Institution: Manchester Metropolitan University		
Unit of Assessment: B7 Earth Systems and Environmental Sciences		
Title of case study: Conservation and restoration of damaged semi-natural habitats: restoring sensitive plant life and increasing carbon stores		
Period when the underpinning research was undertaken: 2000 - 2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Simon Caporn	Lecturer to Professor	1994 - present
Chris Field	Research Associate, Lecturer, Senior Lecturer	2009 - present
Nancy Dise	Professor	2005 - 2013
Robin Sen	Reader	2006 - 2018
Period when the claimed impact occurred: 1 August 2013 – 31 December 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Research on the anthropogenic drivers of biodiversity loss has helped to protect and restore internationally rare and sensitive UK habitats from the effects of nitrogen pollution. In Wales and Shropshire nitrogen threshold levels have been lowered from 4% to 1% of the EU Critical Load for habitat assessments to discourage intensive agriculture near sensitive sites. Stricter thresholds also limited the scope for new housing developments to protect the ancient Ashdown Forest from risks of raised nitrogen pollution. Parallel, pioneering, applied ecology research has underpinned novel Sphagnum-based landscape scale restoration of highly-degraded peatlands. The work in the Peak District and Yorkshire delivers a carbon benefit of 16,000tCO_2e/year. In the Peak District, it has helped to secure 12,000ha of active blanket bog (58% of Peak District peatland), thus safeguarding 11,600,000t stored carbon from future loss. As the UK's only supplier of Sphagnum propagules, Micropropagation Services Ltd has grown annual sales to GBP1,000,000 (61.4% CAGR) and now also exports to Germany. The company has invested heavily in R&D, leading field trials to establish Sphagnum as the UK's first commercial 'carbon crop' which will eliminate peat from compost by 2030.

2. Underpinning research

Atmospheric pollution from nitrogen (N) is a top three threat to global biodiversity. Manchester Metropolitan University is home to one of the longest active N-addition field experiments in the world, which has made a significant contribution to the understanding of how N pollution affects sensitive ecological processes.

The researchers have published approximately 50 peer reviewed papers and ten Government-sponsored policy reports in this field since 2000. The body of work has established the group as a key player in understanding the effects of air pollution on plants in sensitive ecosystems, identifying and monitoring ecosystem degradation, and subsequently developing measures to restore peatlands damaged by historic air pollution and poor management.

The team's field experiments in Ruabon, Wales, were the first to show, in this moorland habitat, the sensitivity to N pollution of ecological processes. Comprehensive analyses indicated raised nitrate leaching, base cation depletion, increased winter injury, and loss of lichens and bryophytes. The researchers proposed these observed changes as key bio-indicators of N pollution in moorlands **[1]**.

Funded through DEFRA's Terrestrial Umbrella programme [G1], Field led a multi-habitat survey in 2009 on pollution indicators and biodiversity, validating these proposed indicators at national scale **[2]**. Manchester Metropolitan led the methodological development, provided specialist knowledge in heathland and peatland habitats, and performed a large component of the laboratory and data analysis. Project collaborators contributed additional habitat and statistical expertise. The project was the first to demonstrate that species composition of five key habitats show similar vulnerability to N pollution and that habitats are sensitive to N pollution at lower levels than current UK and EU Critical Load legislation **[2]**. The team derived metrics for ecosystem recovery from pollution and found significant N effects on soil nutrient levels and carbon accumulation **[3]**.

In follow-up work, Field and Caporn led research in a 2014-15 Joint Nature Conservation Committee (JNCC) project [G2] that investigated landscape-scale evidence of ecosystem harm

from N across all UK Protected Habitats. This work directly underpinned the creation of the JNCC Nitrogen Decision Framework (see Section 4). Insights on changes in plant community composition expanded when Dise and Caporn analysed UK sites as part of a large European consortium [G3] that revealed consistent and significant declines in peatland biodiversity due to pollution and climate change from Southern Europe to the Arctic **[4]**.

To help meet its carbon emissions obligations and 2050 net zero target, the UK Government has stated the need to restore the carbon sink functions of 75% of UK damaged peatbogs. In the English South Pennines, high levels of air pollution played a significant historical role in peatland degradation through the deterioration of blanket bog and Sphagnum moss, the keystone species. Assessment by Caporn of natural recovery of Sphagnum in 2005-6 **[5]** indicated that air quality in the Peak District National Park had improved sufficiently for Sphagnum-based restoration. Soil microbiologist, Sen, demonstrated in parallel work that microbial succession accompanies vegetation re-establishment of bare peat, also supporting this costly peatland restoration procedure to support richer biodiversity.

