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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: SP0556
2. Project title: A compendium of UK peat restoration and management projects
3. Contractor organisation(s):
   Peak District National Park Authority (Moors for the Future Partnership)
   University of Leeds
   University of Manchester
   Durham University
4. Total Defra project costs (agreed fixed price): £ 29970
5. Project: start date .... 01 December 2007
   end date .... 31 March 2008

6. It is Defra's intention to publish this form.
Please confirm your agreement to do so..YES ☒ NO ☐

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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

This report describes the production of a UK peat restoration project compendium and provides summary results from the analysis of the compendium. Data were compiled through use of detailed electronic questionnaires, interviews and survey of recent scientific work. The project also involved organisation of a peat restoration conference at which restoration issues were discussed in workshops with practitioners and policy-makers. The project has produced an electronic compendium of peatland restoration and management projects in the UK, a website to disseminate key project findings, a website that allows continual updating of the compendium as new projects come on stream, a four-page research note/flier and improved communication and knowledge transfer between peat management and restoration projects; we have started a UK peatland restoration network.

The compendium is organic and can grow through time. It currently contains details of 145 UK peat restoration and management projects. 56 of these projects were analysed in detail as they provided comprehensive details for analysis. There was an approximately even balance of lowland and upland peat restoration and management projects identified. Around half of the projects surveyed involved more than one peatland type and these require more complex management decisions and restoration practices. There were more lowland raised bog projects than any others but these tend to be small in area; the area of blanket bog considered as part of restoration projects was more than three times greater than the area of all the other types of peatland put together.

The presence of a conservation status for peatland sites is very important in determining whether there is active restoration or management. Only one project was located on land that had no conservation status while 50 out of 56 projects were on SSSIs. A major driver of management and restoration in England was the SSSI PSA targets. Just over half of the projects were managed as part of a partnership, with over 60 % having a government agency involved in their management. Most project management was delivered by in-house staff, but on average there were only 1.4 FTE staff per project. Stakeholder and landholder consultation efforts were common practice for projects.

The median budget per project was £241K. The median project budget per hectare was £1600. Funding sources were extremely varied. Half of projects were funded by more than one source, while 14 % of projects had four or more sources of funding. Expenditure on practical works forms an average of 55% of project budgets. Two-thirds of projects had expenditure dedicated to monitoring and the proportion of funds for monitoring was greater for the smaller projects. Most of the projects occurred on land which is predominantly privately owned for commercial purposes. 21 % of projects occurred on sites that were owned by a mixture of private commercial, charity and publicly owned land. Such mixed ownership may create problems for implementation of management projects and indeed a number of questionnaires discussed the difficulties experienced under these situations. For projects with budgets between £26K and £100K, approximately 10 % of the budget was spent on land purchase, the same as those larger projects with budgets up to £1.5M. Of those projects that involve land purchase, 60 % are lowland and 40 % are upland.

Most projects reported that one of their main challenges was physical access for machinery to develop practical works on site. Purchase of equipment for bunding peat or baling heather, removal of vegetation such as trees or scrub and archaeological survey costs were all expensive investments for a number of projects. Indeed 32% of projects had to consider archaeological needs for their site. Health and safety considerations were found to be another key challenge, particularly where land was accessible by the public.

Most projects focussed on restoring ecological and hydrological function, or whole ecosystem function. In terms of project justification, biodiversity came across overwhelmingly strongly and was used as a justification for all projects. Hydrological function was the second most important justification factor. Carbon was used as a justification for 62% of the projects, but was only considered extremely important in three cases. There have been changes recently in that less of the newer projects claim that carbon is of no importance or of very low importance when justifying the need for restoration or management. Respondents were asked about whether their projects had been revised. Comments fell into two main categories; i) those which describe changes in projects due to changes in the funding/political environment and ii) changes forced on projects by the practicalities of negotiating land access and ownership. The former included an increasing emphasis on the role of peatlands as carbon stores. In terms of issues that resulted in sites requiring restoration, succession was the most commonly recorded factor that was considered extremely important. However, 70% of these projects were lowland, indicating that there are differences in concerns between peatland types.

For each technique of restoration there are many variants which have been trialled. Drain-blocking and vegetation removal are the most common techniques adopted across the UK. Grazing control, scrub clearance, hydrological control and visitor access were seen as important peatland management issues requiring attention. These factors reflect the highest priority project justifications relating to biodiversity and hydrological control.

There is relatively little published scientific literature on peatland restoration based on the UK experience. Most published UK work relates to the impact of grip-blocking in blanket bogs on water table or water colour or dissolved organic carbon production. There is also a limited amount of work on gully-blocking. The key point is that very little is known about peat restoration processes and impacts in the UK scientific literature. However, there *have* been some large scale regional and national surveys of grip and gully-blocking restoration techniques. These reports have devised methods to prioritise locations to target resources and for determining the most effective technique to use for some strategies such as drain and gully-blocking and this information should be utilised by new restoration projects. Dissemination of such information, and explanation of how to use it, requires resource and this should be considered by Defra.

There was a significant difference in how staff graded the site conditions at the start of their project compared to present conditions. The mean score of site condition (100% is excellent state, 0% is totally destroyed) significantly rose from 46% to 61%. However, the dataset suggested that overall while there were significant improvements in hydrological condition and some improvement in carbon sequestering potential, there were no significant improvements in biodiversity or the proportion of peat that was intact. The mean overall project success score provided by project staff was 67%. Examination of the success scores by length of project showed that perceived success increased rapidly through the first three years of a project before levelling off at 80-100% thereafter. In contrast, the estimated site condition data showed relatively little pattern in time and much greater variation. There is a natural desire to claim project success within a typical 3 year funding window but there was a disparity between success scores and site condition improvements with time. Therefore, the nature of self-reported success needs to be carefully evaluated in the light of supporting measurable data. Projects can succeed in many ways and this success may not map directly onto restoration of biodiversity, water table or peatland condition.

In terms of reasons for project shortfall, funding was a key factor, but problems with implementation were consistently reported as being important as well as ‘opposition’. Other factors such as governance, land acquisition problems, access and lack of guidance/information were factors for more than a quarter of the projects.

Almost all projects are monitoring vegetation, mainly through ground survey but assisted in about half of the cases by air photos and other remote sensing techniques. Indeed there is a widespread use of GIS and remote sensing (air photos and LiDAR) among peat restoration and management projects. Many have noted that these tools were invaluable for the project. Hydrology is being monitored by ground survey in 70% of projects. Invertebrate and bird monitoring are also common occurring in more than 50% of projects while carbon, peat erosion, climate and pollution are being monitored in few cases. Monitoring was delivered by a variety of personnel ranging from academic collaborators to volunteers and private contractors. Most vegetation monitoring was delivered in-house while most monitoring for other variables was delivered by others. Academic collaborators dominated the delivery of carbon and climate monitoring. Monitoring is essential to restoration works although the main drivers vary considerably from project to project. Monitoring is expensive, should be properly costed and should be planned and implemented early in the life of a project. There is a lack of pre-restoration monitoring of long time series (i.e. years) to generate baseline conditions on functions such as hydrology. The conference workshops demonstrated that all practitioners identified that time was a crucial factor in achieving restoration and that this was not always compatible with targets set out. An alternative approach of projects being process-driven was identified so that restoring function to the peatland should be the target rather than counting occurrence of key species.

It is concluded that valuable monitoring data should be exploited to the maximum. There are a large number of projects that are monitoring their sites for a wide range of variables. This implies that there is a resource of data that is not at present being analysed and utilised to inform best practice. It is recommended that a meta-analysis of this monitoring data is performed and this would enable greater scientific understanding of UK peat restoration processes. Standard guidance on monitoring peatland restoration projects, including approximate costings, should be provided. This could be produced as part of the same project as the meta-analysis. Additionally, there is widespread use of GIS and remote sensing data for peat restoration projects. Many respondents noted how crucial it was for project implementation and resource allocation. It is recommended that Defra provides advice and data for peatland restoration and management projects on use of GIS and available remote sensing data. For example a list of peatland sites where LiDAR coverage is currently available would be useful. Finally, there is a clear need to establish a networking organisation for peatland restoration project managers.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

8.1 Objectives

A key objective of the forthcoming Soil Strategy for England will be the protection of organic soils. This Strategy recognises the need to draw together all ongoing action on peat soils. Peats are important for many reasons not least because a significant proportion of UK soil carbon (or even just that of England and Wales) is held within peats (Holden *et al*., 2007). The overall objective of this project is to produce a compendium of peat restoration and management projects. To achieve this overall objective a set of sub-objectives have been devised. These include:

1. Produce a database of past, current and planned peat restoration and management projects.
2. Evaluate the current state of knowledge of peatland restoration management by reviewing current management practice as well as existing and ongoing research into peat restoration and management projects in the UK.
3. Assess the levels of success and failure of current peat restoration and management projects.
4. Assess the motivation, long-term goals and plans behind the projects and any adaptation measures in response to these during the project duration.
5. Identify the technical, logistical, site access, financial and project management difficulties that need to be overcome in the use of successful restoration and management techniques.
6. Collate details on the costs involved in implementing the restoration and management techniques associated with each project.

These objectives have been fully met through the compilation of the compendium, a targeted peat restoration and management conference and a review of the results from the compendium and conference. The results are discussed below and there are additional appendices providing more detail.

8.2 Methods

It should be noted that the work reported here is based on the UK experience. A separate and concurrently running project, also funded by Defra, is reviewing international policies and experience on peat extraction, management and restoration. There were three main methodological components; questionnaire/database, conference and review of existing literature and knowledge.

Government bodies, agencies, NGOs, academics and water companies were consulted via telephone and email. This allowed compilation of recent and ongoing projects, contact details and baseline information. A total of 115 projects were identified at that time (145 projects by end March) Each project was then sent a carefully designed electronic questionnaire allowing us to fulfil the objectives described above. The questions were designed to provide the maximum amount of data but which were still going to give us an optimal return rate. Consultation with Defra and Natural England ensured that questions were checked and were relevant to policy needs and the requirements of the compendium. With questionnaires there is an inevitable balance between length (and hence amount of data obtained) and willingness of stakeholders to complete the questionnaires. Therefore we trialled the questionnaire before it was fully implemented. Some minor changes to phraseology, instructions and length were made following the trial. Each completed questionnaire has been saved and forms part of the compendium produced by this project. Appendix 1 provides screenshots of the electronic questionnaires. The questions asked provide information on:

a) Administration: Project name, location, duration, conservation status of the site, contact details, website, governance/management structure, number of staff, delivery mechanism, budget (including amount on monitoring), funding source and land ownership and type of project (restoration/management/restoration management).

b) Initial site conditions: site condition (destroyed to pristine, hydrology, ecology, soil etc), project justification, project objectives, whether it builds on previous restoration/management.

c) Restoration/Management: restoration/management issues, targets, methods, materials, delivery mechanism, innovation, cost of each treatment.

d) Evaluation: Methods of evaluation used, monitoring delivery, perceived success from monitoring, % success rate, revised site condition assessment, reasons for shortfall in success, gaps in knowledge, any revised project targets

e) Future plans: future projects, funding required

The above provide data in both quantitative and qualitative form. Summary results from this questionnaire are presented below, but the original data forms part of the compendium. There were a number of projects that are known to us but which were not able to complete the main questionnaire. For these projects we have completed as much data as we can on a simplified questionnaire which forms part of the compendium delivered by this project. This information was based on discussion with the restoration/management project staff and other information we could compile about the site.

