*. Rebekka Artz, report in preparation). This figure is based on large scale soils series maps and is about 20% higher than the figure calculated in the current study.

The problem of assigning sensible bulk density values to lowland raised mire sites is discussed in Section 4.2.1 'Methodological issues' above. Further studies need to be undertaken on the bulk density of lowland raised bogs of varying condition before a more accurate estimate of stored carbon can be calculated.

5 Site condition assessment

5.1 Methodological issues

Sites surveyed during 2010/11 are assessed in terms of their quality or condition as lowland raised bogs and are ranked accordingly. Whilst the assessment uses data recorded during the survey, the choice of criteria and the scoring system used is necessarily subjective. Nevertheless the assessment aims to give high scores to factors that indicate favourable condition and low scores to factors that indicate a degraded or damaged condition in order to give a relative site quality score for all sites surveyed based on the restorable peatland area. The five criteria used in the assessment are positive indicator species, ground conditions, artificial drainage, closed canopy woodland and burning and grazing impacts.

In order to make a comparison of site condition between the 2010/11 and 1994/5 surveys a similar approach is used, with the exclusion of the ground conditions criterion which was not available for all sites from the original survey.

The positive indicator species scoring protocol is the same as that used to assess open mire vegetation (see Section 3.3 'Open mire vegetation'). An assessment of positive indicator species is arguably the most important indicator of site quality and is given double weighting compared to other criteria.

Ground conditions scores are based on the area of the site classified as wet. If less than 30% of the restorable peatland area is wet the site scores 0, if the wet area is 30% to 59% the score is 1 and if the wet area is greater than 60% the score is 2. For a definition of the ground condition 'wet' and 'dry' classifications see '3.3.1 Methodological issues'.

Artificial drainage scores are based on the presence or absence of drain type within the peatland expanse on a whole site basis. Sites that have scouring drains only score 0, those that have infilling and scoring drains score 1, those that have infilling drains only score 2 and those that have no drains or dammed drains score 3. For more information on the whole site drainage classification see '3.4.2.1 Methodological issues'.

Closed canopy woodland scores are based on the area of each site classified as broadleaved, conifer or mixed closed canopy woodland. If greater than 60% of the peatland area is occupied by closed canopy woodland the site scores 0, if the area is 30% to 59% the site scores 1 and if the area is less than 30% the site scores 2. For more information of the classification of closed canopy woodland see '3.4.1.1 Methodological issues'.

Burning and grazing impact scores were based on the presence or absence of burning and grazing damage on a whole site basis across the restorable peatland area. Grazing damage is defined as heavy animal grazing, trampling or enrichment impacts and burning damage is defined as either current or historical burning (as recorded during the survey). Sites that have both grazing and burning damage score 0, those with either burning or grazing damage score 1 and those sites with no burning or grazing damage score 2. For more information on the classification of this type of damage see '3.4.3.1 Methodological issues'.

5.2 Current status

The condition assessment scores on a site by site basis are shown in Table 12. The sites are ordered by decreasing total assessment score (best quality sites first).

Table 12. Condition assessment scores by site broken down by assessment criteria (SSSIs highlighted in blue).

Site name	Indicator species	Ground conditions	Drainage	Closed canopy woodland	Burning and grazing	Condition score
LOW MOSS	3	2	2	2	2	**11**
MOSSDALE	3	2	3	1	2	**11**
SHIRGARTON MOSS	3	2	3	1	2	**11**
DRUMBROIDER MOSS	2	2	2	2	2	**10**
EASTER GREENRIG	2	2	2	2	2	**10**
GREENWRAE FLOW	2	2	3	1	2	**10**
MOSS OF ACHNACREE	3	2	1	2	2	**10**
MOSSHOUSE FARM MOSS	2	2	2	2	2	**10**
RAEBURN FLOW	3	2	2	1	2	**10**
SHIELKNOWES	2	2	2	2	2	**10**
TEMPLE HILL (HARPERRIG MOSS)	2	2	2	2	2	**10**
WESTCRAIGS	2	2	2	2	2	**10**
EASTER REDBURN	1	2	2	2	2	**9**
MOSS OF CROMBIE	3	1	1	2	2	**9**
BURNFOOTHILL MOSS	3	1	2	1	1	**8**
CADGILL FLOW	2	2	2	1	1	**8**
CLAYSIKE (NEWBIGGING)	1	1	2	2	2	**8**
COWGARTH FLOW	2	1	2	2	1	**8**
CRAIGMAUD MOSS	2	0	2	2	2	**8**
MOSS OF REDHILLS	0	2	2	2	2	**8**
REDMOSS/BROADLEYS	2	0	2	2	2	**8**
SIDE MOSS	1	1	2	2	2	**8**
STEWARTFIELD	1	1	2	2	2	**8**
WHITE MOSS	1	1	2	2	2	**8**
BANKHEAD MOSS	1	0	3	1	2	**7**
BLACKHILLS MOSS	1	2	1	2	1	**7**

