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Winmarleigh Carbon Farm Case Study

REPORT

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Author(s)

Jo Kennedy, Lancashire Wildlife Trust
Sarah Johnson, Lancashire Wildlife Trust
Mike Longden, Lancashire Wildlife Trust
Jenny Bennion, Lancashire Wildlife Trust
Konstantinos Tzoulas, Manchester Metropolitan University
Neal Wright, Micropropagation Services (EM) Ltd.
Fraser Baker, Manchester Metropolitan University
Anna Keightley, Manchester Metropolitan University
Simon Caporn, Manchester Metropolitan University
Chris Field, Manchester Metropolitan University

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Contact information

Katrien Wijns | Project coordinator Interreg Care-Peat
Natuurpunt Beheer | Coxiestraat 11, 2800 Mechelen, Belgium
katrien.wijns@natuurpunt.be | +32 (0)497/05.29.21
www.nweurope.eu/care-peat

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Introduction

1.1 The importance of peatlands

Peatlands are not only habitats with a highly specialised flora and fauna, they also play an important role in global climate regulation. Peatlands are the most efficient carbon sink on the planet - in the northern hemisphere they account for three to five per cent of total land area but contain approximately 33 per cent of global soil carbon.

Yet many peatlands are in poor condition due to a myriad of reasons including burning, being drained for agricultural use, peat extraction and historic pollution which is causing carbon that has been stored over thousands of years to be released to the atmosphere, contributing to large-scale greenhouse gas (GHG) emissions and particularly increased atmospheric carbon dioxide (CO_2). These carbon stores are further threatened by extreme weather conditions due to climate change (notably longer periods of drought) which will increase the rate of decomposition. Global annual greenhouse gas (GHG) emissions from drained organic soils are 1,600 MT CO_2 eq (twice the CO_2 emissions from aviation) and for the EU in total these emissions are 506 MT/year; for the North West Europe region they are approximately 150 MT/year (more than the annual GHG emissions of Belgium).

The restoration of peatlands is therefore seen as vital in our battle against climate change and key to achieving the European Union's aim to be carbon neutral by 2050. Key to the restoration of peatlands is the rewetting and control of the water table followed by the re-establishment of suitable vegetation capable of future carbon sequestration.

1.2 Aims and objectives of the Winmarleigh Carbon Farm

Peat-friendly land use, which keeps carbon in the ground, will be essential to revert current high emitting peatlands back into carbon storage sites, so that peatlands can once again play an important role in nature-based solutions for climate change, and help us achieve net zero emissions targets by 2050.

Intact peatlands sequester carbon at low rates, building their large stores over many thousands of years. The overall aim for the Care-Peat project was to demonstrate approaches to reduce carbon loss and maximise carbon storage potential, testing if approaches are enhancing carbon storage rates and protecting the carbon store. To achieve this aim the management of 3 hectares (ha) of farmland (grazed pasture) in Lancashire, North-West England was changed, to a 'Carbon Farm' through rewetting and intensive planting of *Sphagnum* moss.The desired medium and long-term vegetation is for a carpet of *Sphagnum* to form within the Carbon Farm.

The Carbon Farm sits on farmland that buffers a lowland raised bog Site of Special Scientific Interest (SSSI). A further aim of the pilot was to help improve the hydrological integrity of the SSSI, reducing GHG emissions and improving conditions for biodiversity. It could demonstrate an alternative approach to buffer land management that would benefit core nature sites and wider nature networks. Converting this field from agriculture to a low intensity land use could also help protect the SSSI from the impacts of agricultural air pollution and run-off (although this aspect wasn't specifically measured in the project). In addition, the Care-Peat project enabled exploration of the potential for providing alternative incomes on marginal land for farmers and land managers, supporting the local economy.

1.3 What is Carbon Farming?

Carbon Farming involves implementing practices to improve the rate at which CO_2 is removed from the atmosphere and converted to plant material and then soil organic matter. Carbon Farming is successful when carbon gains resulting from enhanced land management and/or conservation practices exceed carbon losses. In addition, carbon can be stored long term (decades to millenia) beneficially in soil (carbon sequestration).