A conference was organised and key personnel who had been involved in completion of the questionnaire from peatland management/restoration projects were invited to share experience at the conference held in Castleton on 13 and 14 March 2008. There were a series of workshops that dealt with key issues arising from the analysis of the questionnaire responses. These included: future project direction and governance, monitoring, and techniques employed during restoration. Key results from the questionnaires were presented at the conference to provide baseline information for discussion and further elaboration. Workshops within the conference helped to promote synergies, knowledge exchange and network building between projects. Group discussions allowed the project team to gather more in-depth information and arrive at problem solving in discourse. We also followed up the questionnaires using interviews to ascertain why staff from particular projects felt the projects had been successful or less successful. The main outcomes from the conference and interviews are presented below.

The scientific literature on the UK experience was searched to review the evidence base for success of peatland restoration and management projects. A summary of key findings are reported below.

8.3 The database

The compendium of peatland restoration and management projects in the UK has been compiled and is publicly available on www.peatlands.org.uk This site will use a Content Management System. Content Management

Systems are programs used to create a framework for the content of a website; primarily for interactive use by a potentially large number of contributors. This should facilitate the Peat Compendium website to be user updated. Therefore, peat restoration projects will be able to update, or add new projects as and when new information is available. This information will be stored in the Peat Compendium database. The website allows new projects to upload their information to the compendium so that over time the archive database of projects will grow. This is an important product for Defra which the project has delivered. Additionally as the archive of projects will be stored it will be possible for new projects to investigate for themselves the nature and work of previous projects. This should improve the quality of new projects and means that they will not need to 'reinvent the wheel' when it comes to designing cost-effective peat restoration or management works.

8.4 Analysis of compendium data

A total of 56 projects completed the detailed questionnaire in time for full analysis. An additional 5 projects submitted detailed questionnaires and 11 completed summary versions for the compendium by the time of writing of this report. There are therefore 72 projects within the compendium, plus basic contact information on a further 73. The location of these projects is shown in Figure 1. This section analyses the results from the 56 projects that reported in time for full analysis. Several of these projects had multiple sites where restoration and active management was taking place so that this analysis incorporates information from a total of 412 separate sites. The names of each of the projects with project numbers that are used later in the report and in the compendium are presented in Appendix 2.

8.4.1 Project administration and status

There was a balance of upland and lowland projects with 25 of the former and 31 of the latter. Table 1 presents the number of projects which consisted of different peatland types. Of the 56 projects studied in-depth, 26 involved more than one peatland type as listed in Table 1. Sites with multiple peatland types are therefore going to require more complex management decisions and restoration practices may vary between peat type. While there were more lowland raised bog projects than any others, a much larger area of blanket bog was considered as belonging to restoration or management sites. Indeed the area of blanket bog considered as part of restoration projects was more than three times greater than the area of all the other types of peatland put together.

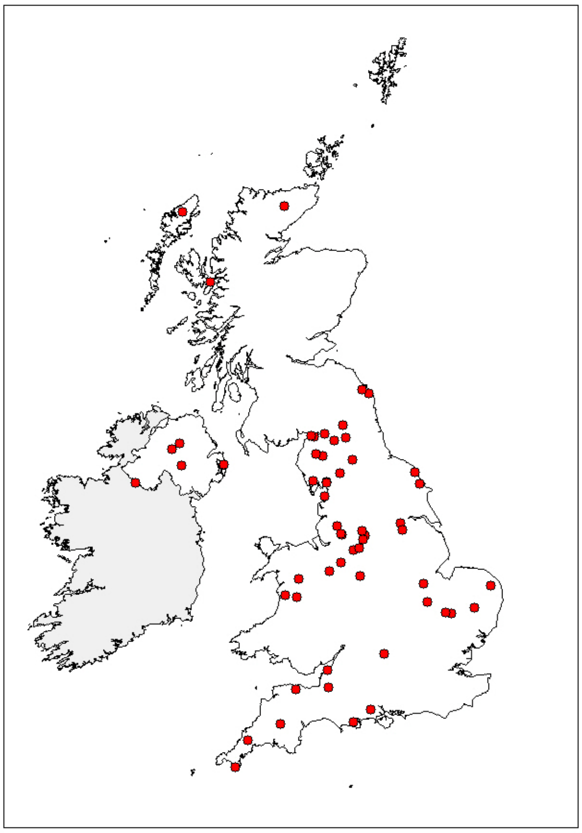

Figure 1. A map showing the location of UK peat restoration and management projects included in the analyses of this report.

Table 1. Number of projects by peatland type and areal coverage

Peatland type	Number of projects	Reported restoration/management area, ha*
Blanket bog	16	15143
Upland heathland	9	1516
Bog+	9	629
Lowland heathland	10	183
Lowland raised bog	18	1159
Fen, marsh and swamp	22	713
Other	9	674

* This is an underestimate because a number of projects were not able to give data on areal coverage of these peatland types and just recorded presence or absence.
+The classifications above are based on the Biodiversity Action Plan classifications which are used widely in restoration projects. The 'bog' classification actually incorporates blanket bog as well as raised mire and mixed bog habitat but this option was included to allow respondents the opportunity to provide the classification they use.

Most of the projects are relatively new and ongoing, with only nine starting prior to 1999. Only six of the projects were considered to have finished. The presence of some sort of conservation status for peatland sites appears to be very important in determining whether there is active restoration or management. Only one project was located on land that had no conservations status (i.e. SSSI, SAC, SPA, NAC, AONB, other). Seven sites were RAMSAR sites[1] and 50 of the sites were SSSIs. Most sites had more than one conservation status (49) while 24 of the sites had four or more different conservation designations. This reflects both the importance of peatlands and the role of such designations in ensuring that restoration and management projects take place. Only six of the projects were considered as solely management projects, while nine were considered as solely restoration projects. The remainder were considered to be both restoration and management projects.

Just over half of the projects (29) were managed as part of a partnership, with 35 of the projects having a government agency involved in their management. Seven were managed by a private business while 19 were managed by charities. A total of 78.1 FTE staff were associated with the 56 projects which is a mean of 1.4 staff per project. Most project management was delivered solely by internal staff, although 8 projects had delivery specialists and four had volunteers to assist in project management.

A small number of projects did not wish to report their budgets. Of those that did, the budgets varied from £2000 to the £30M Great Fen Project. For the latter, half of this budget was for land acquisition. The mean budget of those projects reporting was £1.5M (Figure 2). The £30M figure from the Great Fen project positively skews the view of the budgets somewhat as the second largest project budget is £5M. The median budget was £241K. The median project budget per hectare was £1600. Figure 2 shows data on how budgets were allocated to practical works, monitoring and land acquisition. The projects have been split into approximately equal numbers by budget size in the analysis shown in the figure. Expenditure on practical works forms an average of 55 % of project budgets. Two-thirds of projects had expenditure dedicated to monitoring. For smaller projects, monitoring forms a greater proportion of the budget than for the larger projects. For those projects with budgets under £26K, no land acquisition was considered as part of the budget. Surprisingly, for projects with budgets between £26K and £100K, approximately 10 % of the budget was spent on land purchase, the same as those larger projects with budgets up to £1.5M. Of those projects that involve land purchase, 60 % are lowland and 40 % are upland.

Funding sources were varied as shown in Table 2. Around half of the projects (27) were funded by more than one source, while eight projects had four or more sources of funding. Most of the projects are on land which is predominantly privately owned for commercial purposes (Table 3). However, nine of the projects occurred on land that was solely public land. Twelve projects occurred on sites that were owned by a mixture of private commercial, charity and publicly owned land. Such mixed ownership may create problems for implementation of management projects and indeed a number of questionnaires discussed the difficulties experienced under these situations (see below). One project (no. 39) achieved the first relocation of a public water borehole supply on environmental grounds alone as part of the restoration process. There was a positive relationship between project budget and project site area as shown in Figure 3. The relationship is log-linear. Purchase of equipment for bunding peat or baling heather was a significant investment for some projects (£5000-£20000), removal of vegetation such as trees or scrub was also a significant investment for many projects, while archaeological survey costs were also expensive in some cases (£10,000 for project 18; £80,000 for project no. 49). Project no. 39 was unusual in the scale of capital equipment and infrastructure purchased with £180,000 spent on specialist equipment and £500,000 on a visitor's centre.

Consultation was a common theme for projects; 27 projects mentioned that they had to consult either very widely or with local tenants and landowners about the restoration and management projects to either gain agreement or

[1] The Convention on Wetlands, signed in Ramsar, Iran, in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. There are presently 158 Contracting Parties to the Convention, with 1721 wetland sites, totalling 159 million hectares, designated for inclusion in the Ramsar List of Wetlands of International Importance.

to win hearts and minds. Most projects reported that one of their main challenges was physical access for machinery to develop practical works on site. In many cases access routes had to be found or created to get machinery to the site or care had to be taken where water or gas pipelines crossed the site. Another key challenge was where restoration sites are part of open access land and the health and safety of the public had to be considered when heavy machinery was on site. Some footpaths and routes had to be closed while restoration works took place or to allow helicopters supplying equipment and brash to land. Additionally, some projects mentioned that there were therefore public liability issues where peatland restoration had created, for example, new pools. Several projects have installed boardwalk around the restoration sites to enable access for visitors or for people who are performing monitoring.

Most projects had to obtain special permissions from regulatory authorities. These permissions included tree-felling licences, land drainage and water diversion permission from the Environment Agency, badger licences, and Natural England consent for works on SSSIs. A large number of the projects (18) had to consider special archaeological needs for their site. These did not usually form part of answers to ‘special permissions’ questions in the survey, rather they formed answers to ‘other special considerations’. This is, therefore, a very important point, and one which is often not considered a high priority in peatland reports. However, it is clear that the role of peatlands in preserving in situ archaeological archives must be considered as both a driving factor and a factor requiring special consideration in peatland management and restoration projects. Other important considerations included the timing of works with reference to the needs of birds and other wildlife, (this also affected the location of some routine monitoring sites for some projects; e.g. LIFE Active blanket bog in Wales, Vyrnwy), and to minimise wider damage to soils, vegetation, carbon and archaeology caused by machinery which aided the restoration work.

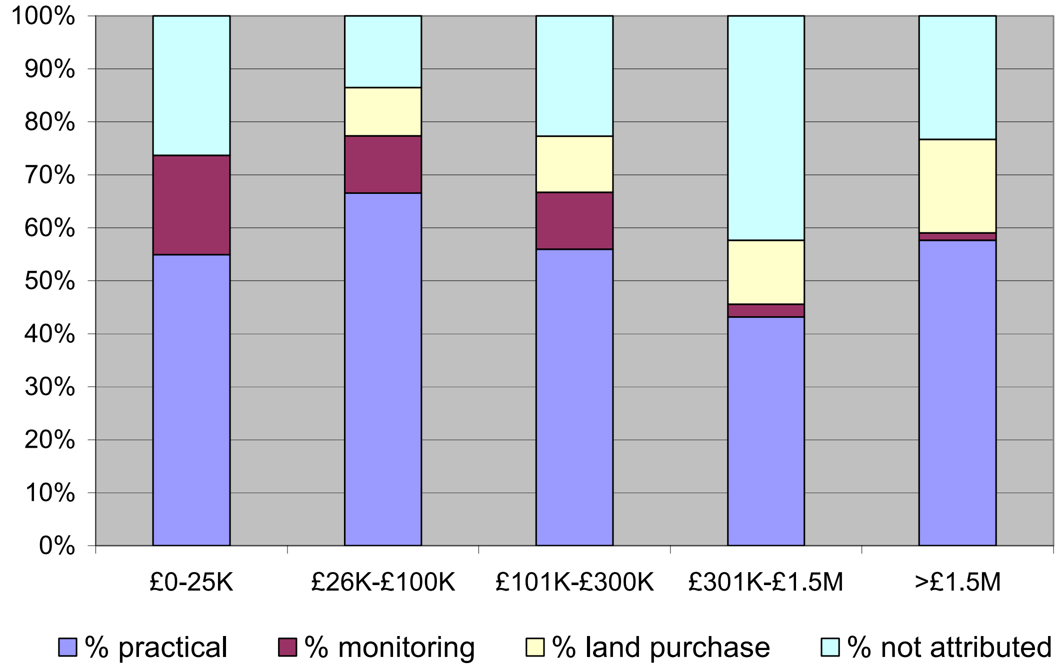

Figure 2. Mean proportion of budget spent on practical works, monitoring and land acquisition for projects of different sizes. To avoid bias caused by larger projects within each category the mean percentage values are shown as determined from the percentage of each project (rather than a percentage of the sum of budgets for all projects within a category).