BLAR NAM FIADH	3	1	1	1	1	**7**
CULVIE MOSS	1	0	3	2	1	**7**
HILLHEAD	1	0	2	2	2	**7**
NETHER LONGFORD MOSS	1	1	2	2	1	**7**
NORTH COWFORDS MOSS	1	1	1	2	2	**7**
TAILEND MOSS	1	1	2	2	1	**7**
AUCHINDERRAN MOSS	0	2	0	2	2	**6**
BLAIRHILL	1	2	0	2	1	**6**
FOGGY MOSS	0	0	3	2	1	**6**
KELHEAD FLOW	3	0	1	0	2	**6**
KETTLEPOOL MOSS	0	2	2	0	2	**6**
MOSS OF BLACKHILLOCK	0	1	2	1	2	**6**
ST. CATHERINE'S WELLS	1	0	2	2	1	**6**
WHITLEY MOSS	1	0	2	1	2	**6**
CRAIBADONA MOSS	0	2	1	0	2	**5**
GARNKIRK MOSS	1	0	1	2	1	**5**
NEWTON OF MIDDLEMUIR	1	0	1	1	2	**5**
ROWAN BAUDS MOSS	1	0	2	0	2	**5**
AUCINTOUL MOSS	0	0	2	0	2	**4**
BALEARN MOSS	1	0	2	0	1	**4**
BRANTETH FLOW	0	0	2	0	2	**4**
CRECA MOSS	0	0	0	2	2	**4**
DUNMORE MOSS	1	0	2	0	1	**4**
LETHAM MOSS	0	0	0	2	2	**4**
ST. FERGUS MOSS	1	0	0	2	1	**4**
GLEDFIELD FARM MOSS	0	0	0	1	2	**3**
MOSS MORRAN	0	0	1	1	1	**3**
RASCARREL MOSS	1	0	1	0	1	**3**
REDHILLS MOSS	0	0	1	0	2	**3**
ARNHALL MOSS	0	0	0	0	2	**2**
GRAYSTONELEE	0	0	1	0	1	**2**
PRIESTSIDE FLOW	0	0	0	0	2	**2**

Three out of five of the SSSIs are in the top quartile of sites and the remaining two are within the second quartile.

5.3 Comparison with 1994/5 survey

A condition assessment score for each site is calculated for the 1994/5 survey and the current survey in order to allow a comparison to be made (Table 13). The results show that a third more sites show deterioration in condition over this period (48%), than show improvement (36%).

Table 13. Change in condition between 1994/5 and 2010/11 on a site by site basis for all sites.

Change in condition	Sites (no.)	%
Improved condition	21	36
Deteriorating condition	28	48
No change	9	16
Total	**58**	**100**

Of the 11 sites managed for conservation[3], the majority (64%) show improvement in condition (Table 14).

Table 14. Change in condition between 1994/5 and 2010/11 on a site by site basis for sites managed for conservation.

Change in condition	Sites	%
Improved condition	7	64
Deteriorating condition	2	18
No change	2	18
Total	**11**	**100**

The full results on a site by site basis are presented in Appendix V.

5.4 Analysis of results

The site assessment scoring protocol provides a snapshot of site quality at the time of survey and provides a relative ranking score as well as the basis for comparing site condition with an assessment undertaken at another time. This approach is unsuitable for comparing the assessed sites with other sites not assessed using the same methodology.

The results highlight sites that are designated SSSIs and it is notable that Side Moss (called Peeswit Moss under its SSSI designation) in Midlothian and Bankhead Moss in Fife are 22nd and 25th in the rankings respectively. Their designation as SSSIs may, in part, be based on the rarity of the habitat in their respective geographical locations but it also highlights the arbitrary nature of past site designation.

The method used to determine site condition is substantially different to the site condition methodology used by Scottish Natural Heritage (JNCC 2004), although the positive indicator species scoring protocol is adapted from this methodology. This is because the SNH method is designed as a rapid field assessment based on criteria recorded at various point locations. The data for the current 2010/11 survey were

[3] Five sites of Special Scientific Interest, four sites receiving environmental grants and two sites restored by the Scottish Wildlife Trust.

recorded on either a whole site basis or a mapped area basis, which is not compatible with the SNH approach.

The results of the comparison of site condition scores for all sites from the 1994/5 and 2011/12 surveys shows a significantly higher number of sites that have deterioration in condition compared to the number than have improved in condition. In contrast, when the subset of sites that have benefited from conservation management are considered the majority are found to have improved in condition, which indicates that restoration measures have a positive impact on site condition.

6 Site restoration

6.1 Attitudes to restoration by private landowners

Private landowners were questioned about their attitude to potential grant-aided site restoration. Each private landowner either wholly or part-owns one of the surveyed lowland raised bogs. Publicly owned sites (local councils and Forestry Enterprise), commercially operated sites, designated SSSIs and sites with unknown ownership were excluded from this survey.

Landowner responses were categorized as follows:

i) Fully supportive of grant-aided restoration with few reservations,
ii) Broadly supportive of grant-aided restoration but with reservations (e.g. the effect restoration measures would have on surrounding farmland and the level of grant available), and
iii) Not interested in grant-aided restoration.

Out of 41 private landowners surveyed, 39 (95%) are either fully supportive or broadly supportive of grant-aided restoration measures.

6.2 Site restoration costs

6.2.1 Approach to estimating restoration costs

The restoration of a lowland raised bog site involves reversing past damage and returning the habitat to a favourable condition. The main forms of damage affecting raised bogs are past and present peat cutting, the presence of scrub and woodland, and artificial drainage. Whilst removed peat cannot be put back in the short-term, restoration efforts can focus on the removal of scrub and woodland, and raising the water table by damming drainage ditches. There may also be ongoing management practices that cause damage, such as poaching damage from livestock and management of the bog vegetation by burning, and it may be possible to address these issues by entering into landowner management agreements.

The actual costs involved in restoring a site are likely to be fairly complex and based on a management prescription specific to each site. Nevertheless a reasonable estimate of costs can, arguably, be made based on past restoration project costs and on grants available for the restoration of raised bogs or similar habitats. This is the approach used to calculate the costs of restoration for the sites surveyed during 2010/11 and the survey results are used as the basis for these calculations. The estimated costs for the restoration of the surveyed sites are also extrapolated to provide indicative restoration costs for the whole Scottish raised bog resource.

Restoration cost information from grants is taken from the South Scotland Bog Scheme (SSBS) which is specific to raised bogs (SNH 2006) and the Scotland Rural Development Programme (SRDP) which includes items that apply to both raised and blanket bogs (SNH 2011). Cost information is also available for recent and current blanket bog restoration work being undertaken by the RSPB at Forsinard in Sutherland, Scotland (Norrie Russell pers. comm.). Other blanket bog restoration projects being overseen by SNH and other conservation bodies have been collated by the IUCN (Clifton Bain *pers. comm*.). The restoration costs from a project at Lake Vyrnwy in Powys, Wales, undertaken between 2009 and 2011, are also used in the current calculations.