Regenerating Sphagnum peatbogs was previously limited by a lack of Sphagnum propagules, however, in a consortium with 'Moors for the Future' and Micropropagation Services Ltd, Manchester Metropolitan piloted and evaluated techniques using the company's prototype BeadaMoss® Sphagnum products. The research proved that planted Sphagnum could establish and grow in harsh upland conditions. Further trials of Sphagnum beads and plugs showed that survival and establishment of plugs was high (99%) and much greater than for Sphagnum beads **[6]**. These products and derivatives are now commonly used across northern England; an Interreg-funded consortium is piloting and monitoring their use alongside other techniques across five European sites [G5].

The successful re-introduction of Sphagnum not only removed a barrier that limited the successful restoration of degraded peatlands, but also suggested that the moss could be farmed in large enough quantities to replace peat in compost **[6]**. Funded by Innovate UK and the Biotechnology and Biological Sciences Research Council (BBSRC) [G6], Caporn and Field, with Micropropagation Services Ltd and partners, set up the UK's first Sphagnum-farming trial sites, successfully demonstrating the potential for Sphagnum biomass production, using novel plant management techniques.

3. References to the research

Note: Citations (Scopus and Web of Science citations versus expected citations); - Jan 2021

1. Edmondson JL, Carroll JA, Price EAC, **Caporn** SJM (2010). *Bio-indicators of nitrogen pollution in heather moorland.* Science of Total Environment. 408(24):6202-6209. DOI: 10.1016/j.scitotenv.2010.08.060. *Citations: Scopus 18, WoS 18 (expected 44.5).*
2. **Field** CD, **Dise** NB, Payne RJ, Britton AJ, Emmett BA, Helliwell RC, Hughes S, Jones L, Lees S, Leake JR, Leith ID, Phoenix GK, Power SA, Sheppard LJ, Southon GE, Stevens CJ, **Caporn** SJM (2014). *The Role of Nitrogen Deposition in Widespread Plant Community Change Across Semi-natural Habitats*. Ecosystems 17:864-877. DOI: 10.1007/s10021-014-9765-5. *Citations: Scopus 69, WoS 63 (expected: 29.52).*
3. Rowe EC, Jones L, **Dise** NB, Evans CD, Mills G, Hall J, Stevens CJ, Mitchell RJ, **Field** C, **Caporn** SJM, Helliwell RC, Britton AJ, Sutton MA, Payne RJ, Vieno M, Dore AJ, Emmett BA (2016). *Metrics for evaluating the ecological benefits of decreased nitrogen deposition.* Biological Conservation. 212:454-463. DOI: 10.1016/j.biocon.2016.11.022. *Citations: Scopus 16, WoS 13 (expected 15.72)*
4. Robroek BJM, Jassey VEJ, Payne RJ, Martí M, Bragazza L, Bleeker A, Buttler A, **Caporn** SJM, **Dise** NB, Kattge J, Zajac K, Svensson BH, Van Ruijven J, Verhoeven JTA (2017). *Taxonomic and functional turnover are decoupled in European peat bogs.* Nature Communications. 8:1161. DOI: 10.1038/s41467-017-01350-5. *Citations: Scopus 34, WoS 31 (Expected: 40.73).*
5. Carroll J, Anderson P, **Caporn** S, Eades P, O'Reilly C, Bonn A (2009). Sphagnum in the Peak District: Current Status and Potential for Restoration. Moors for the Future, Report No 16. https://www.researchgate.net/publication/224807088_Sphagnum_in_the_Peak_District_Current_status_and_potential_for_restoration
6. **Caporn** SJM, Rosenburgh AE, Keightley AT, Hinde SL, Riggs JL, Buckler M, Wright NA (2018). *Sphagnum restoration on degraded blanket and raised bogs in the UK using*

micropropagated source material: a review of progress. Mires and Peat 20(9):1-17. doi: 10.19189/MaP.2017.OMB.306 *Citations: WoS 5 (expected 3.5)*

Grants and funding

G1. Effects of eutrophication and acidification on terrestrial systems. 2001-2010. DEFRA/NERC (Natural Environment Research Council) Terrestrial Umbrella (Contract: CPEA18). Work package leader (2007-11): Caporn. Total to Manchester Metropolitan: GBP110,000.