Table 2. Source of funding for peat restoration and management projects

Funding source	Number of projects
EN wildlife enhancement	15
Regional grants	14
Local grants	11
National grants	10
Private sector	10
ESA	8
Environmental Stewardship Scheme	7
CSS	6
International grants	6
Other	25

Table 3. Number of projects with different land ownership categories

Land ownership	General area	Actual site
Private commercial	29	23
Private charitable	20	19
Public	18	18
Not known	11	11

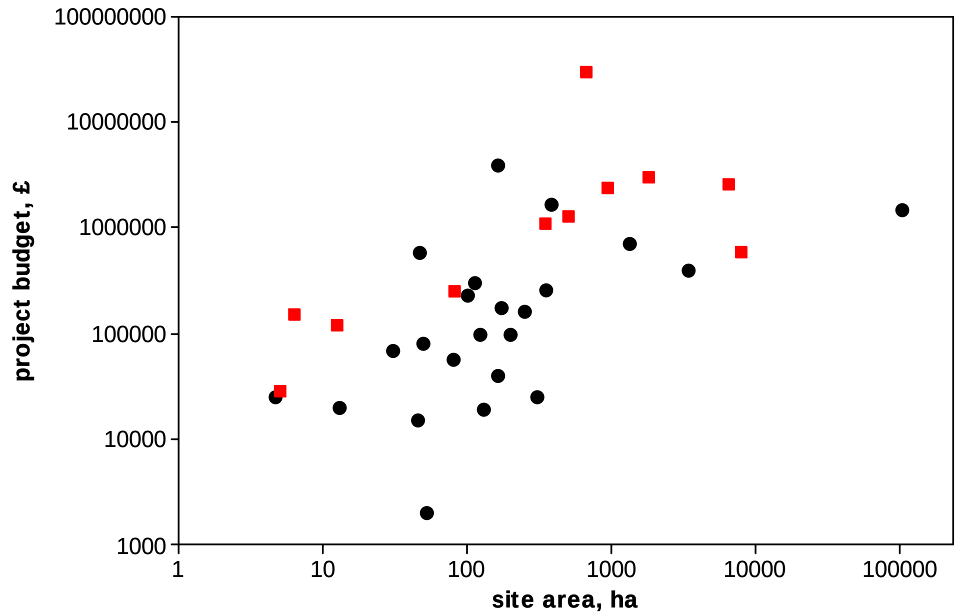

Figure 3. Relationship between peatland site area and project budget. Red symbols indicate those sites that have bought land as part of their budget.

Another key finding from the project survey is the widespread use of GIS and remote sensing data. Indeed 10 projects actually stated that this was essential to their projects (note this was a voluntary expression and not part of the questionnaire). While 9 projects used air photos, 11 used LiDAR and 24 used GIS. Many projects noted that the technological advances were helping them and they would have used GIS/LiDAR etc more had they been available at the start of their project. This may be one area where Defra and the agencies could help peatland restoration projects by providing advice, help and common datasets. Many small projects may not be able to afford the expertise or datasets for restoration or management projects.

Several projects noted that the lack of skilled contractors to carry out the work was problematic and three projects suggested that potential conflicts with agricultural or sporting interests had to be thought through. There was also a feeling that projects would benefit from better communication with each other to learn from best practice elsewhere and from trials that have been ongoing.

8.4.2 Project objectives and justification

Project representatives were asked to rate justifications for their project on a scale of 0 to 5 where 0 is of no importance and 5 is extremely important. Two projects did not provide this information and so the following is based on results from 54 of the projects. Results are presented in Figure 4. Biodiversity came across overwhelmingly strongly and was used as a justification for all projects. Hydrological function was the second most important justification with 29 projects rating it highly. Across all projects there is a balance of responses related to water quality with 14 viewing it as unimportant and 17 as extremely important. Carbon was used as a justification for 34 of the projects, but was only considered extremely important in three cases. Figure 4 shows that the pattern for recreation is similar to that for carbon. It was possible that justifications for projects have changed over time with the growth of interest in carbon and the Water Framework Directive. Therefore, Figure 4 plots data separately for projects which have started since 2005 and those that started prior to 2005. It can be seen that there is little difference in the patterns, although less of the newer projects claim that carbon is of no importance (0) or of very low importance (1) when justifying the need for restoration or management.

The objectives listed for each project are provided in Appendix 3. The appendix adds detail to our understanding of the motivation behind the projects and their long-term goals. Most projects are focussed on restoring ecological and hydrological function, or whole ecosystem function (e.g. ‘functioning blanket bog’), and this backs up Figure 4. An important driver appears to be achieving SSSI Public Service Agreement (PSA). If a SSSI unit is currently assessed as being in favourable or unfavourable recovering condition, it is described as 'meeting the PSA target'.

The government target is for 95 % of SSSIs to be in these states by 2010. While first reading of Appendix 3 suggests that 36 of the projects build on previous trials or work done on the sites, in fact most of the prior work which is being built upon is piecemeal or very small-scale. In most cases large scale restoration projects are being implemented without an understanding of whether they will be successful. This is brave, but necessary, and again highlights the need for the project staff to communicate with one another and for the compendium produced by this report to become publicly available so that new projects can consult it and make contact with old and existing projects to ask for advice.

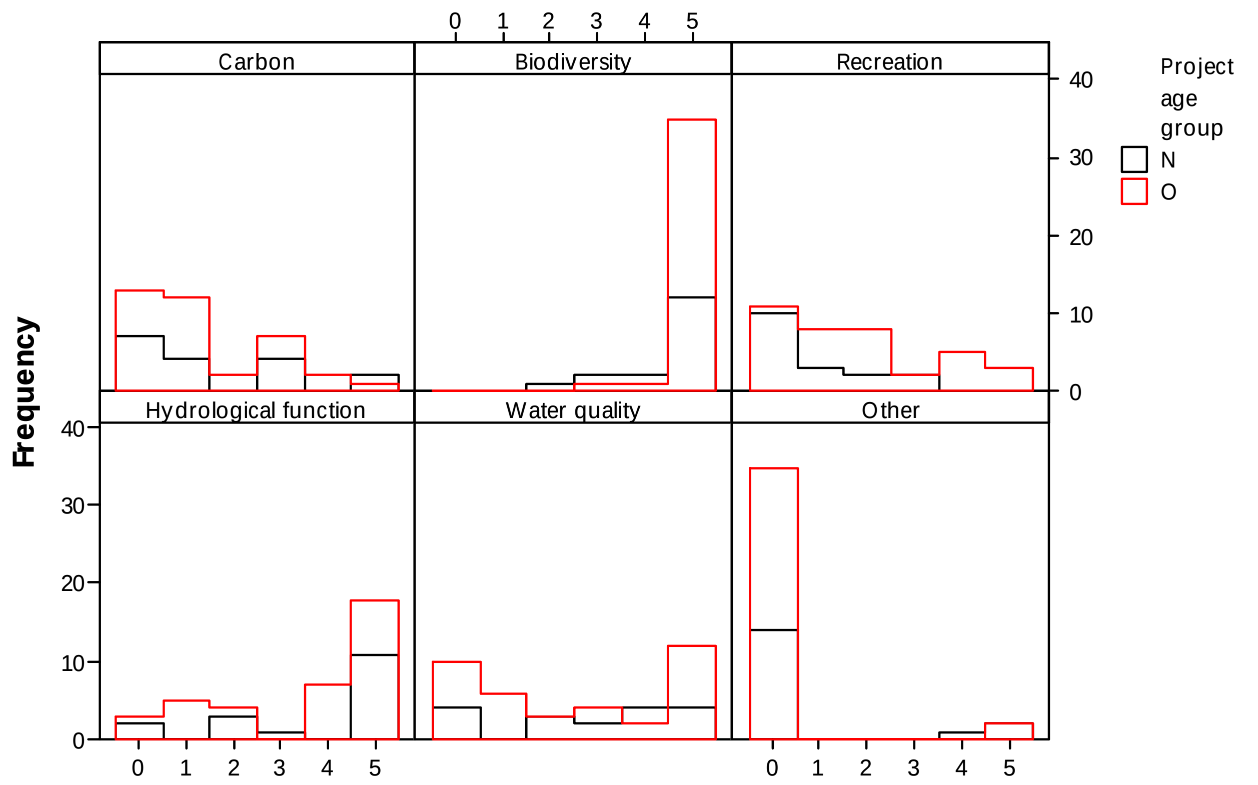

Figure 4. Project justification scores where 0 is not important and 5 is extremely important. The plots show the number of projects giving each score with N = projects stated since 1 Jan 2005 with O = projects which started prior to 1 Jan 2005.

8.4.3 Restoration methods and delivery

Some techniques are purely restorative (e.g. reseeding, peat reprofiling), other techniques can be applied either as a restorative or management tool (e.g., vegetation removal, gully / grip blocking) The difference in the use of these techniques is the initial condition of the peatland(s) - particularly the severity and scale of the restoration issue(s) - and relative intensity or frequency of their delivery. Some techniques are purely management (reparation works to blocks / paths / drains). This section deals with those projects that were either considered to be restoration or restoration and management projects. The six projects that considered themselves as solely management projects are therefore not included in the analysis described in this section. Those surveyed were asked how much of an issue several factors were in resulting in the site requiring restoration. These were scored with a zero for ‘not at all important’ and 5 for ‘extremely important’. Figure 5 displays results. Succession was the most commonly recorded factor that scored 5. However, a further analysis of the dataset showed that out of the 31 projects that scored succession with 3 or above, 22 of these were at lowland sites. There are thus differences in concerns between peatland types.