Carbon Farming covers a whole spectrum of practices from growing cover crops to reduced or no tillage. In the case of the Winmarleigh Carbon Farm we are growing a permanent, non-harvested cover crop of specialised bog species (*Sphagnum* mosses), grown for the sole purpose of protecting soil carbon and sequestering further atmospheric carbon.

Carbon Farming creates a carbon pump and carbon store - plants in the cover crop pull carbon in from the air and turn it into carbohydrates, which is pumped through their roots into the soil (in the case of *Sphagnum*, which has no roots, carbon is stored in the plant. Peat is formed from *Sphagnum* as lower layers die and are only partially decomposed). The plants grow larger and this sets up an ongoing feedback loop that brings more and more carbon into the soil each year - moving carbon from the atmosphere into the soil, and retaining soil carbon already present.

1.3.1 Product

The 'product' of the farm is the carbon that is captured in the vegetation and soils, and the reduction of carbon emissions. It is not about harvesting a crop to sell, although 'selling' the carbon kept in the soil (carbon offsetting) could provide income to "Carbon Farmers".

1.3.2 Why grow *Sphagnum*?

Peat is formed in waterlogged, acidic conditions and is very low in nutrients. Only very specialised plants can thrive in it, but more importantly for climate change, the carbon in these plants is trapped in perpetuity as long as the peat is not drained and remains anaerobic. As *Sphagnum* moss grows, underlying *Sphagnum* vegetation decays but only partially decomposes, forming peat, the majority of which is carbon – effectively absorbing CO_2 from the atmosphere and burying it as peat below the layer of living *Sphagnum*.

Site description

The Winmarleigh Carbon Farm is in Lancashire, NW England UK on a former lowland bog converted to agricultural land (grazed pasture) in the 1970s and acquired by Lancashire Wildlife Trust (LWT) in 2019. It is directly adjacent to the 89.5 ha Winmarleigh and Cockerham Moss SSSI fully owned by LWT since 2012 (Figures 1-3).The SSSI is designated for its lowland raised bog habitat, a habitat of principal importance, as well as for the presence of Bog Bush Cricket and the Large Heath Butterfly. The Carbon Farm is bounded on two sides by lowland raised bog habitat designated as SSSI. The rest of the surrounding habitat is farmland used for livestock grazing and winter feed crops.

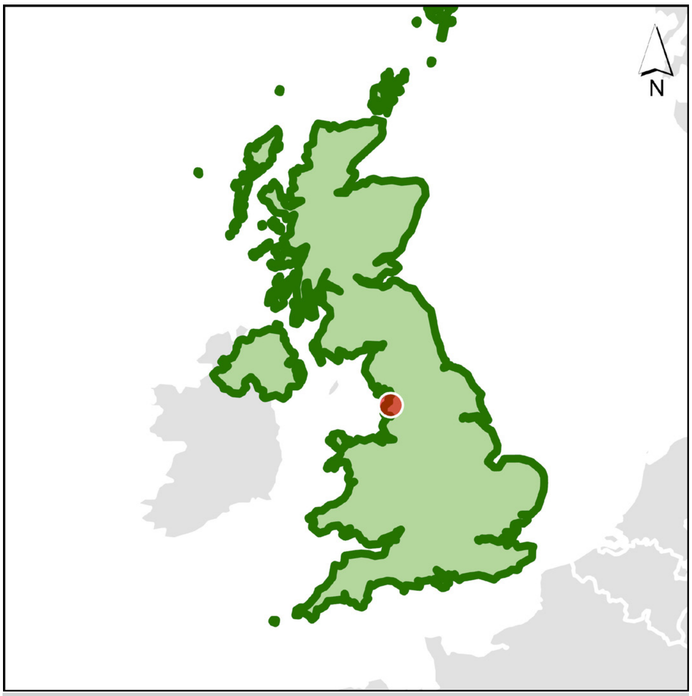


Figure 1: Map showing the location of the Carbon Farm and the SSSI in north west England UK

