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Evidence Project Final Report

Department for Environment Food & Rural Affairs

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Project identification

1. Defra Project code: BD5104

2. Project title: Restoration of blanket bog vegetation for biodiversity, carbon storage and water regulation

3. Contractor organisation(s): University of York

4. Total Defra project costs (agreed fixed price): £ 979,326

5. Project: start date 01/11/2011

   end date 31/05/2017

6. It is Defra's intention to publish this form.

   Please confirm your agreement to do so.....**YES** ☒ **NO** ☐

   (a) When preparing Evidence Project Final Reports contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.

   Defra recognises that in a small minority of cases there may be information, such as intellectual property or commercially confidential data, used in or generated by the research project, which should not be disclosed. In these cases, such information should be detailed in a separate annex (not to be published) so that the Evidence Project Final Report can be placed in the public domain. Where it is impossible to complete the Final Report without including references to any sensitive or confidential data, the information should be included and section (b) completed. NB: only in exceptional circumstances will Defra expect contractors to give a "No" answer.

   In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

   (b) If you have answered NO, please explain why the Final report should not be released into public domain

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.

The overall long-term aim of project BD5104 '*Restoration of blanket bog vegetation for biodiversity, carbon sequestration and water regulation*' was to deliver robust and credible (long-term) experimental evidence to underpin the development and refinement of possible management techniques, to reduce the dominance of ling heather (henceforth referred to as heather) and support the development of 'active' blanket bog vegetation with a high cover of "peat-forming" species, particularly *Sphagnum* moss. Given the relatively slow rate of change in blanket bog vegetation, and recovery of heather (and other vegetation) from management, it was anticipated that the initial phase had to focus on the short-term objectives of assessing the initial re-growth in addition to the assessments of initial carbon, water and biodiversity impacts. However, the study was designed to allow addressing the project's long-term aim in a potential extension phase.

Based on the available information from a literature review and an initial workshop, a paired experimental platform was designed and replicated at three grouse moor managed blanket bog sites in Northern England (ranging from drier to wetter conditions), which included a pre-management change period (to allow assessing differences unrelated to management change). Whilst the two major managements were applied at the catchment-scale (around 10 ha each of burning versus mowing with leaving brash), seven treatments were investigated at the plot-scale (5x5 m) within the respective sub-catchments: burning of heather with or without *Sphagnum* pellet addition; mowing with or without brash removal and either with or without *Sphagnum* pellet addition; uncut management (within the mown catchment). The unique strength of the experimental approach was therefore the combination of catchment- and plot-level replication. However, the uncut and brash removal options could only be assessed at the plot level, lacking a catchment approach, which is particularly relevant for any hydrological and flow impact assessment. The paired catchment-scale comparison of a 'business as usual' burn rotation versus an alternative mowing management was done at the usual management patch size (~0.3 ha), with multiple patches aimed to achieve with each management intervention a total of about 20% of the catchment area (equal to ~25% of the total heather dominated area) within each catchment every two years (equal to a ~10 year rotation). The catchment scale approach allowed capturing landscape processes of runoff, erosion and stream flow and resulting carbon export, whilst plot-level assessments focused on vegetation assessments, carbon stocks and fluxes, peat pipes, micro-topography, greenhouse gas (GHG) emissions, peat water tables and water quality. The uncut plots allowed the effects of management to be placed in context of effects of other environmental factors (e.g. climate) regardless of management as well as addressing the fundamental question of long-term development of an unmanaged heather stand (e.g. the effect of opening up of the increasingly rank heather on the bog vegetation community).

Whilst the project successfully assessed the initial impacts on key biodiversity, carbon storage, GHG emissions and water aspects, it also found that any policy relevant long-term evidence requires monitoring well beyond the initial period, likely to cover a 25 year period. In summary, the findings so far showed considerable site and interannual variability, whilst the findings from the different elements of the project are to be seen as preliminary (only including four years of post-management monitoring), which indicate that mowing could be an appropriate, albeit more costly, alternative to burning of heather dominated blanket bog on grouse moors, benefiting key ecosystem services, particularly related to hydrology, and potentially encouraging development of 'active' blanket bog vegetation. Moreover, so far *Sphagnum* introduction from pellets failed. However, process-level effects, and the associated long-term impacts on ecosystem services, of a complete change in catchment management practice and vegetation re-growth require time to develop, particularly in cold, wet and thus slow growing upland ecosystems.