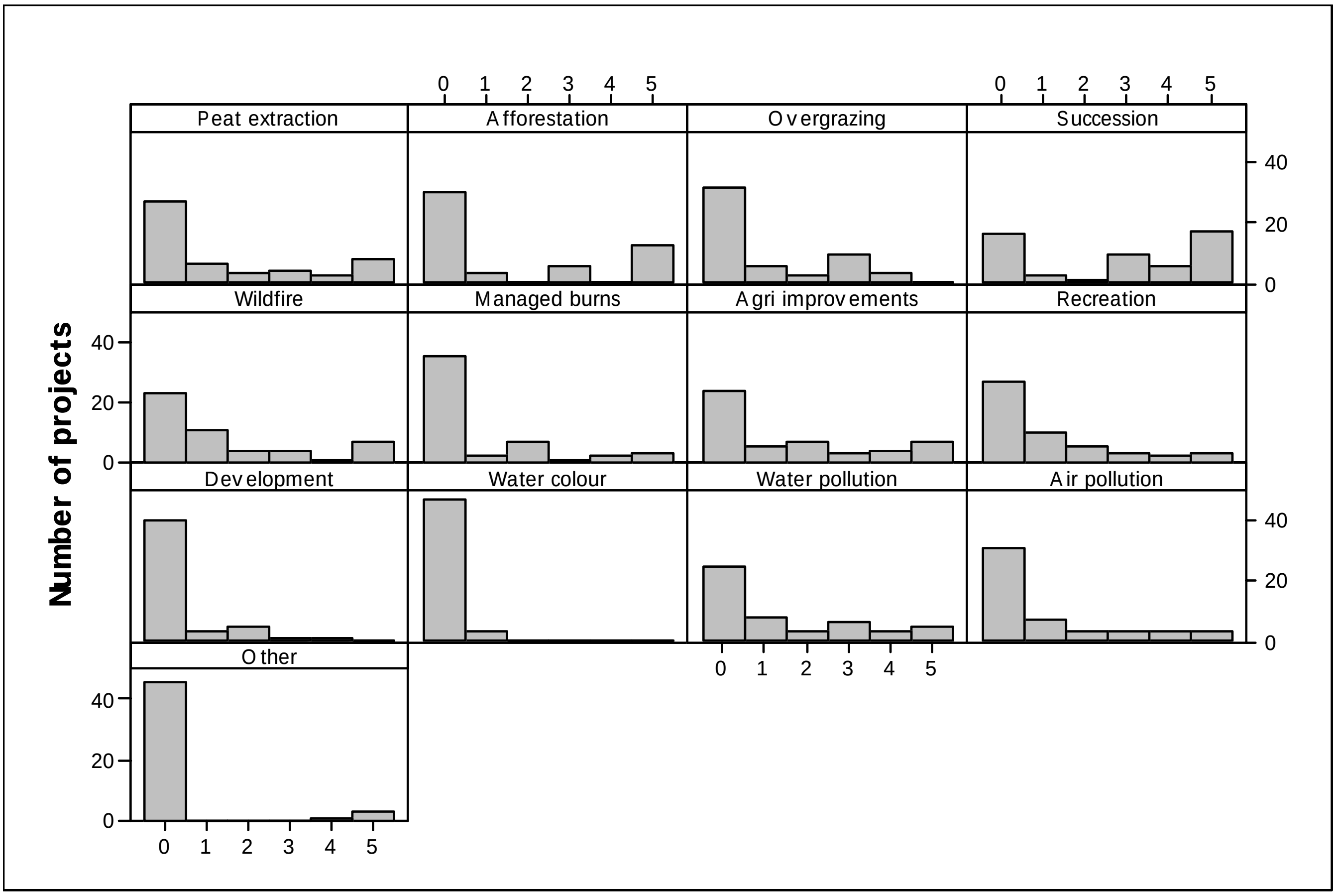

Figure 5. Histograms of factors which resulted in the site requiring restoration with scores indicating zero for not at all important and 5 for extremely important.

Each questionnaire also asked for information on the techniques being used, area covered, and any innovation. The following sections provide the results from each technique.

8.4.3.1 Stabilisation

Seven projects were engaged in stabilisation work (project nos. 22, 24, 30, 31, 33, 42, 49). All but two (Great Fen Project and New Forest Life 3) were upland which is indicative of where peat erosion is most widespread (Holden et al., 2007). The Great Fen project used reseeding of 300 ha performed by specialists, in-house staff and farmers at a cost of £88 per hectare. The other six projects involving stabilisation operated where heather was a common species and all six used heather brash spread over the surface to aid stabilisation. On the heavily eroded Peak District slopes, brash was spread at a rate of 18 tonnes per hectare at a cost of £1700 per hectare which is comparable to the Fylingdales Fire site regeneration project costs. Specialists would produce the brash and then in-house staff or volunteers would help spread it. For remote areas such as Bleaklow, helicopters had to be used to drop off the brash and to help spread it. At two badly eroded blanket bog sites, where gully erosion was severe, geo-jute was used to help stabilise the peats at a rate of application of two widths of geo-textiles to opposite of gully sides. Grass seed was then applied to grow through the geo-jute (Figure 6).

Figure 6. Geo-jute used to stabilise the peat in the Peak District

8.4.3.2 Peat reprofiling
The purpose of peat reprofiliing is to reduce the chance of (further) peat erosion where overhanging peat blocks or bare peat surfaces are exposed (e.g. after peat extraction, or deep gullying following drainage on heavily degraded blanket bogs). Nine projects involved peat reprofiling and employed both hand-cutting and machine methods. Where machines were used, specialist excavators with wide tracks and lightweight chassis were used to profile peat walls along gully and drain edges. Project no. 47 developed a technique for reprofiling following insertion of plastic membrane around cut-over edges. This work was undertaken by contractors with a midi-360 tracked digger. Typical costs of reprofiling are around £600 per ha, but this can be much greater if a large amount of reprofiling is required. The cost is around £5 per metre but the technique is generally used in only small areas. While all the above reprofiling occurred on drain, gully or riverbank edges, one project (no. 36) reprofiled the surface of the mire using a machine from the peat extraction industry. This was used after a major fire incident in 1984 when virtually all vegetation was burnt off part of site. The equipment purchase cost £20,000 but this has allowed management of heather and firebreaks around the entire property for last 20 years.

8.4.3.3 Reseeding
Typically much larger areas of restoration sites are targeted with reseeding than with reprofiling. Ten projects have used reseeding. The only application rate reported in the surveys was from the eroded Bleaklow site where 4.2 kg per ha of nurse crop was applied and 0.65 kg per ha of *Calluna vulgaris* seed. Additionally 1000 kg per ha of granulated lime and 0.95 kg N:P:K (11:32.5:16.5 in year 1 and 13.5:20.5:20.5 in years 2 and 3) fertiliser per ha were applied over three years. The nurse crop and fertiliser are to create a stable surface that can then be colonised by native species (Figure 7). Without a stable surface, seedlings do not survive for long before being washed out or buried by mobile sediment. Four sites reported the use of a nurse crop before seeding with Calluna *vulgaris, Eriophorum spp., Agrostis castellana, Lolium perenne, Deschampsia flexuosa* or *Erica cinerea.* The cost of doing this ranged from £900 per ha on Bleaklow to £250 per ha on the Fylingdales fire site and £95 per ha at Vyrnwy, Wales. The latter was different in that involved encouraging a change in vegetation (from grass to heather), rather than revegetation of a bare surface. Flailing of grass vegetation was followed by seeding with smoked and unsmoked heather seed and electric fencing was used to prevent sheep grazing. The Peatlands Park project (no. 36) was the only one of the projects that reported the practice of spreading of *Sphagnum spp*. across the surface to encourage regrowth. This is interesting as internationally this is a more common practice (e.g. Price et al., 1998). Project no. 45 tested trial plots using *Eriophorum spp.* as a nurse crop for *Sphagnum spp.*. This was found to work only if you have full control of water levels and could therefore only be applied at a field scale if significant further funding could be found.


Figure 7. Colonised nurse crop on Bleaklow

8.4.3.4 Planting
Only two projects reporting planting as part of their restorative measures (nos. 24 and 30) where natural succession by blanket bog species was either unacceptably slow, or unlikely to take place at all. Plug plants of bilberry, crowberry, hare-tail, common cotton grass and cloudberry were used, but these are very expensive both to purchase and to install at £2700 per ha. For Bleaklow, this is despite the plants not being planted over the whole area (i.e. only at a density of 2500 plants per ha and 112,000 plants in total). The work involved contract propagation of five species (i.e. they are not grown under normal commercial conditions) and were chosen for biodiversity and structural characteristics. The plug plants were flown onto site and planted using contractors.

8.4.3.5 Grip-blocking
Grip-blocking (peatland drain blocking) was a very common practice in peat restoration projects with 24 projects undertaking this type of work. A mixture of techniques have been used for grip-blocking including blocking using peat turves, plastic piles, wooden dams, heather bales, straw bales and stone. Most of this work has been done

by specialist contractors, but some in-house delivery has been used. The costs have ranged from £1000 per km to £6500 per km depending on location and the techniques used. Use of plastic piling is more expensive than use of peat turves, for example. Since grip-blocking is such a common form of peat restoration practice used in the UK there should be much known about this technique. However, there is still a lack of communication between projects and a lot of expense is incurred where perhaps this may not be necessary. Appendix 6 describes the results from a UK-wide survey of grip-blocking techniques and their failure rate/success and suggests some simple techniques for determining which grip-blocking methods will be most appropriate for different scenarios (slope, grip depth etc). In addition, it also showcases a technique for determining which grips it would be most effective to block from a hydrological perspective and which may be used to make projects more efficient in the future. Some projects noted that it worked best to start damming the feeder grips upslope first and then work down the slope. Creating gentle escape routes for water from peat dams that encouraged water to seep out across the peat mass (rather than around the dam and back into the drain downslope) is preferable, but this is often not implemented in design (Figure 8).

a)

b)

Figure 8. Dams in grips where (a) allows water to escape and rewet the general peat mass while (b) simply allows water to flow over the dam and back into the grip downslope. (Source: (b) courtesy of Dr Alona Armstrong)

8.4.3.6 Gully-blocking

Gullies are erosions channels that form in degraded peatlands. Six projects have performed gully blocking; that is blocking. A variety of dams have been trialled including peat, wood, stone, plastic, bales, vegetation, wool, concrete and timber sluices (lowland), plastic piling (Figure 9). Most of the upland work has lead to the conclusion that for deeply incised gullies, plastic piling is most effective and that sediment has to be allowed to build up behind the dams. The efficacy of the dams is, however, to some extent dependent on project aims. Semi porous dams such as stone bunds and wooden fencing are effective at trapping sediment and gully stabilisation but do not raise water table as effectively as plastic piling. A dam spacing of 15 m is typical but this depends on slope. The plastic piling technique typically costs about £2500 per km of gully.

Figure 9. Gully blocking in narrow gullies using plastic piling

8.4.3.7 Vegetation removal

A total of 25 projects have employed vegetation removal as part of their restoration strategy. This can be either to remove / control undesired vegetation resulting from natural successional processes or intentional, anthropogenic, planting. 18 of these used specialist contractors, 21 used in–house staff and 16 used volunteers.

Removal of scrub, birch and pine woodland and rhododendron (project no. 40) were common practice. Silver birch is a natural peat bog species and so some thought ought to be given as to whether such removal is necessary. Seven of these projects claimed to have developed innovative practice in their vegetation removal projects including the use of sacrificial areas to store cut trees to avoid nutrient enrichment elsewhere; the cutting of trees followed by pulling into windrows, with stumps ground down to reduce regrowth and windrowed material incinerated in forced-draft air-burner with ash removed. This technique is now capable of clearing up to 1 ha per week. Several projects have encouraged incursion of animals such as Polish Konik ponies, sheep, cattle and water buffalo to remove unwanted vegetation from fens. Vegetation removal is very expensive costing between £1000 and £10 000 per hectare. Seven sites reported areas larger than 100 ha being restored in this way.

8.4.3.8 Stock reduction/exclosure

Nine projects reported stock reduction and exclosure as a restoration measure they were adopting to facilitate recovery of either the existing / remaining, or restored, vegetation. One of these projects reported total exclusion under ESA for 10 years. Typical practices included removal of winter grazing and reductions from 2 ewes per ha to 0.5 ewes per ha. Blanket bog has a notoriously low grazing capacity and hence the numbers are so small. Wildlife enhancement scheme and CSS were cited as mechanisms for allowing stock reductions.