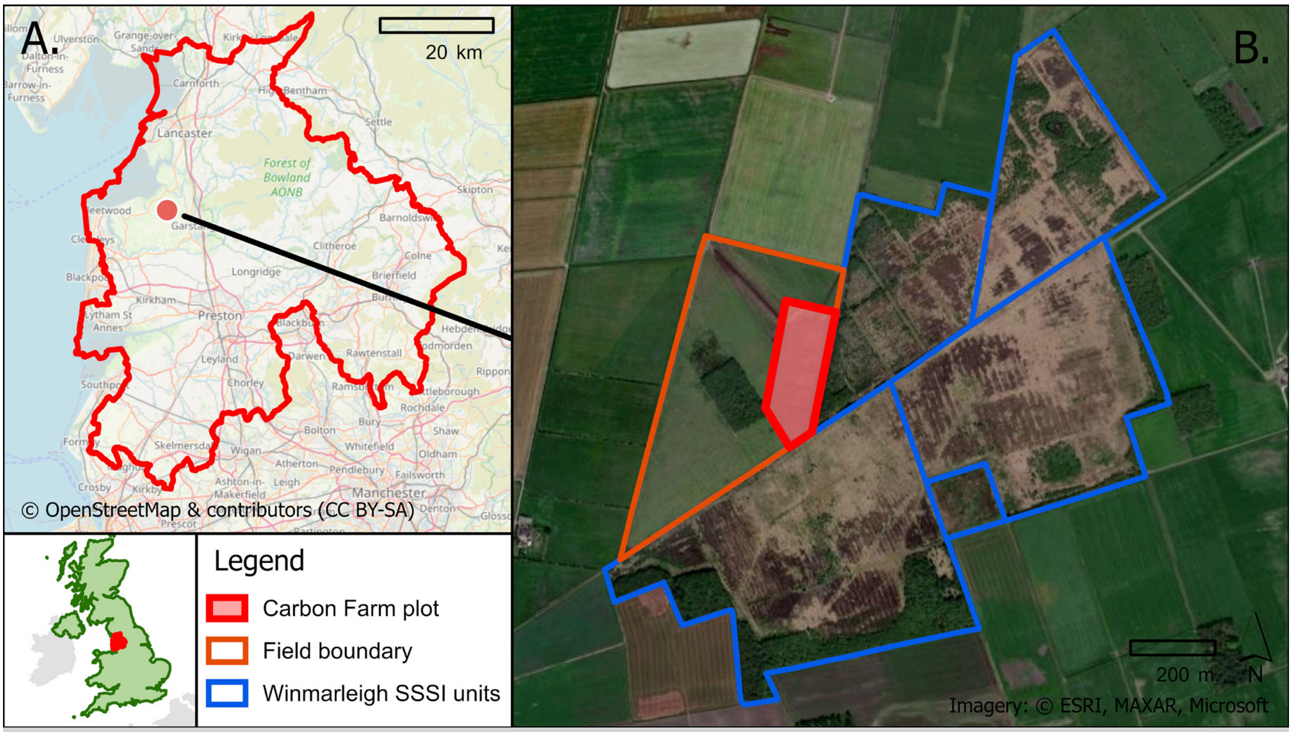


Figure 2: Map indicating the location in Lancashire and the Carbon Farm pilot area within the agricultural field buffering the SSSI.

Figure 3: The original field prior to conversion to carbon farm, Spring 2019

Over the two-year study period, annual rainfall and average air temperature was 1011 mm and 9.8°C in year 1, and 980 mm and 14.4°C in year 2. Minimum and maximum air temperatures for January and July were -6.4°C and 9.9°C, and 9.4°C and 29.0°C respectively in year 1 and -3.5°C and 14.0°C and 11.2°C and 38.6°C respectively in year 2.

The original field where the Carbon Farm was created was relatively flat, drained, dominated by agricultural grasses grown for winter feed crop and also grazed by sheep, leaving oxidised surface peat containing high levels of farming nutrients. The top ~20 cm of the site was organo-peat, formed from the past agricultural use, which sits over good quality peat with *Sphagnum* rich layers. There is 1.5 to 1.7 m of peat remaining in the area.