A number of broad assumptions are made when calculating site restoration costs. For example, it is assumed that the example costs relating to blanket bog projects can be applied to raised bog sites, and that the size of the site has no bearing on cost (many of the raised bog sites are relatively small in size and may not benefit from economies of scale). Furthermore, although past project costs are necessarily historic, it is assumed that inflation has no bearing on current or future costs.

The estimate of capital and annual management costs covers the restorable peatland area and excludes areas of archaic peat and non-peat. It is assumed that agriculturally improved or urbanised archaic peat cannot be restored.

All other specific assumptions are outlined in Section 6.2.2 'Restoration cost calculations'.

6.2.2 Restoration cost calculations

The capital costs considered in the calculations are scrub removal and control, woodland removal and control, and the installation of dams to block drainage ditches. The 2010/11 survey generated data on scrub, woodland and drainage density category types by area for the entire peatland area and these data are used as the basis for estimating restoration costs.

Estimates of the capital restoration costs for the sites surveyed during 2010/11 are summarised in Table 15. A breakdown of costs on a site by site basis is provided in Appendices II and III.

Table 15. Estimate of capital costs of restoration for all 2010/11 survey sites.

Capital expenditure category (all survey sites)	Cost (£)
Scrub clearance	259,600
Tree clearance	1,904,700
Dam installation	1,372,600
Total	**3,536,900**

The estimates of restoration capital costs are based on the following assumptions:

1. Open scrub is equivalent to 'light scrub' under the SSBS and SRDP. The clearance and treatment cost per hectare is an average of the SSBS and SRDP figures (£525/ha).
2. Closed scrub is equivalent to 'intermediate scrub' under the SSBS and SRDP. The clearance and treatment cost per hectare is an average of the SSBS and SRDP figures (£900/ha).
3. Removal of cut material is only required for closed scrub, cut open scrub is left on site (£1,050/ha).

4. The cost per hectare of clearing closed canopy conifers is an average of Forsinard and Lake Vyrnwy figures (£2,050/ha). The cost of control of regeneration up to five years post-felling is based on Forsinard figures (£380/ha in total).
5. The clearance of open conifer woodland is equivalent to 'felling to waste of young/low yielding conifers' from the Lake Vyrnwy project and 'shear to waste of small to medium lodgepole pine/sitka spruce trees' from the Forsinard project. The clearance cost per hectare value used is an average of the figures from these two projects (£744/ha).
6. The income generated from the timber produced by closed conifer plantation clearance assumes a timber yield of 120-140 tonnes per hectare and income of £1,000-£2,400 per hectare (based on the Forsinard project). The lower value from the income range is used (£1,000/ha).
7. The cost of clearance and control of regeneration of closed canopy and open canopy broadleaved and mixed woodland is equivalent to the costs associated with the clearance of closed and open canopy conifer plantations (no past project or grant-aided costs specific to clearing broadleaved or mixed woodland from peatland sites are available).
8. The income generated from the timber produced by closed canopy broadleaved and mixed woodland clearance is zero.
9. Narrow-spaced drains are 7.5m apart on average (or equivalent density if not parallel), moderate-spaced drains are 30m apart on average, and wide-space drains are 75m apart on average.
10. The recorded drain density category is equivalent to the actual drain density (N.B. the actual drain length was not measured either in the field or from aerial photographs).
11. Installed dams are 'medium' plastic piling and (1m wide x 1m deep) as defined by the SSBP and SDRP. The cost of installing each dam is the average of the SSBP and SDRP figures (£90).
12. The gradient is equivalent to a 1m drop every 200m and a dam is installed at every 0.25m drop (therefore every 50m).
13. Conifer plantation has wide-spaced drains by default for the purposes of costing dam installation post-felling. The 2010/11 survey generally classed the furrows created by the ridge and furrow planting technique to be drains and therefore categorised the drains as narrow-spaced. However, it is assumed that only the major drainage channels are dammed in practice (for example this was the case at Longbridge Muir).
14. Sites that have dams installed are excluded from the dam installation cost calculations.
15. Areas of bare peat (at commercial peat extraction sties) regenerate naturally without the need for specific re-vegetation techniques.

The principle capital costs that are excluded from these calculations are those associated with site livestock grazing (to inhibit scrub and tree regeneration), the realignment of perimeter drains, the provision of buffer land and the commissioning of a management plan. These costs are site-specific and the information recorded during the survey is not suitable for estimating the requirement for these capital costs.

Annual management costs are also estimated and presented in Table 16.

Table 16. Annual management costs for all 2010/11 survey sites.

Annual expenditure (all sites)	**Cost (£/yr)**
Grazing	75,200
Monitoring and maintenance of dams	26,100
Scrub control monitoring	8,700
Total	**110,000**

The estimate of annual management costs is based on the following assumptions:

1. Grazing is required to inhibit regeneration of scrub and trees across all areas of primary and secondary mire (including recently felled areas).
2. Annual grazing management costs are equivalent to those detailed in the SSBP (£40/yr/ha for the first 50 hectares, £10/yr/ha thereafter with a maximum cost of £3,000 per site).
3. The costs associated with the monitoring and maintenance of dams are equivalent to those detailed in the SSBP (a flat £450 per site).
4. Scrub control and monitoring costs are equivalent to those detailed in the SSBP (a flat £150 per site)

N.B. The annual management costs taken from the SSBP for 'monitoring and maintenance of dams' and for 'scrub control and monitoring' are not related to site size and are likely to significantly under-estimate the costs for larger sites.

The main annual management costs excluded from these calculations are general management costs and treatment of invasive species such as *Rhododendron ponticum*.

For indicative purposes the restoration costs are extrapolated to cover the whole Scotland raised bog resource based on figures for the extent of the resource taken from SNH's lowland raised bog inventory (LRBI) (Lindsay and Immirzi 1996). The extrapolated figures are presented in Table 17.

Table 17. Extrapolation of the annual management and capital costs to the whole Scotland resource.