8.4.3.9 Rewetting

Grip and gully-blocking described above were the primary methods for peat rewetting. It was clear from the questionnaire results that techniques have developed over time so that the earlier projects were more pioneering using trial and error while later projects could be more confident in their approach (and the move toward peat dams and plastic piling as convention). However, general bunding and compartmentalising of the peats was sometimes required on more lowland sites. For example, 12 Yards Road mossland site (project no. 1) used drainage pipes and right angled knuckle bends in combination with plastic piling to control the water levels so that the desired and optimal water levels could be reached. Peat compartments were identified and bunding works were undertaken to isolate the selected compartments. This ensured that water quality remained unaffected by contamination from groundwater and that the compartments were fed purely by rainfall. Such a concern is very important particularly given that in situ archaeological resources can be significantly damaged by changes to water chemistry so that even if water tables are maintained if the chemistry differs the archaeological and peat deposits can be irrevocably damaged (Holden et al., 2006). The costs of such complex sluiceways and peat bunding can be very wide-ranging, from £8,000 to £50,000 per hectare. The Great Fen project has had to install a series of sluice gates and channel water from higher areas to maintain wetness at restoration sites. Floodplain peatland projects have seen river bank profiling and installation of sluice gates to maintain enhanced wetting of the area. Clearly such techniques are not appropriate for upland sites. Two projects had created new wetlands on rye grass fields. It was envisaged that these would eventually become lagg fen. This reflooding cost £2,000 per ha over 32 ha. One project relocated a public water borehole supply (on environmental grounds).

8.4.3.10 Draining

Only one site reported drain clearance (at £3 per metre using in-house excavators) as an on–site measure. However, this was solely to protect a nearby non-project owned farm from flooding.

8.4.4 Management methods and delivery

This section considers the 47 projects which considered that they had a wider peat management role (i.e. not just restoration). Figure 10 outlines results of the scoring for each management factor where 0 is not at all important and 5 is extremely important. Each questionnaire also asked for information on the techniques being used, area covered, and any innovation. The following sections provide the results from each technique.

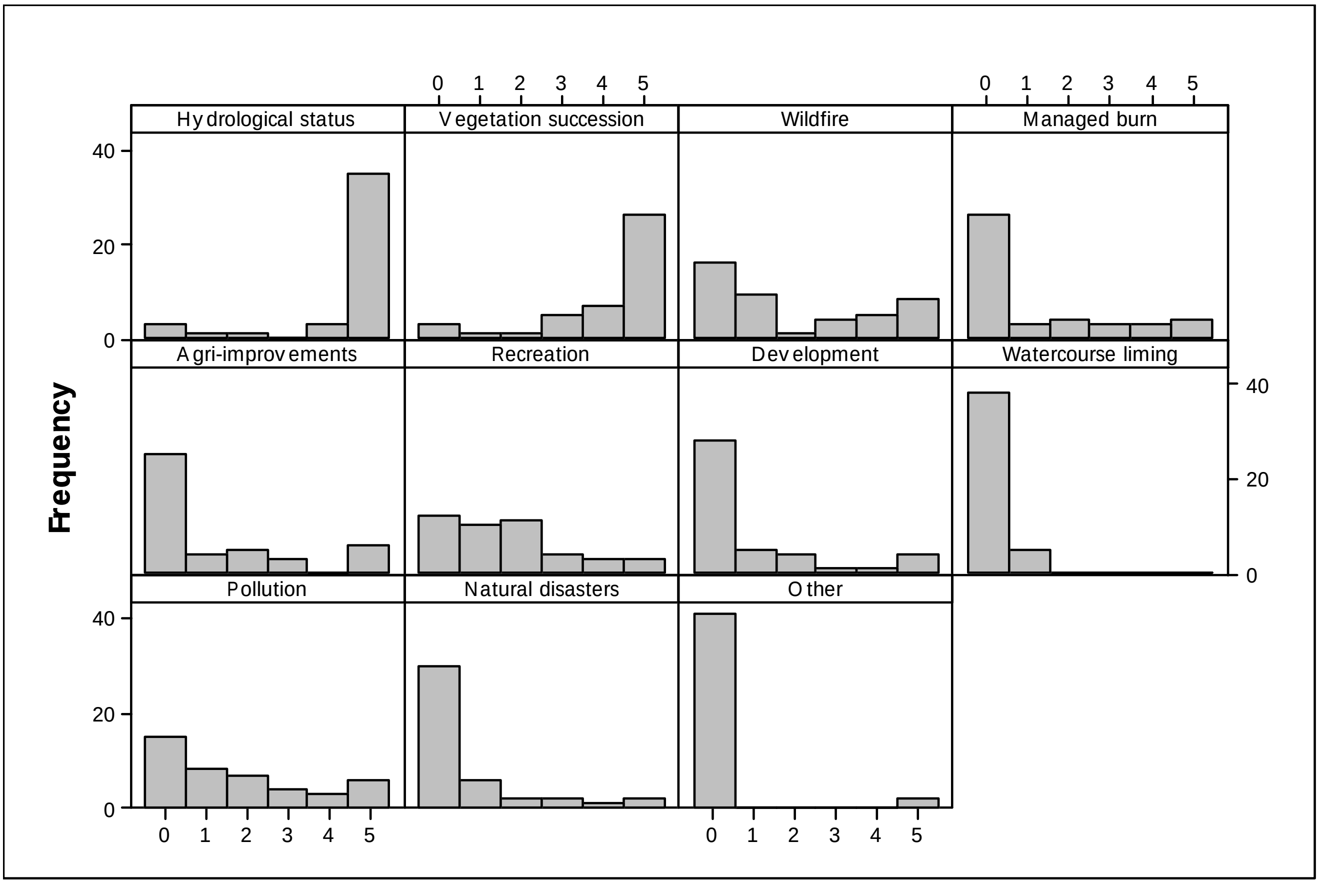

Figure 10. Histograms of factors which resulted in the site requiring management intervention with scores indicating zero for not at all important and 5 for extremely important.

8.4.4.1 Hydrological management

Hydrological management was performed by 26 projects. This was done mainly by the drain and gully blocking techniques described above for upland sites and drain blocking and sluice creation with bunding for the fenland sites. Since these issues have already been discussed above they are not described any further here. Please examine the electronic compendium of projects for further information if required. The only additional issue raised by the survey relating to hydrological management was that funds were required for ongoing checking and maintenance of bunds, dams and sluices. This was particularly important for lowland sites and raised mires, and where there might be the potential for flood risk to non-project land elsewhere.

8.4.4.2 Mowing

Twelve projects viewed mowing of vegetation as part of their peatland management strategy (6 lowland and 6 upland). The areas mown range between 5 and 500 ha generally delivered either by a specialist contractor or in-house. The cost is between £128 and £200 per ha. Most often mowing is done to control rushes and *Molinia caerulea,* but in some cases it is used as an alternative to heather burning for sporting interests (e.g. Vyrnwy). One project reported the following*: "Move away from "traditional" conservation mowing (reproducing former agricultural hay production, which produces uniform vegetation structure and large quantities of difficult-to-dispose-of arisings, towards mixture of extensive grazing and scrub roguing by staff and volunteers – combined. This produces the effect of large grazers, retarding succession and producing a variety of vegetation structures. This and more usual conservation mowing methods, are currently being evaluated in 3-year Natural England/Broads Authority project looking at management, vegetation structure and invertebrates in Broads fen sites."*

8.4.4.3 Grazing

Control of grazing is seen as a management practice for peatlands adopted by 21 projects and is the most dominant factor when one considers the area of peatland projects covered by this practice. It is four times greater than the area managed by all the other factors described in this section put together at 117,000 ha for the projects surveyed. There are both reductions (in eroded areas) and increases (where vegetation clearance or control is required) in stocking. Approaches used tend to be site specific or regionally based.

8.4.4.4 Burning

At the nine projects where burning is seen as a management practice, this is under strict regulation of the Muirburn or Grass and Heather burning code. One project reported that it occurred to 'appease' sporting interests. No particular innovations or management techniques were reported.

8.4.4.5 Scrub clearance
Scrub clearance was a very common management practice with 25 projects reporting their techniques and delivery mechanism. The cost of scrub clearance varies from £400 to £3000 per ha but is mainly done by in-house staff or volunteers. Typically the work is done by cutting by hands or with chainsaws, mowing/flailing, spraying bracken and rhododendron and some controlled burning. At some sites cattle and ponies have been introduced to remove scrub. Spraying is a concern where water supply off-takes occur downstream.

8.4.4.7 Visitor facilities
Visitor facilities were seen as functions of peatland management by 11 projects. Peatlands are very sensitive to trampling and if a peatland receives many visitors who concentrate in particular areas it may suffer severe damage (Holden et al., 2007). Typically the provision of access, boardwalks (all peatland types), raised viewing platforms (more appropriate for fenland projects) and other paths serve the management function, but visitor centres were installed by two projects. Mown trackways and self-guided trails were also provided at one site. One project response noted how the waste wood from a vegetation clearance exercise on the site has been used to make the boardwalks and this should be seen as good practice.

8.4.5 Project evaluation

8.4.5.1 Site condition and success
Project representatives were asked to score the initial site condition and the present site condition. A low score of 0 would mean that the peatland was completely destroyed while 100 % would be in perfect condition. In addition to scoring the overall site in this way, survey respondents were asked to score the hydrological status (since hydrology is such a fundamental component of peatland function and status; Holden et al., 2007; Defra report SP0352), % area that the target biodiversity community covers, % area of peat intact, % condition for carbon storage. Of course all of these factors can be measured in different (and costly) ways, but from a project evaluation perspective it was deemed useful to gather this information from the projects in this way. In addition respondents were asked to score the overall success of their projects from 0 for totally unsuccessful to 100 for completely successful.

The mean scores for each category are provided in Table 5 while results from a Mann-Whitney U test are shown in Table 6. The latter tested for whether results were significantly greater in the current assessment compared with the initial assessment. This was found not be the case for the biodiversity category and the proportion of peat that was intact. This is to be expected as peat takes many centuries to form and it would be expected that biodiversity indicators would lag well behind hydrological improvements to sites in peatlands. The main success story of restoration strategies appears to be for site hydrology. To some extent this then influences the perception of whether the peatland is actively functioning as a carbon store and uptake route. Improvements in the carbon condition of the peat were found to be significant at the 95% confidence level.

Table 5. Scores evaluating the initial site condition (A) and the current site condition (B) for each peatland project.

Category	Mean	Standard deviation	Maximum	Minimum	Median
Overall site A	46	25	100	0	50
Overall site B	61	19	100	22	63
Hydrology A	46	26	100	0	50
Hydrology B	67	24	100	0	70
Biodiversity A	60	36	100	5	60
Biodiversity B	63	31	100	5	55
Peat A	70	25	100	10	75
Peat B	71	25	100	20	70
Carbon A	50	25	100	0	50
Carbon B	60	25	100	10	60
Overall success	67	26	100	0	75

Table 6. P-values from the Mann-Whitney U test comparing initial with current site condition for each category. Probability is for improvement in the category to be zero.

Category	Probability
Overall site	0.0010
Hydrology	0.0002
Biodiversity	0.3740
Peat	0.4224

Carbon	0.0465

The mean overall success rate for the 56 projects was 67%. This seems to fit the idea that improvements were generally seen in three out of the five categories shown in Table 5. For one project it was considered that the site condition was worthy of an initial score of zero. This improved to 15% following the restoration. There was also one project where the overall success was scored at zero. This site's condition was initially assessed at 70% and was still at 70%. However, this is explained by the fact that the project only began in January 2008 and the survey was completed in February 2008. In order to examine the role of project age in determining success the present overall site condition and project success score were both plotted against the age of the project (Figure 11). There was no significant relationship between either of these pairings. However, there were no projects that were older than 9 years that had success scores lower than 75%. In other words those projects that have run for longest are deemed to have been successful. There were no differences between upland and lowland peatlands in this regard (Figure 11).