G2. A decision framework to attribute atmospheric nitrogen deposition as a threat to or cause of unfavourable habitat condition on protected sites. 2014-2015. JNCC: PI: Field. Total award to Manchester Metropolitan: GBP2,500

G3. PEATBOG (Pollution Precipitation & Temperature Impacts on Peatland Biodiversity & Biogeochemistry). 2009-2013. NERC (ERA Net BiodivERsA Programme, Ref: NE/G002363/1). Award: GBP456,606. PI: Dise.

G4. Impact of atmospheric pollutants on the current and future status of protected habitats. 2015-2016. NERC Policy Fellowship (Ref: NE/M019888/1). Award: GBP56,496. PI: Field.

G5. Carbon loss reduction from peatlands: an integrated approach. 2019-2023. EU Interreg-NW Programme (Ref: NWE808). Total award: EUR6,200,000 (01-2019). Total to Manchester Metropolitan: GBP184,216. Lead: Field.

G6. Sphagnum Farming UK - A Sustainable Alternative to Peat in Growing Media. 2018-2019. BBSRC (ISCF WAVE 1 AGRI TECH, Ref: BB/R021678/1). Award: GBP167,445. PI: Caporn.

Additional indicators of research quality

- Field supported the regulatory review of coal-fired power stations as a temporary member of the Inter-Agency Air Quality Technical Advisory Group (2015-16). His NERC Policy Fellowship [G4] with the Environment Agency applied the findings of his research to test alternatives to conventional critical loads in electricity supply permitting decisions.
- Field and Caporn are both contributing to the 2020-2022 United Nations Economic Commission for Europe (UNECE) review of European Critical Loads for Nitrogen; (Field is lead author of the chapter on Mires, Bogs and Fens).
- Lengthy relationship and small project grants from Micropropagation Services Ltd (MPS) and 'Moors for the Future' indicate research track record. The BBSRC grant [G6] indicates the innovative nature and commercial potential of Sphagnum farming.
- Field and Caporn are leading scientific support in the Greater Manchester Peat Pilot study (2019-2020), which will inform DEFRA's delayed England Peatland Strategy.

4. Details of the impact

Changing policy and regulation to protect sensitive ecosystems

Drawing on the full body of atmospheric nitrogen deposition research from Manchester Metropolitan and collaborators, Caporn was the first author for a Natural England-commissioned report, entitled '*Assessing the effects of small increments of atmospheric nitrogen deposition (above the critical load) on semi-natural habitats of conservation importance'* (NERC210, published 2016).This review, which highlights the underpinning body of work on the effects of nitrogen deposition on sensitive habitats, has directly influenced policy and regulatory change. For example, it directly informed changes to Natural Resources Wales (NRW) permitting guidelines for new intensive livestock units in Wales. Drawing directly on NERC210 and the research (e.g. reference [2]), NRW changed how it protects lower plant communities under the Industrial Emissions Directive (IED). Specifically, the new GN020 guidance reduced the thresholds used to assess applications for intensive livestock units from 4% of the EU Critical Load to 1% **[A]**.

This move has provided a much-needed policy tool to help control the rapid expansion of intensive agricultural units in Wales, and offers increased protection for internationally rare and sensitive habitats, such as Wales' ancient oak woodlands, which contain half of the world's Western Atlantic sessile oak and many rare species of mosses, liverworts and lichens. The research also underpins the current development of 'low emission zones' around 560 of these sensitive sites in Wales, to be introduced through nitrogen emission measures under the post-CAP Sustainable Farm Scheme **[B]**. NRW's Principal Adviser for Air Quality and Biodiversity says: *"The new thresholds we have put in place are intended to support business activity, by discouraging inappropriate agricultural development in these zones of interest. This approach supports LPAs in their assessment of cumulative impact at a strategic level to support the development of sustainable agriculture and protect Welsh biodiversity"* **[B]**.