Extrapolation (based on all surveyed sites)	Value	Unit
Survey area (restorable peatland area)	2,760	ha
Survey area (sites)	58	sites
All Scottish raised peat bogs (area - excl archaic peat sites)*	23,861	ha
Conversion factor (proportion of site that is restorable)	0.68	
All Scottish raised peat bogs (restorable area)	16,225	ha
Capital cost of restoration (survey area)	3,536,937	£
Capital cost of restoration by unit area (survey area)	1,281	£/ha
Annual management cost (survey area)	109,954	£/yr
Annual management cost by unit area (survey area)	40	£/yr/ha
Capital cost of restoration (all Scottish raised peat bogs)	**20,792,934**	**£**
Annual management cost (all Scottish raised peat bogs)	**646,397**	**£/yr**

*unclassified sites are assumed to be restorable

The extrapolated figures are based on the same underlying assumptions detailed for the calculation of the survey area restoration costs. More specifically, these figures are based on the assumption that the capital and annual restoration costs per unit area of the 2010/11 survey area are equivalent to the restoration costs per unit area of the whole Scotland raised bog resource.

Table 18 gives the cost of restoring 50 sites of a typical 34 hectare size.

Table 18. Calculations for the cost of restoring 50 sites of 34 hectares each.

Cost of restoring 50 sites (average size 34 ha)		
Number of sites	50	sites
Average size of site (area)	34	ha
Conversion factor (proportion of site that is restorable)	0.68	
Capital cost of restoration by unit area (survey area)	1,281	£/ha
Annual management cost by unit area (survey area)	40	£/yr/ha
Capital cost of restoration (1 site)	29,628	£
Annual management cost (1 site)	921	£/yr
Capital cost of restoration (50 sites)	1,481,413	£
Annual management cost (50 sites)	46,053	£/yr

6.2.3 Analysis of estimated costs

The calculation of the survey area and whole Scotland restoration costs are based on a large number of assumptions and there will therefore be a large margin of error implicit in the stated values.

With regard to the estimated capital costs for the 2010/11 survey area, the values for clearance of scrub and woodland are likely to be fairly accurate, notwithstanding the assumption that the clearance costs of broadleaves are equivalent to conifers. The boundary of scrub and woodland shows up clearly on aerial photographs and the use of ArcGIS for mapping, combined with corrections made at the ground-truthing stage, should allow accurate area data to be generated. Furthermore the assumed costs of clearing woodland and scrub on a per hectare basis are unlikely to vary from site to site assuming that vehicular access is reasonable (which is likely to be the case for lowland raised bogs). The estimates of damming costs are, however, more problematical because the values generated are very sensitive to the underlying assumptions. For example, the gradient of the mire surface will vary depending on whether it has been cut-over or whether it is a primary mire with a pronounced dome. It is assumed that dams are installed on average every 50m along drainage ditches; if this average were in fact every 25m the cost of installing dams across the total peatland area of the sites surveyed during 2010/11 would double from £1.4m to £2.8m. Furthermore the 2010/11 survey did not record the size of ditches and the assumption that all ditches require medium plastic piling dams may be an over-estimate of costs.

Annual management costs are likely to be more difficult to estimate because they will be site and project specific. The figures used to estimate these costs have been taken from the South Scotland Bog Scheme (SNH 2006) and there are two main areas of uncertainty. The first concerns the project specific levels of grant-aid for grazing, monitoring and maintenance used by the SSBS which do not appear directly related to actual costs (they may be designed in part to influence behaviour). The second is the application of grazing costs to the entire 2010/11 restorable peatland area. Not all sites have a problem with regeneration of scrub and woodland, and the degree of regeneration post-felling is difficult to predict, therefore the estimated cost of grazing may be an over-estimate. Furthermore the flat rate for 'monitoring and maintenance of dams' and for 'scrub control and monitoring' are likely to be too low for large sites and therefore the values for the study sites and the extrapolated figures for all Scottish sites may be an under-estimate.

The capital and annual management restoration costs for the survey area are also extrapolated to cover the whole of Scotland raised bog resource based on area data taken from the lowland raised bog inventory (LRBI) (Lindsay and Immirzi 1996). As stated in Section 4.2 'Restoration cost calculations' these figures should be only considered as indicative because they are based on the assumption that the surveyed sites are representative of the Scottish raised bogs indentified in the LRBI that were not surveyed. There is some evidence to suggest that this is not the case. During the 2010/11 survey 58 sites were surveyed with an average site area of 70 hectares whilst the remaining 749 un-surveyed sites have an average area of 29 hectares. It is therefore likely that the un-surveyed sites contain a higher proportion of small degraded raised bogs that will have a higher cost of restoration on a unit area basis.

7 Conclusion

Analysis of the current status of the 2010/11 surveyed sites demonstrates that they suffer from a high level of degradation and damage. This is clear from the high proportion of sites that have artificial drainage ditches present across the peatland expanse, and the high proportion of the restorable peatland area that has been colonised by scrub and woodland. These and other forms of damage have significantly impacted on the extent and quality of natural raised bog vegetation. This has resulted in *Sphagnum* dominated areas accounting for only a small proportion of the restorable peatland area which illustrates the limited potential sites have for peat accumulation and carbon sequestration in their existing condition.

A comparison of the 2011/12 and 1994/5 surveys indicates a net deterioration in condition over 17 years, particularly when sites managed for conservation are excluded from the results. This is despite evidence of less intensive use and management of sites overall which has led to some positive effects such as less livestock trampling damage and reduced maintenance of artificial drains. However, these effects appear to be outweighed by negative factors such as the increase in self-sown woodland and the continued deterioration in the hydrological condition of sites.

The comparison results show a clear trend of increasing numbers of sites with drains that are naturally infilling with vegetation and decreasing numbers of sites with scouring drains. However there is no evidence of an improvement in ground conditions or in the quality of mire vegetation (that would indicate a rising water table). This may be the result of an over-riding drying effect from another factor such as the increase in self-sown woodland cover. Alternatively, it may indicate that infilling drains remain hydrologically active for a considerable period of time or that the perimeter drains have a disproportionately greater effect on overall site hydrology compared to the drains within the peatland expanse.