Soil chemistry and soil water nutrients and metals were analysed pre-restoration. The site had relatively high levels of plant available inorganic nitrogen (N). The soil profile showed that soil N falls rapidly below 10 cm depth suggesting this as an optimum depth for soil removal. Soil pH was also higher in the upper soil horizons suggesting that some liming has taken place and initial analysis of calcium suggested this was also higher in the upper horizons. Soil carbon percentage at Winmarleigh is organo-peat in the upper profile and peat from around 20 cm down.

The original agricultural field had a network of underground field drains and there was also a large drain (known as Crawley's Dyke) between the SSSI to the south removing water. This also affected the SSSI, causing a drawdown of water and drying out of the bog surface. Another drainage ditch borders the east side of the pilot site, adjacent to the part of the SSSI known as Gull Moss.

Site restoration

The transition to Carbon Farm was achieved through raising the water table by blocking drains and creating bunds, removing the nutrient and seed-rich, organic topsoil that had formed over the peat, and installing a permanent irrigation system. The site was then planted with *Sphagnum* moss species.

3.1 Creation of the Carbon Farm

The upper 10 cm surface of 3 ha of the pilot site was stripped between May and June 2020 to remove nutrient-rich soil, along with agricultural plant roots and seeds, then 2 ha were laser-levelled and peat-bunded into 8 cells of 50 x 50 m divided by water channels to irrigate the cells (Figure 4). A water retention area was also created across the third hectare and an irrigation system installed in August 2020. The channels are fed from the water retention area, with water automatically pumped using solar power, and controlled to achieve optimum levels throughout (Figure 6).