NRW recently concluded public consultation to map and apply "extremely strict controls" requiring detailed modelling near Special Areas of Conservation, Sites of Special Scientific Interest, and undesignated areas with nitrogen-sensitive species **[A]**. The modelling will assess N impacts from all agricultural developments (not just livestock units), highlighting the fact that GN020 is just a significant first step towards evidence-based biodiversity regulation in Wales.

Following Wales' lead, Shropshire County Council also introduced the same threshold reductions in their application guidance **[A]**. In response to NERC210, the Environment Agency is conducting a full review of its regulatory approach to nitrogen deposition. The Senior Air Pollution Adviser at JNCC states: *"The evidence review and its use in agency procedures will enhance protection of the most at risk areas of the 42,049 km ^{2} of air pollution sensitive habitat receiving excess atmospheric nutrient nitrogen. This research will be used to encourage proposers of new and existing emission sources to employ best practice or even relocate their activity away from key conservation sites"* **[C]**. The Institute of Air Quality Management (IAQM), a professional body for over 500 practising air quality specialists, recommends the same stricter threshold criteria to assess air quality impacts on designated nature conservation sites **[D]**. This guidance has been applied in nitrogen impact assessments for projects ranging from infrastructure development (e.g. the Wheelabrator Kemsley waste-to-energy facility) to air quality habitat regulation **[D]**.

The underpinning research and NERC210 report led to changes in the Highways England Design Manual for Roads and Bridges (DMRB LA 105 Air Quality, published 2019). The guidance supports additional protection for sensitive habitats close to future proposed motorways and trunk roads in England. Developers must evaluate whether nitrogen deposition is likely to affect air quality significantly and hence, put sensitive plant communities at risk **[E]**.

The JNCC Nitrogen Decision Framework uses a scoring mechanism to attribute poor site condition to N pollution. The tool enables agencies and planners to identify the likelihood of risk to habitat integrity from nitrogen deposition, using site-specific research data made available through the Air Pollution Information System (APIS). APIS integrated Manchester Metropolitan nitrogen data for 400 previously unknown sensitive sites in 2017. This online service is used by staff in UK conservation and regulatory agencies, industry, and local authorities to facilitate assessment of air pollutants on habitats and species. Almost 100,000 users access APIS each year and this number is growing **[C,D]**. The resource has reduced pressure on UK agency staff to provide technical nitrogen data; APIS provides trusted, best available evidence for air quality assessments. The JNCC Senior Air Pollution Advisor states: *"Without MMU's contribution, thousands of APIS users, hectares of habitat and pounds of public money would be at greater risk from nitrogen deposition and its effects on ecosystems"* **[C]**.

One of the first applications of the Nitrogen Decision Framework was for nitrogen deposition assessments in Ashdown Forest in the High Weald. Made famous as the setting for the 'Winnie the Pooh' children's stories, this ancient forest has international protection because of its wildlife and, as one of the largest, contiguous areas (2,500ha) of rare heathland in Europe **[C]**. Use of the Framework led to a reduction in the number of proposed new-build homes in the area, from 14,101 properties to 11,456, alongside habitat creation to reduce nitrogen impacts **[C,F]**.

Restoring peatlands: locking in carbon and commercial benefits for MPS

Peatlands cover just 3% of global land surface but store around 33% of soil carbon and twice as much carbon as all the world's forests. Degraded peatlands are responsible for a disproportionate 5% of global anthropogenic carbon dioxide emissions. The Manchester Metropolitan research [5-7] underpins, and essentially provided, the 'green light' for landscape-scale Sphagnum-based peatland restoration. In particular, the research supported the use of novel, cultivated propagules and derivative methods. This restoration now helps to safeguard vast quantities of carbon stored in peat, and has driven spectacular commercial growth for Micropropagation Service Ltd (MPS), the UK's sole supplier of Sphagnum propagules.