It can therefore be concluded that site neglect alone will be insufficient to allow damaged sites to return to a more natural condition. This reinforces the need for active restoration to counteract past damage and to bring sites into a favourable condition. Furthermore, a programme of site restoration will have clear wildlife benefits whilst reducing carbon emissions and promoting the long-term storage of carbon through peat accumulation. There is also historical evidence that lowland raised bog sites that are in good condition are more resilient and able to adapt to climate change.

Restoration effort should focus on work that will raise the water table and maintain an open mire habitat. In practice this may include the removal of woodland and scrub, the installation of dams, the use of livestock to inhibit woodland regeneration, and the creation of buffer zones at the peatland margin.

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9 Appendices

Appendix I – Site area and other selected area data by site

Site name	Site area (ha)	Restorable peatland area (ha)	Closed canopy woodland (ha)	Sphagnum dominated (ha)
ARNHALL MOSS	12.7	7.6	7.6	0.0
AUCHINDERRAN MOSS	32.3	13.1	1.2	0.1
AUCINTOUL MOSS	94.3	74.4	55.7	7.1
BALEARN MOSS	177.1	171.7	117.3	0.0
BLAIRHILL	34.8	9.2	0.0	0.0
BLAR NAM FIADH	62.4	51.9	22.5	22.6
BRANTETH FLOW	50.1	37.8	35.5	0.0
BURNFOOTHILL MOSS	22.9	12.1	6.5	0.6
Bankhead Moss	12.5	7.6	4.2	0.0
BLACKHILLS MOSS	19.5	10.3	0.0	0.0
CADGILL FLOW	26.7	26.4	9.6	9.0
CLAYSIKE (NEWBIGGING)	42.6	10.9	1.7	0.0
COWGARTH FLOW	14.3	12.0	1.2	6.2
CRAIBADONA MOSS	26.2	16.1	12.9	0.0
CRAIGMAUD MOSS	19.8	17.0	0.0	0.0
CRECA MOSS	46.5	38.4	5.6	0.0
CULVIE MOSS	26.5	15.8	2.9	2.1
DRUMBROIDER MOSS	23.9	21.9	2.1	13.5
DUNMORE MOSS	129.5	117.4	72.5	20.3
EASTER GREENRIG	17.8	17.8	0.0	1.1
EASTER REDBURN	12.9	3.2	0.0	2.0
FOGGY MOSS	16.9	15.7	0.7	0.0
GARNKIRK MOSS	142.1	62.0	12.6	0.0
GLEDFIELD FARM MOSS	25.2	6.7	2.2	0.0
GRAYSTONELEE	125.3	36.5	36.2	0.0
GREENWRAE FLOW	23.6	18.2	9.5	0.5
HILLHEAD	13.9	12.4	0.0	0.0
KELHEAD FLOW	38.8	37.9	31.2	3.3
KETTLEPOOL MOSS	46.0	5.3	3.6	0.0
LETHAM MOSS	167.3	165.8	29.6	0.0
LOW MOSS	31.5	21.1	0.0	6.6
MOSS MORRAN	397.0	126.3	37.9	0.0
MOSS OF ACHNACREE	338.6	236.9	13.2	91.7
MOSS OF BLACKHILLOCK	30.0	10.6	3.8	0.0
MOSS OF REDHILLS	34.9	28.8	0.0	0.0
MOSSDALE	9.5	6.4	3.7	2.8

MOSS OF CROMBIE	155.3	149.7	8.8	0.0
MOSSHOUSE FARM MOSS	6.7	3.8	0.0	0.0
NETHER LONGFORD MOSS	58.9	35.3	4.3	3.3
NEWTON OF MIDDLEMUIR	17.7	13.1	6.3	2.4
NORTH COWFORDS MOSS	19.8	13.2	2.2	0.0
PRIESTSIDE FLOW	228.1	76.7	76.7	0.0
RASCARREL MOSS	209.5	150.1	131.9	0.0
REDHILLS MOSS	156.7	84.0	68.0	0.0
REDMOSS/BROADLEYS	17.9	8.4	0.0	0.0
ROWAN BAUDS MOSS	85.3	60.2	36.8	2.2
RAEBURN FLOW	77.6	71.2	23.1	39.8
SHIELKNOWES	32.5	13.8	0.0	4.4
ST. CATHERINE'S WELLS	27.0	27.0	0.9	0.0
ST. FERGUS MOSS	210.0	188.3	0.0	0.3
STEWARTFIELD	20.8	20.8	0.0	0.0
SHIRGARTON MOSS	38.4	38.4	12.3	18.9
SIDE MOSS	53.1	47.7	1.8	0.0
TEMPLE HILL (HARPERRIG MOSS)	43.4	43.4	0.0	0.0
TAILEND MOSS	33.4	28.2	4.0	0.0
WESTCRAIGS	24.6	19.4	0.0	17.0
WHITE MOSS	92.9	83.6	9.4	3.8
WHITLEY MOSS	104.0	99.8	51.7	9.5
Total	**4,060**	**2,760**	**982**	**288**