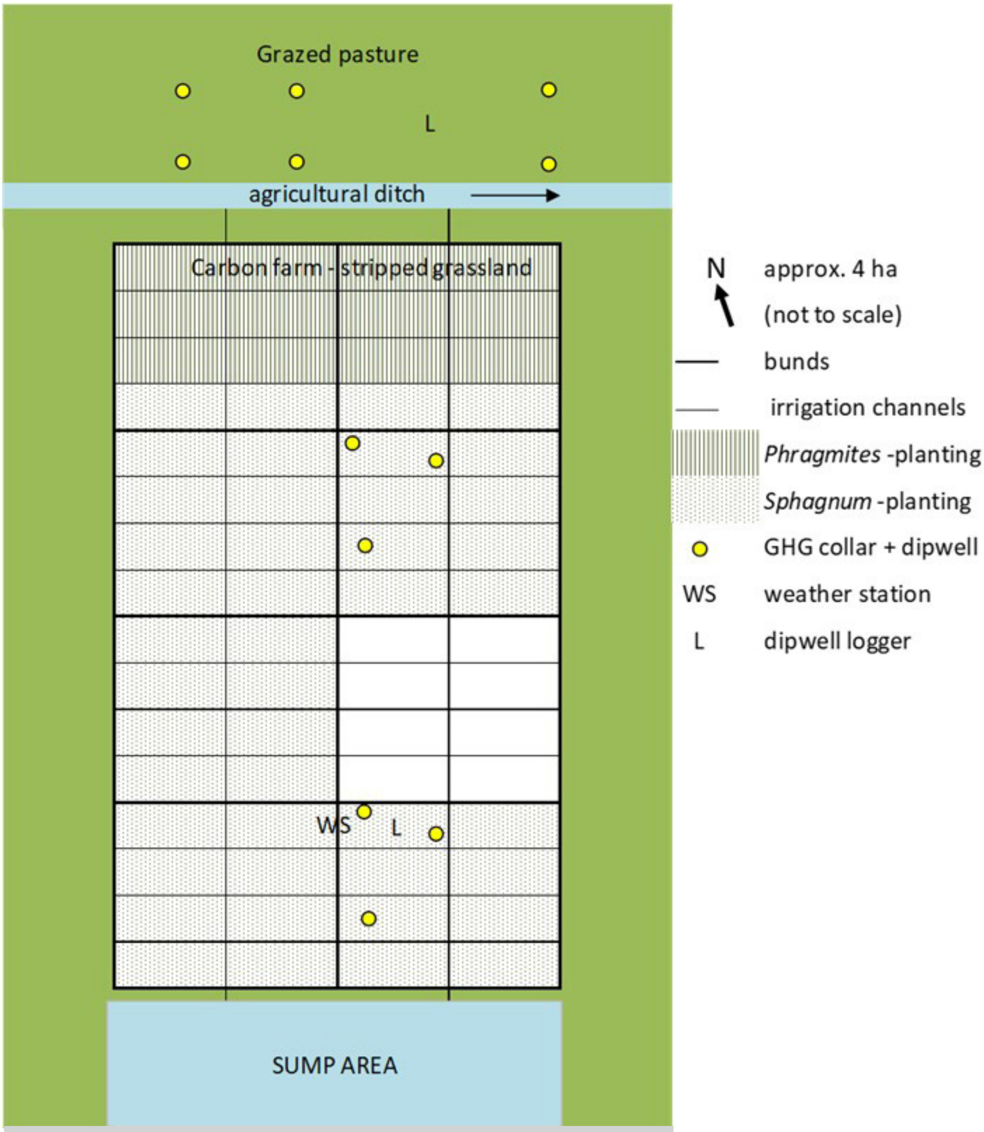


Figure 4. Layout of the carbon farm

Figure 5. Carbon Farm in November 2020 showing the cells, main irrigation ditches and channels with cells. Note that the photo shows a protective layer of straw added after initial planting.

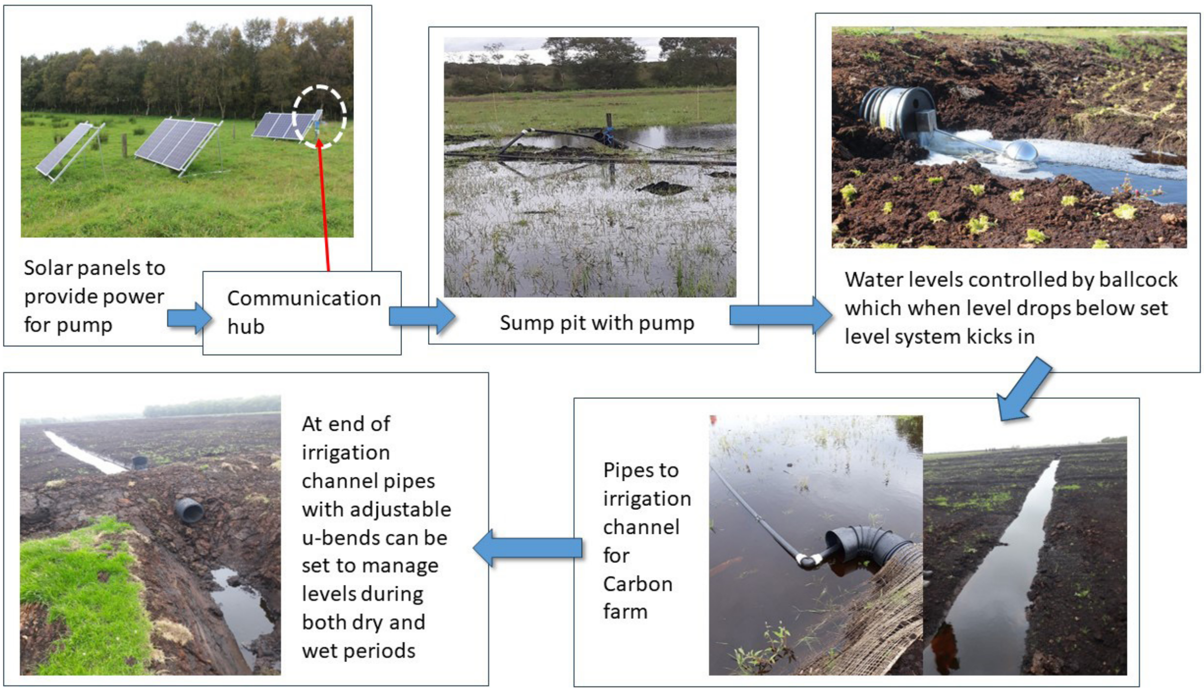


Figure 6. pump design

Project partner Micropropagation Services (MPS) supplied the *Sphagnum* product, BeadaHumok™, which has been developed to give a clump of *Sphagnum* which is resilient, big enough to establish quickly but which is compact to handle and easy to plant by hand.