Mowing did not cause peat compaction but decreased micro-topography at the plot-level. Either management resulted in better heather nutritious value for grouse and management did not differ in heather regrowth nor vegetation cover after four years, but indicated a likely different trajectory towards "active" bog vegetation on mown plots. So far, burning appeared to be the least beneficial form of management intervention towards supporting 'active' bog vegetation, particularly at the driest site. The uncut option showed few, if any, downsides apart from limited recovery of a peat-forming bryophyte layer at the driest site. Mowing regardless of brash management seems to encourage key species and re-establishment of a peat-forming 'typical' bog community, particularly at the wettest site. Overall plant species diversity was low, decreasing from the wettest to the driest site. Mowing increased peat moisture and water tables (wetter) with benefits to cranefly abundance and thus bird populations under dry conditions but potential negative impacts on generally wet sites, of particular relevance for climate change impact scenarios. Mowing also showed reduced stream flow (loss) with important downstream flood alleviation impacts during intense short-term rainfall events. So far, water quality was affected by vegetation type and climate but not by management. Whilst carbon flux losses were higher for burning due to initial vegetation combustion, decomposition rates decreased under burning but overall losses for mowing from brash decomposition remain unknown. Charcoal input from vegetation burning explained high peat carbon accumulation. Net CO_2 flux budgets for uncut plots showed greatest carbon gains at the wettest site whilst the driest site was a small net carbon source. Both managements switched from a net carbon sink to a similar net source after management, which was on average 8 times larger than the C gains of the uncut scenario. Stream carbon export did not differ between management but showed high seasonal variability and a positive correlation with temperature. Methane emissions increased with higher water tables, and showed a weak positive effect of sedge cover and soil temperature. Uncut net greenhouse gas emissions were only negative at the site with intermediate water tables. During the study period, the results of the uncut plots for the two drier sites agreed fairly well with current assumptions of the IUCN UK's Peatland Code for modified and drained blanket bog sites. However, on the wettest and less modified site, the final two years resulted in much higher net GHG emissions, indicating a possible water table depth threshold in relation to achieving both, a net C sink and a beneficial net GHG balance. Whilst mowing was six times more costly than burning, burning showed about 70 times higher CO_2 emissions (including combustion but not including unknown brash decomposition losses) and considerable air pollution. Modelled peat accumulation revealed large past losses, highlighting potential considerable carbon gains from restoration. Overall, based on 30 parameters, mowing was marginally more beneficial than burning. However, for all these effects, long-term trajectories remain unknown.

Overall, comparisons between the two types of management highlighted the need for continued management and monitoring over at least a complete management cycle (requiring ca. 10-15 years), possibly together with additional plot-level treatments like repeated mowing and additional *Sphagnum* addition (as plugs) to burnt and uncut plots. Moreover a catchment-scale 'no management' scenario (natural layering and opening up of old heather stands) should be considered in future research as other available management option to encourage 'active' bog vegetation. Furthermore, specific experimental research and monitoring is needed to assess long-term carbon budgets, GHG emissions and biodiversity impacts and if there is a water table threshold for achieving an optimum outcome (e.g. mowing might cause too wet a bog under some conditions as seen for GHG emissions and cranefly emergence). Clearly including 'pristine' bog sites in future monitoring would allow an assessment of what impact the management interventions have on the restoration trajectory towards unmodified or less modified bog, i.e. are both management practices potential 'blockers', which in effect are repeatedly resetting the ecological trajectory back compared to no intervention?

Required time periods for a continuation of monitoring towards providing a robust long-term policy relevant evidence on key ecosystem parameters (based on catchment rotational management, interannual climate variability and vegetation growth rates and plant community development) can be estimated to require between 10 to 25+ years depending on the parameter, e.g. for C budgets (10+ years), methane emissions (15+ years), water budgets (20+ years) and vegetation dynamics and biodiversity (25+ years). To tease apart site and climate effects from management impacts requires long-term datasets; notably, these are

the only long-term data for blanket bogs under active grouse moor management. The current work, whilst providing much needed policy evidence advice on burning and alternative blanket bog management impacts on ecosystem services, has the potential to also demonstrate realistic practitioner-relevant outcomes with multiple benefits to all stakeholders.

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 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 Exchange).

(See separate document)

As per submissions documents; this project required a much longer report together with several additional documents.

This report should be cited as:

Heinemeyer A., Vallack H.W., Morton P.A., Pateman R., Dytham C., Ineson P., McClean C., Bristow C. and Pearce-Higgins J.W. (2019) with an Appendix by Richard A. Lindsay. Restoration of heather-dominated blanket bog vegetation on grouse moors for biodiversity, carbon storage, greenhouse gas emissions and water regulation: comparing burning to alternative mowing and uncut management. Final Report to Defra on Project BD5104, Stockholm Environment Institute at the University of York, York, UK.

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.

P.A. Morton & A. Heinemeyer (2019) Bog breathing: the extent of peat shrinkage and expansion on blanket bogs in relation to water table, heather management and dominant vegetation and its implications for carbon stock assessments.Wetlands Ecology and Management. http://link.springer.com/article/10.1007/s11273-019-09672-5

A. Heinemeyer, T.J. Sloan & R. Berry (2019) Assessing soil compaction and micro-topography impacts of alternative heather cutting as compared to burning as part of grouse moor management on blanket bog. PeerJ. (in press)

A. Heinemeyer, Q. Asena, W.L. Burn, A.L. Jones & M. Ashby (2019) Response to: Comment on "Peatland carbon stocks and burn history: Blanket bog peat core evidence highlights charcoal impacts on peat physical properties and long-term carbon storage by Evans et al. GEO: Geography and Environment. (in press)

A. Heinemeyer, Q. Asena, W.L. Burn & A.L. Jones (2018) Peatland carbon stocks and burn history: blanket bog peat core evidence highlights charcoal impacts on peat physical properties and long-term carbon storage. GEO: Geography and Environment 5(2), e00063. https://doi.org/10.1002/geo2.63

A. Heinemeyer & G.T. Swindles (2018) Unraveling past impacts of climate change and land management on historic peatland development using proxy-based reconstruction, monitoring data and process modeling. Global Change Biology, 24(9): 4131-4142. https://doi.org/10.1111/gcb.14298

P.A. Morton & A. Heinemeyer (2018) Vegetation matters: Correcting chamber carbon flux measurements using plant volumes. Science of the Total Environment, 639: 769–772. https://doi.org/10.1016/j.scitotenv.2018.05.192

P.A. Morton (2016) A Burning Issue: Assessing the impact of alternative grouse moor managements on vegetation dynamics and carbon cycling on UK blanket bogs. PhD thesis, University of York. http://etheses.whiterose.ac.uk/id/eprint/17199