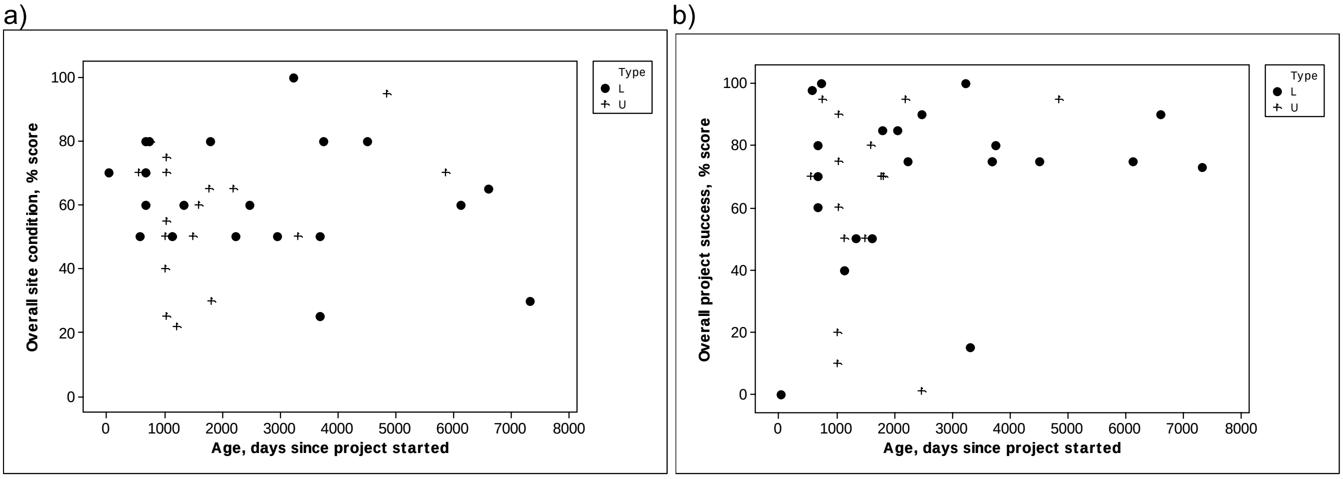

Figure 11. Plots showing site condition (a) and project success (b) scores with age of project for upland and lowland peat projects.

Figure 11 illustrates some interesting patterns in the reporting of project success. Figure 11b suggests that project success increases rapidly through the first three years of a project before levelling off at 80 to 100% thereafter. In contrast, the estimated site condition data show relatively little pattern in time and much greater variation. There is a natural desire to claim success within a typical 3 year funding window but the disparity between the plots perhaps suggests that the nature of self-reported success needs to be carefully evaluated in the light of supporting measurable data. Projects can succeed in many ways and this success may not map directly onto restoration of biodiversity, water table or peatland condition.

Eleven projects returned an overall success of ≤50 %. Follow up interviews of these projects elicited responses from all 11 projects. The 'low' success of five projects (45%) was a result of the project being within early-mid stages of its duration; one project was postponed to the next year as a result of bad weather (i.e. running behind schedule); one project experienced staffing recruitment problems; one project 'got off to a slow start'; one experienced problems on works outside their SSSI boundary; for one, vegetation succession after tree removal was slower than expected and for one, a very degraded area was not re-wetting as well as anticipated (it is not known whether this reflects actual slow recovery or unrealistic recovery times). Full details are given in Appendix 4.

The projects were asked to score from 0 (no importance) to 5 (extremely important) reasons as to why there might have been a shortfall in success. Results are presented in Figure 12. Funding was a key factor, but problems with implementation were consistently reported as being important as well as opposition. Other factors such as governance, land acquisition problems, access and lack of guidance/information were factors for more than a quarter of the projects.

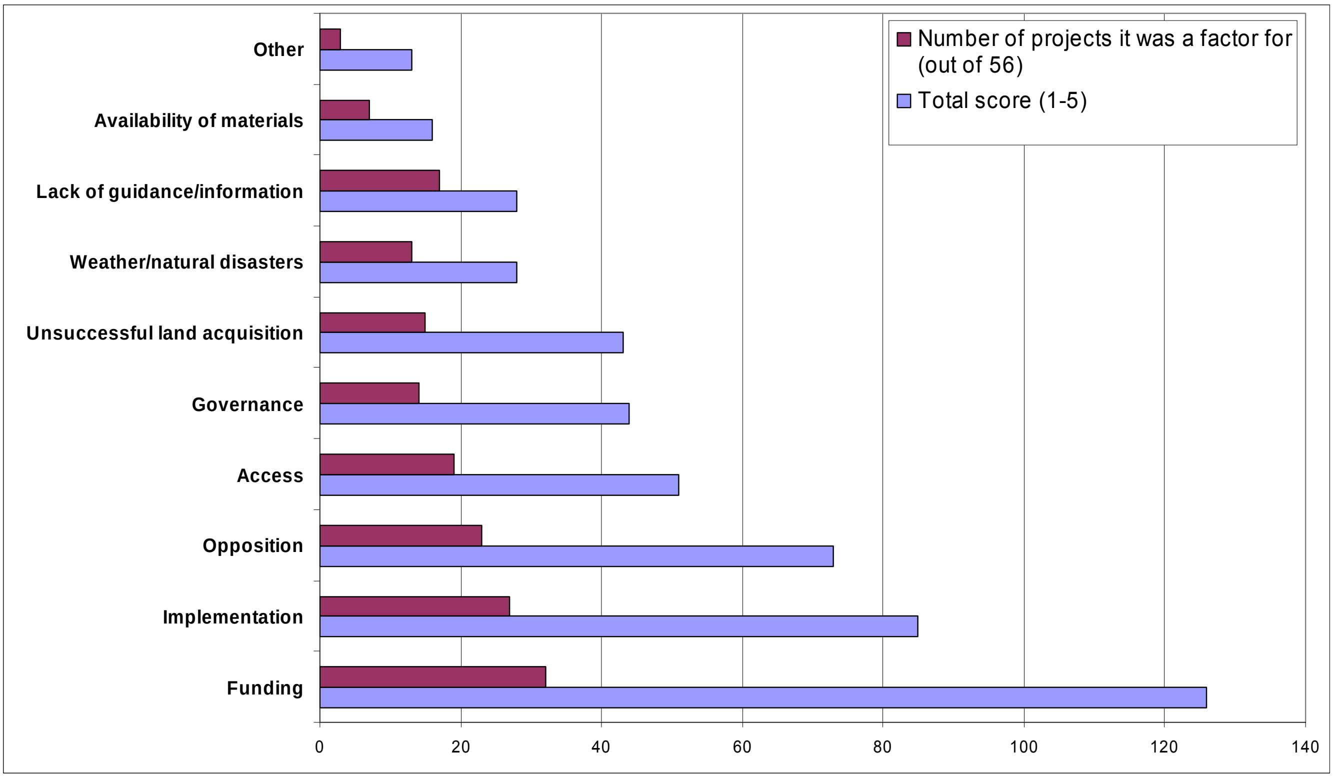

Figure 12. Reasons that project staff thought there had been shortfall in success. Total score is the sum of all scores for each project. Maximum possible score would be 56 x 5 (280).

8.4.5.2 How monitoring is undertaken

The importance of peat restoration and management project monitoring was outlined in Defra report SP0352 (Holden et al., 2007). The questionnaire asked how the projects were being monitored. Results are shown in Table 7. Almost all projects are monitoring vegetation, mainly through ground survey but assisted in about half of the cases by air photos and other remote sensing techniques. Hydrology is being monitored by ground survey in 39 projects. Invertebrate and bird monitoring are also common occurring in more than 50 % of projects while carbon, peat erosion, climate and pollution are being monitored in few cases. Monitoring was delivered by a variety of personnel ranging from academic collaborators to volunteers and private contractors (Table 8). Most vegetation monitoring was delivered in-house while most monitoring for other variables was delivered by others. Academic collaborators dominated the delivery of carbon and climate monitoring.

The length of monitoring is an important factor in measuring success as peatlands may respond differently in the short-term than they do in the long-term to management intervention (e.g. Holden et al., 2006) and there may be lags between different parts of the peat ecosystem. Table 9 outlines the length of monitoring that each project anticipates will occur at their sites. Other than for vegetation and birds, most monitoring is under 7 years in length although for invertebrates and hydrology 8 projects listed their monitoring as being ‘ongoing’. Seven projects collected *baseline* information for vegetation and invertebrates while only one hydrological monitoring project mentioned that they were also monitoring a control catchment where no restoration had taken place. Essentially there is a desire for long-term monitoring of biodiversity indicators (which came out as the most important project justification as described earlier in this report), but there is potentially a large number of these projects which do not have funding secured to perform this monitoring.

Despite the high percentage of projects that report that they are monitoring their projects in one way or another it is not clear how this monitoring has informed the measures of success of the project reported in Table 5. Further, it is not clear from the questionnaires what monitoring actually consisted of in terms of level of detail or robustness of monitoring design, i.e. does pre-restoration monitoring exist? Are there control sites? Is there sufficient monitoring to demonstrate improvement in a statistically robust manner? However, the reported level of monitoring does imply that there is a resource of data that is not at present being analysed and utilised to inform best practice. Although out of the scope of this compendium, a meta-analysis of this monitoring data could and should be performed.

Table 7. Number of projects monitoring peat restoration indicators and methods by which they are doing so. There was an option to enter 'other' methods on the forms, but no entries were received under this category

	Any	Ground surveys	Remote sensing	Air photos	Infrared images	LiDAR
Vegetation	53	53	26	26	9	11
Invertebrates	27	27				
Birds	31					
Hydrology / water quality	39	39	6	3	2	4
Carbon/GHGs	8	8	2	2	1	1
Peat erosion	10	10	2	2	1	0
Climate	8	8	1	1	1	1
Pollution	4	0	0	0	0	0
Other	4	4	1	0	0	1

Table 8. Project monitoring delivery mechanisms, number of projects

	In-house	Academic collaborator	Academic contractor	Private contractor	Hired technicians	Volunteers
Vegetation	41	14	6	18	2	15
Invertebrates	6	8	5	9	0	12
Birds	13	2	1	8	2	16
Hydrology / water quality	21	8	3	5	1	10
Carbon/GHGs	0	5	1	2	0	0
Peat erosion	2	2	2	2	0	1
Climate	2	5	0	1	0	0
Pollution	3	1	0	0	0	2
Other	4	1	0	1	0	1

Table 9. Mean number of years of planned monitoring or number of projects where listed as ongoing or indefinite. Note that the mean has been calculated only from those projects that provided data on number of years of planned monitoring and the calculation does not include zeros for those projects without any monitoring of each variable.

	Mean years	Number listed as 'ongoing/indefinite'
Vegetation	17.1	17
Invertebrates	6.2	8
Birds	21.8	6
Hydrology / water quality	5.6	8
Carbon/GHGs	2.5	2
Peat erosion	1.3	2
Climate	2.5	2
Pollution	5.0	0

8.4.5.3 Future plans

Project respondents were asked about the future plans for their project. Post project plans were being created as part of the project for restoration in 37 cases and for management in 37 cases. When asked whether it was anticipated that the project continues beyond its set end date to deliver restoration or management 31 said yes to the former and 37 said yes to the latter. Respondents were asked to estimate the number of years that their project site would be stable or persist without future work. For restoration projects the mean number of years was 20, while for management projects it was 17.