The mixes, SBHYP BeadaHumok™ Yorkshire Mix (63% of the planting) and SBHCH BeadaHumok™ Chunky (37%) consist of a variety of species that provide tolerance to site conditions, including potential elevated nutrients, have potential to grow rapidly and maximise carbon storage and are also species indicative of good condition peatlands.

Table 1. *Sphagnum* species mixes of the different BeadaHumok™s planted.

Species	Yorkshire (%)	Chunky (%)
S capillifolium	30	25
S papillosum	30	25
S palustre	30	15
S magellanicum	5	25
S subnitens	5	10

Figure 7. Roll of 20 BeadaHumok™ and Beadhumok™ unrolled

Five cells were planted in September and October 2020 with 150,000 BeadaMoss® plug plants spaced 20 cm apart (Figure 8), with two final cells planted with Common Reed (*Phragmites australis*), intended to filter irrigation water before it re-entered the natural water course. The *Sphagnum* was protected during establishment by a thin layer of straw. A further 25,000 plugs of *Sphagnum* were introduced into any areas of poor growth and the remaining unplanted cell in June 2022.

Figure 8. Planting the plugs, September 2020

Maintenance and Monitoring

4.1 Operation and adjustments

Operation and maintenance of the Carbon Farm since its start up has been about ensuring that the conditions support good *Sphagnum* growth by keeping the irrigation system functioning and controlling weeds (mainly *Juncus effusus*).

Modifications have been made to the irrigation system to fine-tune its operation, which included adjusting levels, improving monitoring, de-clogging channels and adjusting pipes. There was a prolonged dry period in Spring 2021 (first year of establishment), water reserves dried up, and emergency measures involved running a mains water pipe across from the neighbouring farm into the water retention area. Use of mains water was not ideal but nutrients were filtered out through the peat, and it was a better option than risking the young *Sphagnum* failing entirely. Consequently, the water retention area was enlarged considerably later that year. After this, despite record temperatures in 2022, the Carbon Farm retained good water levels which supported the *Sphagnum* through further dry periods.

Weed control measures included installing fencing to allow continued grazing on the surrounding land to reduce the chances of weeds spreading to the Carbon Farm; periodic Topping Control strimming (by contractors and volunteers) of the weeds and, on occasion, herbicide application topically to address more problematic weeds (thistle). It is anticipated once *Sphagnum* coverage is more substantial, weed control will be required less (particularly as presence of weeds is less of an issue for the objectives of a Carbon Farm, as opposed to a harvested *Sphagnum* farm).

4.2 Monitoring

The Carbon Farm has been monitored by project partner Manchester Metropolitan University for carbon greenhouse gas emissions (CGHG) and a range of other parameters to see how it is performing compared to the control plot which represents the previous land use (drained, improved, grazed). CGHG monitoring collars with associated dipwells were inserted in areas with a likely range of moisture levels: 6 in the Carbon Farm (restoration) and 6 on a nearby drained, grazed pasture (control).
A weather-station is within the pilot site (Figure 9). Measurements were made over a continuous 2-year period from December 2020, divided into 'establishment' and 'post-establishment/mature' years.
Sphagnum cover within CGHG collars was measured as a percentage cover of plugs within the collar area.