Appendix II – Capital restoration costs by site

Site	Scrub costs (£)	Woodland costs (£)	Dam costs (£)	Total (£)
ARNHALL MOSS	0.00	18,498.86	3,856.27	22,355.13
AUCHINDERRAN MOSS	17,658.23	4,158.90	1,245.21	23,062.33
AUCINTOUL MOSS	388.25	79,615.25	12,895.51	92,899.00
BALEARN MOSS	5,429.43	167,726.99	81,611.93	254,768.35
BLAIRHILL	0.00	0.00	275.21	275.21
BLAR NAM FIADH	3,284.97	32,143.25	6,719.78	42,148.00
BRANTETH FLOW	0.00	50,724.25	9,083.16	59,807.41
BURNFOOTHILL MOSS	0.00	9,730.20	3,377.73	13,107.94
BANKHEAD MOSS	0.00	8,358.52	0.00	8,358.52
BLACKHILLS MOSS	6,298.81	0.00	793.73	7,092.54
CADGILL FLOW	0.00	25,371.93	4,896.52	30,268.45
CLAYSIKE (NEWBIGGING)	436.75	4,195.15	3,272.79	7,904.69
COWGARTH FLOW	0.00	2,868.37	2,332.14	5,200.51
CRAIBADONA MOSS	0.00	33,737.26	7,678.70	41,415.96
CRAIGMAUD MOSS	779.57	0.00	2,132.04	2,911.62
CRECA MOSS	5,810.61	15,838.09	74,834.42	96,483.12
CULVIE MOSS	2,291.06	9,152.39	0.00	11,443.44
DRUMBROIDER MOSS	0.00	5,210.41	3,546.29	8,756.70
DUNMORE MOSS	20,543.61	188,278.39	61,302.05	270,124.05
EASTER GREENRIG	0.00	0.00	3,719.69	3,719.69
EASTER REDBURN	0.00	0.00	628.52	628.52
FOGGY MOSS	1,024.55	4,825.53	0.00	5,850.08
GARNKIRK MOSS	38,066.93	43,382.87	15,127.16	96,576.95
GLEDFIELD FARM MOSS	1,267.11	3,895.59	513.84	5,676.55
GRAYSTONELEE	506.81	81,413.23	72,371.21	154,291.24
GREENWRAE FLOW	951.21	28,262.28	498.19	29,711.68
HILLHEAD	0.00	0.00	2,525.28	2,525.28
KELHEAD FLOW	0.00	49,603.69	11,445.90	61,049.59
KETTLEPOOL MOSS	0.00	8,805.83	847.97	9,653.80
LETHAM MOSS	1,133.21	71,962.26	95,566.85	168,662.33
LOW MOSS	0.00	0.00	50,630.95	50,630.95
MOSS MORRAN	0.00	85,897.98	188,061.74	273,959.72
MOSS OF ACHNACREE	14,632.49	34,604.53	32,910.04	82,147.06
MOSS OF BLACKHILLOCK	362.12	10,899.64	930.27	12,192.03
MOSS OF REDHILLS	12,440.69	717.22	1,810.29	14,968.20
MOSSDALE	0.00	5,273.55	0.00	5,273.55
MOSS OF CROMBIE	30,743.89	21,488.98	0.00	52,232.86
MOSSHOUSE FARM MOSS	0.00	0.00	701.20	701.20

NETHER LONGFORD MOSS	1,748.18	8,855.41	22,754.82	33,358.41
NEWTON OF MIDDLEMUIR	1,416.29	16,004.01	4,249.02	21,669.32
NORTH COWFORDS MOSS	5,809.59	4,036.38	1,793.87	11,639.84
PRIESTSIDE FLOW	0.00	115,959.15	17,950.98	133,910.13
RASCARREL MOSS	0.00	197,870.08	64,557.66	262,427.75
REDHILLS MOSS	0.00	157,845.28	26,755.44	184,600.72
REDMOSS/BROADLEYS	85.79	0.00	2,129.21	2,214.99
ROWAN BAUDS MOSS	23,515.25	90,146.94	10,936.62	124,598.81
RAEBURN FLOW	9,513.47	54,602.03	5,612.82	69,728.32
SHIELKNOWES	0.00	1,287.05	5,464.11	6,751.16
ST. CATHERINE'S WELLS	530.36	2,222.96	8,061.65	10,814.97
ST. FERGUS MOSS	0.00	0.00	304,689.61	304,689.61
STEWARTFIELD	0.00	0.00	1,763.21	1,763.21
SHIRGARTON MOSS	10,969.34	32,409.30	0.00	43,378.63
SIDE MOSS	0.00	2,591.73	31,510.86	34,102.60
TEMPLE HILL (HARPERRIG MOSS)	0.00	0.00	8,362.22	8,362.22
TAILEND MOSS	0.00	10,657.47	4,298.46	14,955.93
WESTCRAIGS	0.00	0.00	3,979.03	3,979.03
WHITE MOSS	33,976.61	23,907.89	53,097.49	110,981.98
WHITLEY MOSS	8,025.23	79,649.75	36,499.99	124,174.96
Total	**259,640**	**1,904,687**	**1,372,610**	**3,536,937**

Appendix III – Annual management restoration costs by site

Site	Grazing cost (£/yr)	Monitoring and maintenance of dams (£/yr)	Scrub control monitoring (£/yr)	Total (£/yr)
ARNHALL MOSS	304.51	450.00	150.00	904.51
AUCHINDERRAN MOSS	524.47	450.00	150.00	1,124.47
AUCINTOUL MOSS	2,244.25	450.00	150.00	2,844.25
BALEARN MOSS	3,000.00	450.00	150.00	3,600.00
BLAIRHILL	366.00	450.00	150.00	966.00
BLAR NAM FIADH	2,018.77	450.00	150.00	2,618.77
BRANTETH FLOW	1,512.84	450.00	150.00	2,112.84
BURNFOOTHILL MOSS	485.24	450.00	150.00	1,085.24
BANKHEAD MOSS	302.69	450.00	150.00	902.69
BLACKHILLS MOSS	412.67	450.00	150.00	1,012.67
CADGILL FLOW	1,056.98	450.00	150.00	1,656.98
CLAYSIKE (NEWBIGGING)	436.05	450.00	150.00	1,036.05
COWGARTH FLOW	478.45	450.00	150.00	1,078.45
CRAIBADONA MOSS	642.05	450.00	150.00	1,242.05
CRAIGMAUD MOSS	680.99	450.00	150.00	1,280.99
CRECA MOSS	1,536.05	450.00	150.00	2,136.05
CULVIE MOSS	631.19	450.00	150.00	1,231.19
DRUMBROIDER MOSS	875.47	450.00	150.00	1,475.47
DUNMORE MOSS	2,674.16	450.00	150.00	3,274.16
EASTER GREENRIG	711.41	450.00	150.00	1,311.41
EASTER REDBURN	129.27	450.00	150.00	729.27
FOGGY MOSS	629.26	450.00	150.00	1,229.26
GARNKIRK MOSS	2,120.50	450.00	150.00	2,720.50
GLEDFIELD FARM MOSS	266.88	450.00	150.00	866.88
GRAYSTONELEE	1,460.32	450.00	150.00	2,060.32
GREENWRAE FLOW	728.00	450.00	150.00	1,328.00
HILLHEAD	497.30	450.00	150.00	1,097.30
KELHEAD FLOW	1,517.09	450.00	150.00	2,117.09
KETTLEPOOL MOSS	212.76	450.00	150.00	812.76
LETHAM MOSS	3,000.00	450.00	150.00	3,600.00
LOW MOSS	845.96	450.00	150.00	1,445.96
MOSS MORRAN	2,762.63	450.00	150.00	3,362.63
MOSS OF ACHNACREE	3,000.00	450.00	150.00	3,600.00
MOSS OF BLACKHILLOCK	424.87	450.00	150.00	1,024.87
MOSS OF REDHILLS	1,151.41	450.00	150.00	1,751.41
MOSSDALE	257.74	450.00	150.00	857.74
MOSS OF CROMBIE	2,997.19	450.00	150.00	3,597.19