On average for the existing projects there was perceived to be a funding shortfall of £803,000 just to complete the planned restoration works and £41,000 to complete already planned management on the peat projects sites. Thirteen projects stated that they could restore a much larger area than their current site if they had more funds and the total shortfall for these 13 projects alone amounted to £70.8M.

8.4.5.4 Knowledge gaps identified by project staff and revision of project targets

The following is a list of responses of key knowledge gaps provided by those surveyed:

- The hydrological properties of peat in terms of changing conductivity as it dries out and if by re-wetting, the conductivity of the peat remains the same as before drying out.

- The effects of underlying substrate such as sand lenses on the effectiveness of rewetting proposals.

- One of the biggest tasks is to establish appropriate hydrological management on adjacent land to lessen the stresses on the mossland water table.
- The main difficulty in this case was lack of understanding of the hydrology of the system, as the site is fed by numerous flushes and small streams, and some key water sources are likely to be under the peat. So was difficult to predict how the system would react to alterations to the water supply system.
- For this project the biggest stumbling blocks have been money and unwillingness of surrounding landowners to sell land x 3
- Time scale required for the original vegetation community to re-establish is unknown. X 2
- Vegetation recovery following restoration takes a long time.
- Lack of understanding of long term processes
- I think the biggest problem is actually more to do with resources, i.e. money and the form in which it can be obtained. Acquisition is the best way forward for managing peatlands but this is expensive and often difficult to negotiate
- Poor understanding of how climate change may impact on 'growing' peat bodies. Hence, if some sites become non-active through climate change, we should not expect them to remain carbon sinks or spend funds trying to restore them.
- Lack of understanding of whether the techniques used will be a success in the long term. Will nature restore the peatlands if we remove active management, would this be a cheaper option than capital works? Lack of understanding of how peat will respond to the changing climate.
- Knowledge of areas damaged in the past - currently unknown whether they are improving or become further degraded. Further analysis may help, we hope.
- The main challenge is to monitor and quantify the impacts of our activities on our land in terms of recovery. Changes are noticeable but it's hard to justify to the public eyes how much we improve the population of various animal and plants. In the same way, it's a challenge to know how to inform effectively local communities about the work and to make them understand the changes such as introducing graziers.
- Ditch blocking techniques now well understood, but peat pipes remain a mystery area.
- Causes of, and techniques to mitigate, DOC production. Formation and importance of peat pipes. Lack of data on carbon budgeting and the effects of different management techniques x 2
- Water flow control on deep peat, supremacy of land drainage act over habitat regulations?
- Hydrological requirements of fen habitats
- Appropriate techniques, best practice and how this varies within and between sites, lack of literature on other projects even in grey literature, lack of quality control and review of literature produced, historically very poor monitoring making conclusions from previous projects uncertain at best, lack of co-ordinations between the various organisations in identifying multiple benefits from such work across different interest groups and legislation- e.g. habitats, soils, Water Framework Directive, the carbon issue, water quality and the utility companies.
- Our biggest gaps are in a cost/benefit analysis of carrying out restoration work, both in terms of ecosystem services (carbon storage, water quality, flood alleviation) and finances. Lack of information about the requirements of *Sphagnum* propagation, inoculation and requirements on blanket bog
- Long term effects of grazing lowland calcareous systems with large herbivores
- Long term effects on porosity and lateral flow of peats caused by restorative works (compaction, change in flow regimes through hydrological buffering).
- Knowledge of the extent of land around each of the raised bogs that is necessary to restore them to a self-sustaining state.

- It has not proved possible to find the staff time or funds to do very much site-specific monitoring.

- Don't know how to deal with the very big and deep grips, especially where they have eroded down to mineral soils and it is difficult to key in/seal any block or dam.

- Most of the work is too recent to be able to assess long term success, or to be sure how long degraded areas will take to recover. We don't know whether bunds will fail in longer term. Still learning and refining restoration techniques. All sites are different and can respond to works in different ways.

- How to create fen habitats from degraded peat (been in arable agriculture for decades). What is the likely timescale, how to improve chance of success?

- Catchment scale impacts of grip blocking, grip re-profiling, gully blocking on hydrological pathways, and hydrological recovery of moorlands, specifically relating to production of water colour.

The main issues addressed in these responses are summarised in Figure 13. By far the largest area of uncertainty related to knowledge shortfalls is understanding of peatland hydrology. The second major concern relates to the practical implementation of restoration techniques. It is notable that the understanding of vegetation processes is relatively rarely identified despite the fact that biodiversity is a key driver of the majority of restoration projects. This may reflect the longer history of concern over peatland vegetation management and the relatively recent emergence of concerns over the physical peat system and associated ecosystem services such as carbon sequestration. A significant number of responses over a range of topics raise the concern that long term system responses are poorly understood. Similarly, several respondents expressed concern over limited opportunities for monitoring. These issues are linked since effective monitoring of ongoing projects will provide the data on long term change to support future peatland restoration.

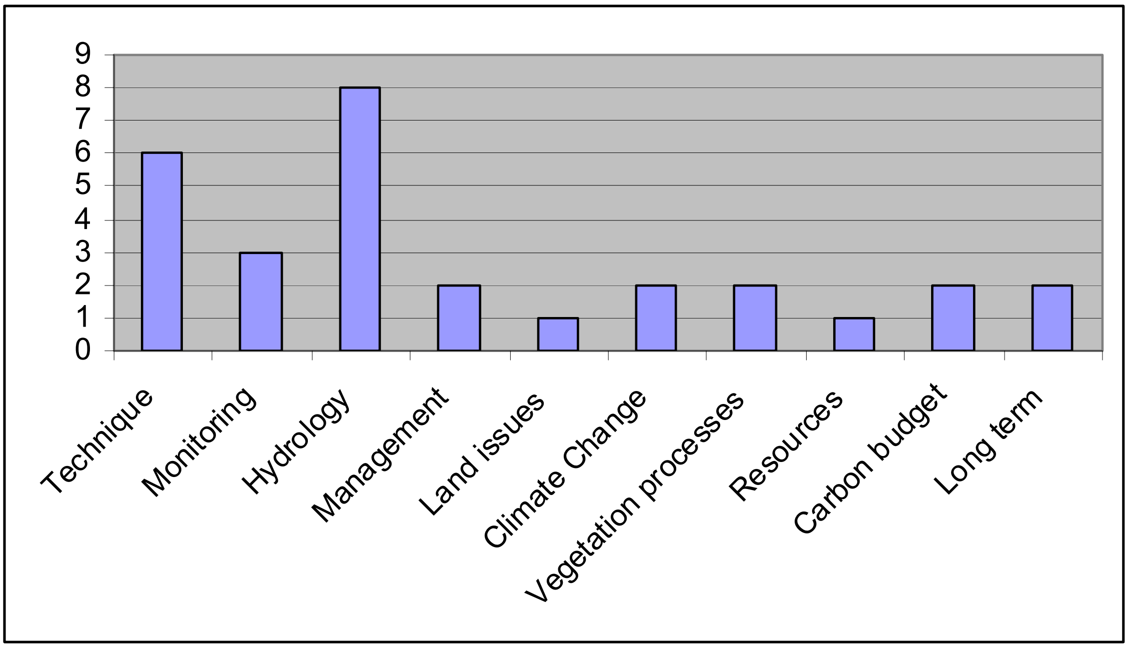

Figure 13. Classification of the qualitative feedback on knowledge gaps encountered by restoration projects

The following is a list of responses when asked whether project targets had been revised:

- It was originally thought that peat extraction might be required to reduce the surface level to groundwater level, and that more modification of surface water flow might be needed. Results so far indicate that the works carried out have been more successful in re-wetting a large proportion of the site than expected and so no more works, other than grazing, fen cutting and scrub control are planned at this stage

- As we work toward a PSA target to have 90% of the SSSIs in recovering conditions by 2010, we cannot move the thresholds. However we are extending the project to restore non designated sites on our land and apply those techniques developed through the project to enhance conservation values on selected sites.

- Land acquisition is going to be more difficult than we thought.
- Acquisition of more land with more difficult management issues.
- It has become obvious that some land necessary for raised bog restoration lies outside designated sites.
- Owing to difficulties with certain owners I have had to be flexible in my approach.
- We increased the area of land to be treated, but due to delays in negotiating permissions with the landowner, the grip blocking works was carried out a year later than originally planned, giving less time for post-blocking monitoring. Therefore we couldn't do before and after monitoring of the treatment site, and have to rely on monitoring from the control site only for comparison.
- Project target area has increased as project develops due to increasing number of ditches being found on restoration sites and due to an increasing number of sites emerging which need restoration.
- Expected completion date deferred due to wet summer 2007. Funds may not be available in 2008
- Changing targets annually based on funding streams and availability of material / our understanding of the issues and technology.
- We have increased the area to be treated and have removed gully blocking at present, but it will be put back in the next phase of restoration. In addition plug planting was not in the original plan.
- Project has moved on to a delivery project. Carbon has become important as well as biodiversity.
- We have revised our objectives, with carbon management becoming much more important.
- Target is still there. 70% of the site is either favorable or recovering. But as mires only accumulate peat at a rate of 2mm / year we now have to wait while the vegetation community re-establishes, which will be decades. Hydrology over 70% of the site is probably near optimum but again optimum will only come with appropriate vegetation cover. Turning from carbon source to carbon sink has been estimated by Macaulay Institute to take up to 20 years on restored sites. Need to work outside the site and restore the catchment which is the next big area of work
- Only one large area in the Broads remains to be cleared, this should be done in 2008-09. Cost have risen to approx £12,000+VAT/ha. Some areas originally identified for clearance are not going to be treated due to anticipated climate change/sea level rise impacts causing scrub regression. All cleared areas require ongoing management to counter succession, a variety of methods will continue to be used, detailed in site management plans.
- Emphasis shifted away from just blocking gullies as project progressed with inclusion of additional methods such as reprofiling and inclusion of membranes, also identified need for greater area of tree and scrub removal. Broad targets still the same
- Constantly refining restoration methods and learning from previous years work

Essentially these comments fall into two categories; those which describe changes in projects due to changes in the funding/political environment and changes forced on projects by the practicalities of negotiating land access and ownership. The former include an increasing emphasis on the role of peatlands as carbon stores. A third theme which emerges in some of the comments relates to the progressive refinement of restoration techniques over the lifespan of projects. This may partially reflect the scarcity of published guidance on appropriate techniques so that projects are learning 'on the job' and to some extent risk re-inventing the wheel. On the other hand it is probably also the case that what constitutes an appropriate restoration technique is strongly site specific so that effective restoration requires a flexible approach to work on the ground.

8.5 Analysis of conference outcomes

At the peat compendium conference we held three workshops for practitioners. Delegates were divided into three groups, with each workshop run three times to ensure all delegates attended all three workshops while keeping workshop sizes to an optimum. The three workshops developed three important areas that either could not be fully explored within the format of the Project Information Form, or that picked up interesting outcomes of the analysis of data: The three workshops were:

Workshop 1 - Implementation: What are the restoration / management methods and what affects their delivery?

Workshop 2 - Monitoring: How are we monitoring our work and what affects our aims, methodologies and results?
Workshop 3 - Future work: What lessons have we learnt and what will influence future plans?

Full details of the results of each workshop are provided in Appendix 5 and only summary conclusions are provided below.

8.5.1 Conclusions from Implementation workshop
The workshop consistently identified some issues pertinent to all restoration:

i) Identify the need for restoration – if the need is known then it can be removed or mitigated against. This saves time and money and increases likelihood of achieving sustainable solutions.

ii) Restoration should be process-driven and not target-driven. All practitioners identified that time was a crucial factor in achieving restoration and that this was not always compatible with targets set out. An alternative approach of being process-driven was identified, i.e. restoring function to the wetland or peat rather than counting occurrence of key species. The questionnaire identified a mismatch between reasons for funding restoration and management projects and the perceived success of projects.

iii) Present drivers for restoration and management, based largely upon biodiversity, have the wrong geographical definition of wetlands in that they outline an existing site rather than outlining the wetland's catchment.