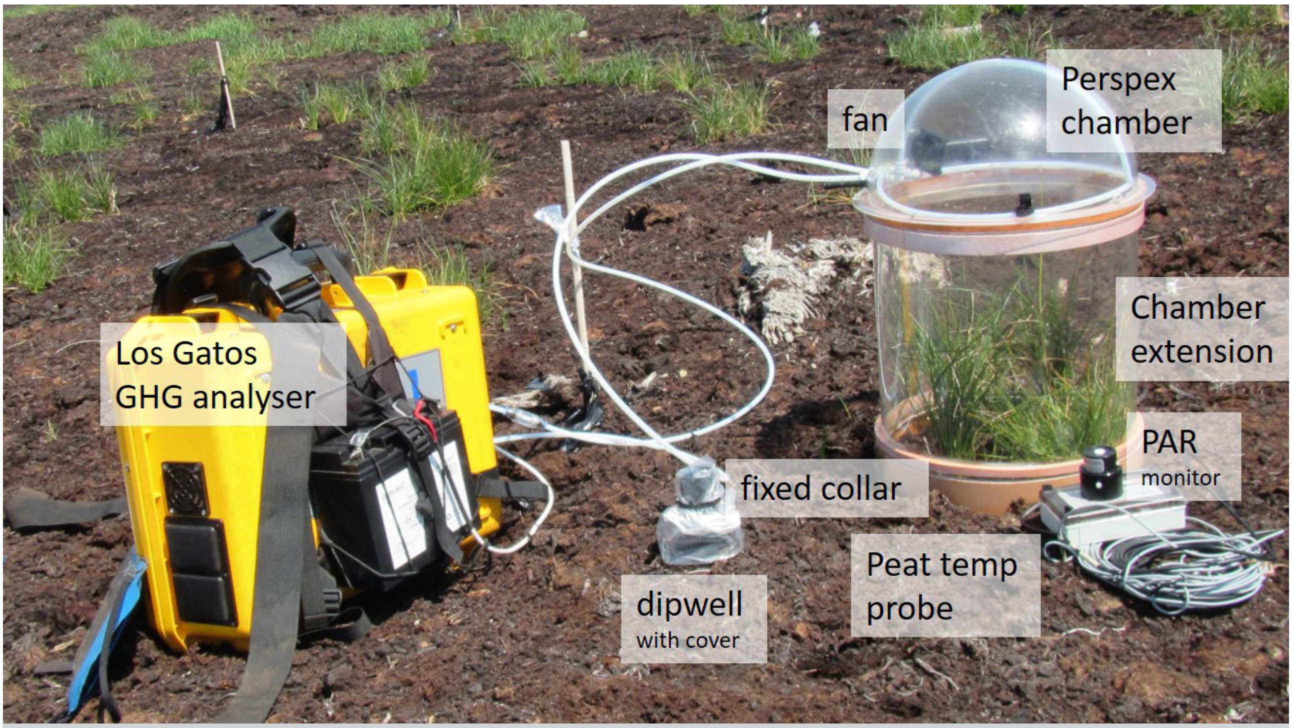


Figure 9. The CGHG monitoring set up, showing the GHG flux measurement equipment and the weather station. The control plot is shown overleaf, and highlights the difference between the carbon farm and adjacent agricultural grassland.

Outcomes

5.1 Water table depth

The water table on the Carbon Farm rose well above that of the drained, grazed control pasture area immediately on rewetting and has been a minimum of 5 cm and a maximum of 63 cm higher than the control pasture over the project period (Figure 10). There were problems with a long drought period and irrigation difficulties in 2021, but a much more favourable and stable water table depth (WTD) is now achieved on the Carbon Farm, mostly maintained within 20 cm of the surface helped by the expansion of the water storage capacity. The optimum WTD below the surface for favourable CO_2 balance is 10 cm (Evans et al., 2021, Nature, 593), which has not yet been achieved continuously on the Carbon Farm as the balance between water demand and availability is difficult to manage.