MOSSHOUSE FARM MOSS	152.28	450.00	150.00	752.28
NETHER LONGFORD MOSS	1,413.45	450.00	150.00	2,013.45
NEWTON OF MIDDLEMUIR	524.24	450.00	150.00	1,124.24
NORTH COWFORDS MOSS	527.82	450.00	150.00	1,127.82
PRIESTSIDE FLOW	2,267.14	450.00	150.00	2,867.14
RASCARREL MOSS	3,000.00	450.00	150.00	3,600.00
REDHILLS MOSS	2,340.31	450.00	150.00	2,940.31
REDMOSS/BROADLEYS	335.12	450.00	150.00	935.12
ROWAN BAUDS MOSS	2,101.57	450.00	150.00	2,701.57
RAEBURN FLOW	2,211.56	450.00	150.00	2,811.56
SHIELKNOWES	553.15	450.00	150.00	1,153.15
ST. CATHERINE'S WELLS	1,081.72	450.00	150.00	1,681.72
ST. FERGUS MOSS	3,000.00	450.00	150.00	3,600.00
STEWARTFIELD	830.38	450.00	150.00	1,430.38
SHIRGARTON MOSS	1,537.36	450.00	150.00	2,137.36
SIDE MOSS	1,909.18	450.00	150.00	2,509.18
TEMPLE HILL (HARPERRIG MOSS)	1,735.64	450.00	150.00	2,335.64
TAILEND MOSS	1,129.24	450.00	150.00	1,729.24
WESTCRAIGS	774.96	450.00	150.00	1,374.96
WHITE MOSS	2,335.58	450.00	150.00	2,935.58
WHITLEY MOSS	2,497.87	450.00	150.00	3,097.87
	75,154	**26,100**	**8,700**	**109,954**

Appendix IV – Carbon storage estimates by site

Site	primary (ha)	Depth (m)	secondary (ha)	Depth (m)	Volume (m3)	Factor*	kg C/m3**	C (tonne)	C (Mt)
ARNHALL	0.0	0	7.6	1.4	106578	3	52	16626	0.02
AUCHINDERRAN MOSS	0.4	4.7	12.7	0.7	107439	1	52	5587	0.01
AUCINTOUL MOSS	55.1	0.65	19.3	0.5	454787	3	52	70947	0.07
BALEARN MOSS	19.2	6	152.5	1.4	3288475	3	52	513002	0.51
BLAIRHILL	3.3	5	5.8	2.3	300406	1	52	15621	0.02
BLAR NAM FIADH	43.4	5	8.5	2.4	2373208	2	52	246814	0.25
BRANTETH FLOW	36.8	5.5	1.0	2.2	2046112	3	52	319194	0.32
BURNFOOTHILL MOSS	1.8	6	10.3	2.7	387198	2	52	40269	0.04
BANKHEAD MOSS	7.2	7	0.4	2.2	510341	3	52	79613	0.08
BLACKHILLS MOSS	2.6	2.8	7.7	1	149504	1	52	7774	0.01
CADGILL FLOW	9.0	7	17.4	1.5	891509	1	52	46358	0.05
CLAYSIKE (NEWBIGGING)	5.1	6	5.8	6	654072	2	52	68023	0.07
COWGARTH FLOW	11.1	5	0.8	2.1	574445	2	52	59742	0.06
CRAIBADONA MOSS	3.1	2.2	12.9	2	327274	1	52	17018	0.02
CRAIGMAUD MOSS	8.9	4.7	8.1	2.2	597171	3	52	93159	0.09
CRECA MOSS	3.0	4.7	35.4	2.1	884069	3	52	137915	0.14
CULVIE MOSS	2.5	2.1	13.3	1.45	245231	3	52	38256	0.04
DRUMBROIDER MOSS	16.1	5	5.8	2.4	943878	1	52	49082	0.05
DUNMORE MOSS	0.0	0	117.4	2.6	3052811	3	52	476238	0.48
EASTER GREENRIG	11.4	6.1	6.4	2	824521	1	52	42875	0.04
EASTER REDBURN	2.7	4.2	0.5	1.2	119360	1	52	6207	0.01
FOGGY MOSS	0.9	1	14.9	0.6	97887	3	52	15270	0.02
GARNKIRK MOSS	8.6	5.7	53.4	5.2	3269701	3	52	510073	0.51