The Peak District is Europe's most degraded peatland landscape, but also a premier area of blanket bog; the extensive restoration and protection work here has national and international significance, not least as a demonstrator site for novel restoration techniques, such as the use of Sphagnum propagule. Since 2010, the pioneering MoorLIFE and MoorLIFE2020 projects have invested EUR22,700,000 to restore peatland at landscape scale: MPS Sphagnum propagules have directly restored 3,134ha **[G]**. A core component of an integrated strategy involving stabilisation, rewetting and revegetation, the Sphagnum restoration plays a key role in protecting

the integrity of 12,000ha (58.0%) of fragile Peak District active blanket bog **[G]**. Based on success in the Peak District, additional restoration with MPS Sphagnum has taken place in Yorkshire (462ha) **[G],** lowland Lancashire (through CARE-PEAT), the Shropshire Marches, and the East Anglian Fens **[H].**

The Peak District MPS Sphagnum restoration today delivers a direct carbon benefit (emissions prevented) of 14,040tCO_2e/year and secures approximately 3,000,000t stored carbon from future loss (equivalent to a forest over twice the size of Wales). By contributing to active blanket bog protection, the work indirectly safeguards a carbon sink function of 36,000tCO_2e/year and approximately 11,600,000t stored carbon (equivalent to 12.1% of the UK's 351.1MtCO_2e emissions in 2019) **[I,G]**. The work also contributes to wildfire and flood prevention, and improves water quality **[G]**.

In 2019, the restoration required 2,200,000 million Sphagnum plugs and involved 20,000 person-hours of planting, alongside a large project management effort, providing significant employment to the rural Peak District economy **[H]**.

The rise in demand for Sphagnum for restoration has driven tremendous commercial impacts for MPS. The company's product sales have skyrocketed from GBP35,000 in 2012 to over GBP1,000,000 million in 2019 (CAGR 61.4%). Staff headcount has increased three-fold and the company now exports product(s) to Germany (200,000 propagules ordered for 2021). Since 2015 the company has invested GBP1,000,000 in capital for growth and GBP600,000 in research and development (R&D) **[H]**.

Establishing the feasibility of Sphagnum as the UK's first 'carbon crop'

In collaboration with Manchester Metropolitan, MPS and partners are working to develop and demonstrate Sphagnum as the UK's first 'carbon crop' and suitable biomass for compost peat replacement. MPS has committed GBP107,000 in a GBP499,000 Innovate UK project to pioneer methods for large-scale farming for carbon sequestration into land, whilst enabling the UK to remove all peat from growing media by 2030 **[H]**. There is already demand for Sphagnum biomass, as MPS' Managing Director confirms: *"Melcourt Industries Ltd, the leading peat-free growing media company in the UK… are extremely keen to obtain commercial quantities of Sphagnum biomass as soon as possible. They would place orders for 20,000m^3 immediately if it was available. Klasmann-Deilmann, a leading growing media company in Germany, are committed to reduce their peat use by 15% by 2025 (representing around 200,000 cubic meters of biomass) and believe that farmed Sphagnum is the best option"* **[H]**.

5. Sources to corroborate the impact

A. Guidance GN020 (NRW), GN2 (Shropshire) and NRW consultation page are *evidence of guidance and action to mandate lower nitrogen thresholds for livestock unit permits.*

B. Statement from NRW's Principle Adviser for Air Quality and Biodiversity *describes the impact of GN020 to shift intensive farming units away from sensitive habitats.*

C. Testimonial from Senior Air Pollution Adviser, Joint Nature Conservation Committee *on the significance and adoption of lower nitrogen assessment thresholds, the Nitrogen Decision Framework and the reach and importance of APIS in air quality impact assessments*

D. A guide to the assessment of air quality impacts on designated nature conservation sites (IAQM, 2019) *recommends lower thresholds.* Planning documents related to the Kemsley facility upgrade and the Fareham Borough Local Plan *provide examples of adoption of the IAQM guidance and use of data from APIS.*

E. Design Manual for Roads and Bridges (DMRB LA 105 Air Quality), Standards for Highways, Highways England, 2019 *informs nitrogen impact assessments for new road developments.*

F. News article *reports reductions in number of new homes due to nitrogen assessments.* Letter to Wealden from Natural England *references APIS and the Nitrogen Decision Framework in its advice regarding air quality assessments.*

G. MoorLIFE and Yorkshire Peat Partnership reports and MoorLIFE2020 homepage *evidence total area restored by Sphagnum propagules, total stored carbon, and the additional area indirectly protected.* Peak District National Park webpage *indicates area of blanket bog.*

H. Managing Director, Micropropagation Services *provides evidence of significant commercial growth, customers, exports and R&D investment to diversify into Sphagnum farming.*

I. "MoorLIFE: A Carbon Audit of the Project" *provides carbon benefit factor of 4.48tCO_2e/ha/yr and carbon sink value of -3tCO_2e/ha/yr.*