8.5.2 Conclusions from Monitoring workshop
In summary there was a clear consensus from the workshops that monitoring of restoration projects is an important area of activity. The discussion was wide ranging but nevertheless some themes recurred in several contexts and form the basis for the following conclusions and recommendations:

Conclusions:
- Monitoring is essential to restoration works although the main drivers for this perception vary considerably from project to project.
- Monitoring is expensive, should be properly costed and should be planned and implemented early in the life of a project.
- Valuable monitoring data should be exploited to the maximum. This requires networking with other projects to share results and demonstrated best practice and networking with academic institutions to ensure that data is fully analysed.
- Standard guidance on the implementation of peatland restoration monitoring including approximate costings would be welcomed.
- It is important that the most basic monitoring including recording project actions, recording managers' qualitative feedback, and fixed point photography are not neglected.

Recommendations:
- There is a clear need to establish a networking organisation/opportunity for peatland restoration project managers. This can be easily implemented through support for the initiatives discussed at the compendium conference.

- Standard guidance on monitoring peatland restoration projects should be provided. This could be efficiently implemented as part of the proposed peatland compendium website.

8.5.3 Conclusions from Future Work workshop
Overall the major consensus was that attention and allocation of time and resources to the early stages of project development was key to the delivery of a successful project.

Other factors identified as important to a successful project include:

- A clear and strong vision and good, effective management.
- Partnerships – partnership working is beneficial in terms of efficient use of resources, in providing wider access to expertise and resources, and resulting in multiple benefits. However, with it there were a number of potential obstacles including delays caused from securing agreement within large partnerships, administrative difficulties associated with a diversity of partner working methods and project partners occasionally not working together to deliver project objectives.
- Engagement with all parties of interest was considered essential in order to secure buy-in to reduce levels of opposition and enable more effective conflict resolution.
- Communications – effective and up-to-date project communications are important, both internally and externally. This includes dissemination of project news, successes and best practice.

- Realistic aims and objectives and flexibility within these to adapt to changing conditions (physically, financially and politically).

8.6 Analysis of additional compendium entries

A further 5 projects returned entries for the compendium in addition to the 56 that were returned in time for in-depth analysis. These are indicated in Appendix 2. There were no additional factors of importance that emerged in these surveys that did not emerge in the above discussion.

8.7 Analysis of existing science-base

There is relatively little published literature on peatland restoration based on the UK experience. Much more is understood from international work which is being reviewed as part of a concurrently running Defra project (SP0565) and is therefore not covered here. Most published UK work relates to the impact of grip-blocking in blanket bogs on water table or water colour or DOC production (Wallage et al., 2006; Worrall et al, 2007a, b). There is also a limited amount of work on gully-blocking (Evans et al. 2005). The key point is that very little is known about peat restoration processes and impacts in the UK scientific literature. Appendix 6 provides a review of the literature covering only those topics where there is a reasonable body of literature. Scientific information is lacking in many areas of peatland restoration and hence those areas are not covered in the Appendix.

A key finding through survey of the scientific published and grey literature shows that there *have* been some large scale regional and national surveys of restoration techniques. These reports have devised methods to prioritise locations to target resources and for determining the most effective technique to use for some strategies such as drain and gully-blocking. A summary of such literature is provided in Appendix 6.

8.8 Products of the project

This project has produced a number of products which are in addition to this report. These include:

1. The electronic compendium of peatland restoration and management projects in the UK.
2. A website to disseminate key project findings
3. A website that allows continual updating of the compendium as new projects come on stream
4. Four-page research note/flier
5. Improved communication and knowledge transfer between peat management and restoration projects; we have a started a UK peatland restoration network.

8.9 Summary of main findings

- Around half of the projects surveyed involved more than one peatland type and these require more complex management decisions and restoration practices. There were more lowland raised bog projects than any others but these tend to be small in area; the area of blanket bog considered as part of restoration projects was more than three times greater than the area of all the other types of peatland put together.

- The presence of a conservation status for peatland sites is very important in determining whether there is active restoration or management. Only one project was located on land that had no conservation status while 50 out of 56 projects were on SSSIs. A major driver of management and restoration in England was the SSSI PSA targets.

- Just over half of the projects were managed as part of a partnership, with over 60 % having a government agency involved in their management. Most project management was delivered by in-house staff, but on average there were only 1.4 FTE staff per project. Stakeholder and landholder consultation efforts were common practice for projects.

- The median budget per project was £241K. The median project budget per hectare was £1600. Funding sources were extremely varied. Half of projects were funded by more than one source, while 14 % of projects had four or more sources of funding. Expenditure on practical works forms an average of 55% of project budgets. Two-thirds of projects had expenditure dedicated to monitoring and the proportion of funds for monitoring was greater for the smaller projects. Most of the projects occurred on land which is predominantly privately owned for commercial purposes. 21 % of projects occurred on sites that were owned by a mixture of private commercial, charity and publicly owned land. Such mixed ownership may create problems for implementation of management projects and indeed a number of questionnaires discussed the difficulties experienced under these situations. For projects with budgets between £26K and £100K, approximately 10 % of the budget was spent on land purchase, the same as those larger projects with budgets up to £1.5M. Of those projects that involve land purchase, 60 % are lowland and 40 % are upland.

- Most projects reported that one of their main challenges was physical access for machinery to develop practical works on site. Purchase of equipment for bunding peat or baling heather, removal of vegetation such as trees or scrub and archaeological survey costs were all expensive investments for a number of projects. Indeed 32 % of projects had to consider archaeological needs for their site. Health and safety considerations were found to be another key challenge, particularly where land was accessibly by the public.

- Most projects are focussed on restoring ecological and hydrological function, or whole ecosystem function. In terms of project justification, biodiversity came across overwhelmingly strongly and was used as a justification for all projects. Hydrological function was the second most important justification factor. Carbon was used as a justification for 62 % of the projects, but was only considered extremely important in three cases. There have been changes recently in that less of the newer projects claim that carbon is of no importance or of very low importance when justifying the need for restoration or management.

- In terms of issues that resulted in sites requiring restoration, succession was the most commonly recorded factor that was considered extremely important. However, 70 % of these projects were lowland indicating that there are differences in concerns between peatland types.

- For each technique of restoration there are many variants which have been trialled. Drain-blocking and vegetation removal are the most common techniques adopted across the UK.

- Grazing control, scrub clearance, hydrological control and visitor access were seen as important peatland management issues requiring attention. These factors reflect the highest priority project justifications relating to biodiversity and hydrological control.

- There was a significant difference in how staff graded the site conditions at the start of their project compared to present conditions. The mean score of site condition (100 % is excellent state, 0 % is totally destroyed) significantly rose from 46 % to 61 %. However, the dataset suggested that overall while there were significant improvements in hydrological condition and some improvement in carbon sequestering potential, there were no significant improvements in biodiversity or the proportion of peat that was intact.

- The mean overall project success score provided by project staff was 67 %. Examination of the success scores by length of project showed that perceived success increased rapidly through the first three years of a project before levelling off at 80-100% thereafter. In contrast, the estimated site condition data showed relatively little pattern in time and much greater variation. There is a natural desire to claim project success within a typical 3 year funding window but there was a disparity between success scores and site condition improvements with time. Therefore, the nature of self-reported success needs to be carefully evaluated in the light of supporting measurable data. Projects can succeed in many ways and this success may not map directly onto restoration of biodiversity, water table or peatland condition.

- In terms of reasons for project shortfall, funding was a key factor, but problems with implementation were consistently reported as being important as well as ‘opposition’. Other factors such as governance, land acquisition problems, access and lack of guidance/information were factors for more than a quarter of the projects.

- Almost all projects are monitoring vegetation, mainly through ground survey but assisted in about half of the cases by air photos and other remote sensing techniques. Indeed there is a widespread use of GIS and remote sensing (air photos and LiDAR) among peat restoration and management projects. Many have noted that these tools were invaluable for the project. Hydrology is being monitored by ground survey in 70 % of projects. Invertebrate and bird monitoring are also common occurring in more than 50 % of projects while carbon, peat erosion, climate and pollution are being monitored in few cases. Monitoring was delivered by a variety of personnel ranging from academic collaborators to volunteers and private contractors. Most vegetation monitoring was delivered in-house while most monitoring for other variables was delivered by others. Academic collaborators dominated the delivery of carbon and climate monitoring. Monitoring is essential to restoration works although the main drivers vary considerably from project to project. Monitoring is expensive, should be properly costed and should be planned and implemented early in the life of a project. There is a lack of pre-restoration monitoring of long time series (i.e. years) to generate baseline conditions on functions such as hydrology.

- Two-thirds of projects noted that post project plans were being created as part of their project and it was envisaged that these projects would continue beyond their set end date. These aims were, of course, made in the hope of securing funds.

- By far the largest area of uncertainty expressed by the peat restoration project personnel was understanding of peatland hydrology. The second major concern related to the practical implementation of restoration techniques. It was notable that the understanding of vegetation processes was rarely identified despite the fact that biodiversity is a key driver of the majority of restoration projects. A significant number of responses over a range of topics raise the concern that long term system responses are poorly understood. Similarly, several respondents expressed concern over limited opportunities for monitoring. These issues are linked since effective monitoring of ongoing projects will provide the data on long term change to support future peatland restoration.

- Respondents were asked about whether their projects had been revised. Comments fell into two main categories; i) those which describe changes in projects due to changes in the funding/political environment and ii) changes forced on projects by the practicalities of negotiating land access and ownership. The former included an increasing emphasis on the role of peatlands as carbon stores.

- Survey of the scientific published and grey literature shows that there *have* been some large scale regional and national surveys of restoration techniques. These reports have devised methods to prioritise locations to target resources and for determining the most effective technique to use for some strategies such as drain and gully-blocking.

- Restoration should be process-driven and not target-driven. All practitioners identified that time was a crucial factor in achieving restoration and that this was not always compatible with targets set out. An alternative approach of being process-driven was identified, i.e. restoring function to the wetland or peat rather than counting occurrence of key species.

- Present drivers for restoration and management, based largely upon biodiversity, have the wrong geographical definition of peatlands in that they outline an existing site rather than outlining the peatland's catchment.

8.10 Recommendations for future work

- Valuable monitoring data should be exploited to the maximum. There are a large number of projects that are monitoring their sites for a wide range of variables. This implies that there is a resource of data that is not at present being analysed and utilised to inform best practice. It is recommended that a meta-analysis of this monitoring data is performed.

- Standard guidance on monitoring peatland restoration projects, including approximate costings, should be provided. This could be produced as part of the same project as the meta-analysis.

- There is widespread use of GIS and remote sensing data for peat restoration projects. Many respondents noted how crucial it was for project implementation and resource allocation. It is recommended that Defra provides advice and data for peatland restoration and management projects on use of GIS and available remote sensing data. For example a list of peatland sites where LiDAR coverage is currently available would be useful.

- There is a clear need to establish a networking organisation for peatland restoration project managers. This can be easily implemented through support for a number of initiatives that were raised at the compendium conference.

- Funding to help disseminate findings in the literature of some of the large-scale scientific regional and national surveys of restoration practice should be made available. For example, methods have been devised to prioritise locations to target resources and for determining the most effective technique to use for some strategies such as drain and gully-blocking and this information could be utilised by new restoration projects.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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