GRAYSTONELEE	36.5	2.8	0.0	0	1022227	3	52	159467	0.16
GLEDFIELD FARM MOSS	0.0	0	6.7	1.45	96744	3	52	15092	0.02
GREENWRAE FLOW	13.5	4.4	4.7	2.2	698126	1	52	36303	0.04
HILLHEAD	0.0	0	12.4	1.15	142975	3	52	22304	0.02
KELHEAD FLOW	20.7	6	17.2	2.2	1620989	3	52	252874	0.25
KETTLEPOOL MOSS	0.0	0	5.3	1.65	87765	1	52	4564	0.00
LETHAM MOSS	21.4	4.7	144.4	2.2	4182499	3	52	652470	0.65
LOW MOSS	21.1	6	0.0	0	1268946	1	52	65985	0.07
MOSS MORRAN	5.3	3.6	121.0	1.6	2126070	3	52	331667	0.33
MOSS OF ACHNACREE	214.2	2.15	22.7	1.15	4866041	1	52	253034	0.25
MOSS OF BLACKHILLOCK	0.0	0	10.6	1.15	122150	2	52	12704	0.01
MOSSDALE	6.4	5	0.0	0	322170	1	52	16753	0.02
MOSS OF REDHILLS	0.0	0	28.8	0.9	259068	1	52	13472	0.01
MOSS OF CROMBIE	27.6	4.75	122.1	1.4	3020486	2	52	314131	0.31
MOSSHOUSE FARM MOSS	3.7	4	0.1	2.2	150066	1	52	7803	0.01
NETHER LONGFORD MOSS	34.5	5.2	0.9	2.2	1810965	2	52	188340	0.19
NEWTON OF MIDDLEMUIR	0.0	0	13.1	4.45	583217	3	52	90982	0.09
NORTH COWFORDS MOSS	7.0	4.4	6.2	3.7	537343	2	52	55884	0.06
PRIESTSIDE FLOW	70.5	4.5	6.3	2.2	3308162	3	52	516073	0.52
RASCARREL MOSS	0.0	0	150.1	3.7	5555021	3	52	866583	0.87
REDHILLS MOSS	0.0	0	84.0	4	3361244	3	52	524354	0.52
REDMOSS/BROADLEYS	0.0	0	8.4	3.65	305801	3	52	47705	0.05
ROWAN BAUDS MOSS	33.7	1.05	26.5	0.7	538927	3	52	84073	0.08
RAEBURN FLOW	44.3	6	26.9	1.35	3019116	1	52	156994	0.16

SHIELKNOWES	13.2	6.8	0.6	4.4	925176	1	52	48109	0.05
ST. CATHERINE'S WELLS	0.0	0	27.0	1.35	365081	3	52	56953	0.06
ST. FERGUS MOSS	9.5	4.7	178.8	2.2	4379465	3	52	683196	0.68
STEWARTFIELD	10.7	4.4	10.1	3.3	802755	2	52	83486	0.08
SHIRGARTON MOSS	31.8	6	6.6	1.9	2035196	1	52	105830	0.11
SIDE MOSS	44.1	7	3.6	3.1	3199752	2	52	332774	0.33
TEMPLE HILL (HARPERRIG MOSS)	40.0	6	3.3	0.95	2434527	1	52	126595	0.13
TAILEND MOSS	20.2	7	8.0	2.4	1608586	2	52	167293	0.17
WESTCRAIGS	17.6	5.1	1.8	2.2	937186	1	52	48734	0.05
WHITE MOSS	52.3	4.9	31.3	4.4	3937854	2	52	409537	0.41
WHITLEY MOSS	7.0	5.6	92.7	2.9	3083905	3	52	481089	0.48
								10,108,871	**10.11**

Appendix V – Site condition assessment scores: comparison of 1994/5 with 2011/12

N.B. See Section 5 'Site condition assessment' for details of scoring methodology.

Site	Score 1994/5	Score 2010/11
ARNHALL MOSS	4	2
AUCHINDERRAN MOSS	6	4
AUCINTOUL MOSS	3	4
BALEARN MOSS	5	5
BANKHEAD MOSS	7	8
BLACKHILLS MOSS	8	6
BLAIRHILL	6	5
BLAR NAM FIADH	7	9
BRANTETH FLOW	5	4
BURNFOOTHILL MOSS	11	10
CADGILL FLOW	12	8
CLAYSIKE (NEWBIGGING)	6	8
COWGARTH FLOW	9	9
CRAIBADONA MOSS	3	3
CRAIGMAUD MOSS	10	10
CRECA MOSS	7	4
CULVIE MOSS	4	8
DRUMBROIDER MOSS	11	10
DUNMORE MOSS	6	5
EASTER GREENRIG	12	10
EASTER REDBURN	11	8
FOGGY MOSS	9	8
GARNKIRK MOSS	4	6
GLEDFIELD FARM MOSS	5	3
GRAYSTONELEE	5	2
GREENWRAE FLOW	11	10
HILLHEAD	8	8
KELHEAD FLOW	8	9
KETTLEPOOL MOSS	4	4
LETHAM MOSS	6	4
LOW MOSS	10	12
MOSS MORRAN	5	3
MOSS OF ACHNACREE	5	11
MOSS OF BLACKHILLOCK	3	5
MOSS OF CROMBIE	7	11
MOSS OF REDHILLS	6	6
MOSSDALE	9	12

MOSSHOUSE FARM MOSS	9	10
NETHER LONGFORD MOSS	8	7
NEWTON OF MIDDLEMUIR	6	6
NORTH COWFORDS MOSS	5	7
PRIESTSIDE FLOW	1	2
RAEBURN FLOW	10	11
RASCARREL MOSS	5	4
REDHILLS MOSS	3	3
REDMOSS/BROADLEYS	11	10
ROWAN BAUDS MOSS	7	6
SHIELKNOWES	7	10
SHIRGARTON MOSS	10	12
SIDE MOSS	6	8
ST. CATHERINE'S WELLS	9	7
ST. FERGUS MOSS	9	5
STEWARTFIELD	10	8
TAILEND MOSS	7	7
TEMPLE HILL (HARPERRIG MOSS)	9	10
WESTCRAIGS	12	10
WHITE MOSS	9	8
WHITLEY MOSS	8	7