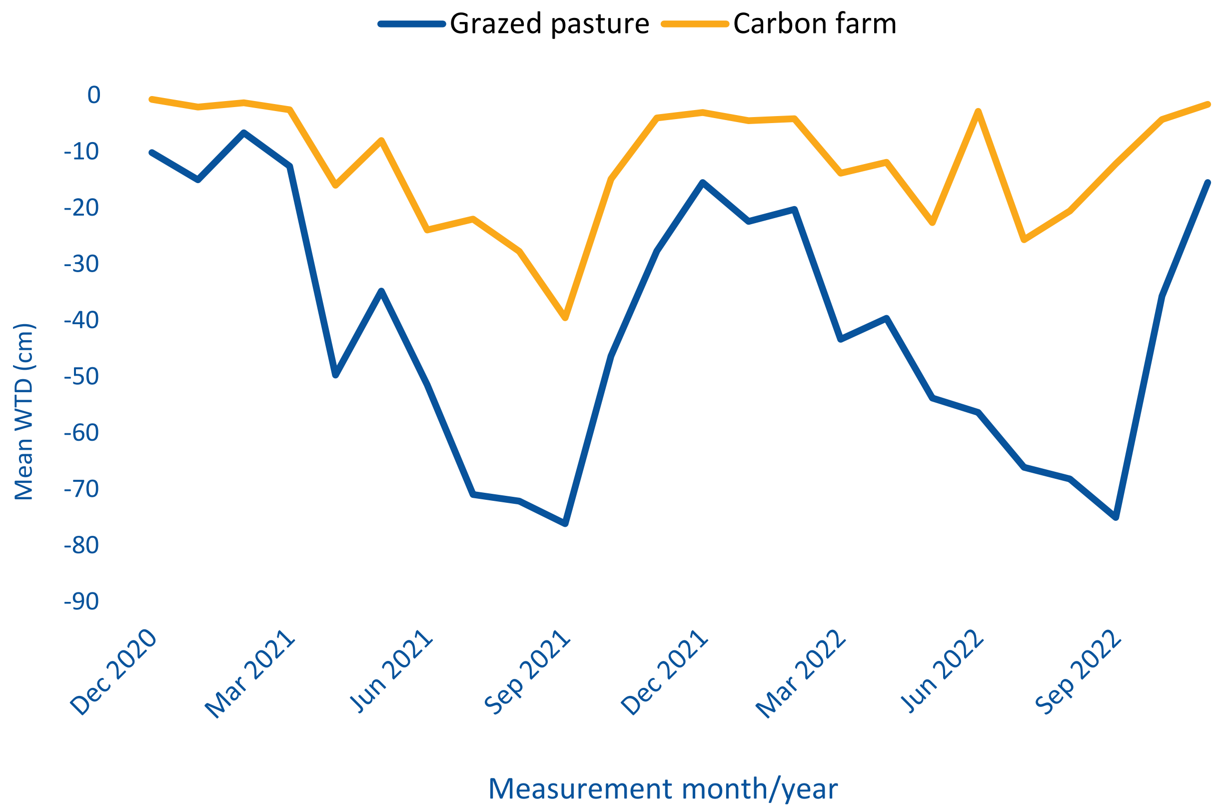


Figure 10. Mean Water table depth (WTD) measurements on the Winmarleigh Carbon Farm pilot, showing seasonal variation, and wide differences between levels on the Carbon Farm (Restoration) and grazed pasture (Control).

5.2 *Sphagnum* growth

The extent of *Sphagnum* colonisation has varied across the site and closely relates to the stability of water levels, with areas that have had a more consistent level close to the surface showing increased cover. Cells at the south end of the site nearer the water retention area tend to receive more water in the ditches than cells farther north – this links to better *Sphagnum* growth concentrated towards the south end of the site (although not necessarily in the monitoring quadrats).

There was a higher percentage cover of *Sphagnum* in quadrats on the east side than the west of the Carbon Farm. Analysis of soil and water samples taken indicate that this is likely to be related to differences in nutrient levels, peat quality and water availability. There was greater initial weed growth on the west side too, also likely to be related to nutrients, as well as calcium (probably from wind drift of lime application on neighbouring agricultural fields) which inhibits the *Sphagnum* growth. This could lead to more competition from the weeds, and possibly inhibit *Sphagnum* growth. By November 2022, (26 months after planting) an average of 57% coverage (Figure 13) had been achieved within the CGHG monitoring collars from a baseline of essentially zero (a completely bare peat surface) (Figure 14). The site is developing well and we expect full *Sphagnum* cover in cells by the end of 2024.

The *Sphagnum* plugs are growing, spreading and in some areas joining up to form hummocks, and the different *Sphagnum* species are apparent (Figures 11 and 12).

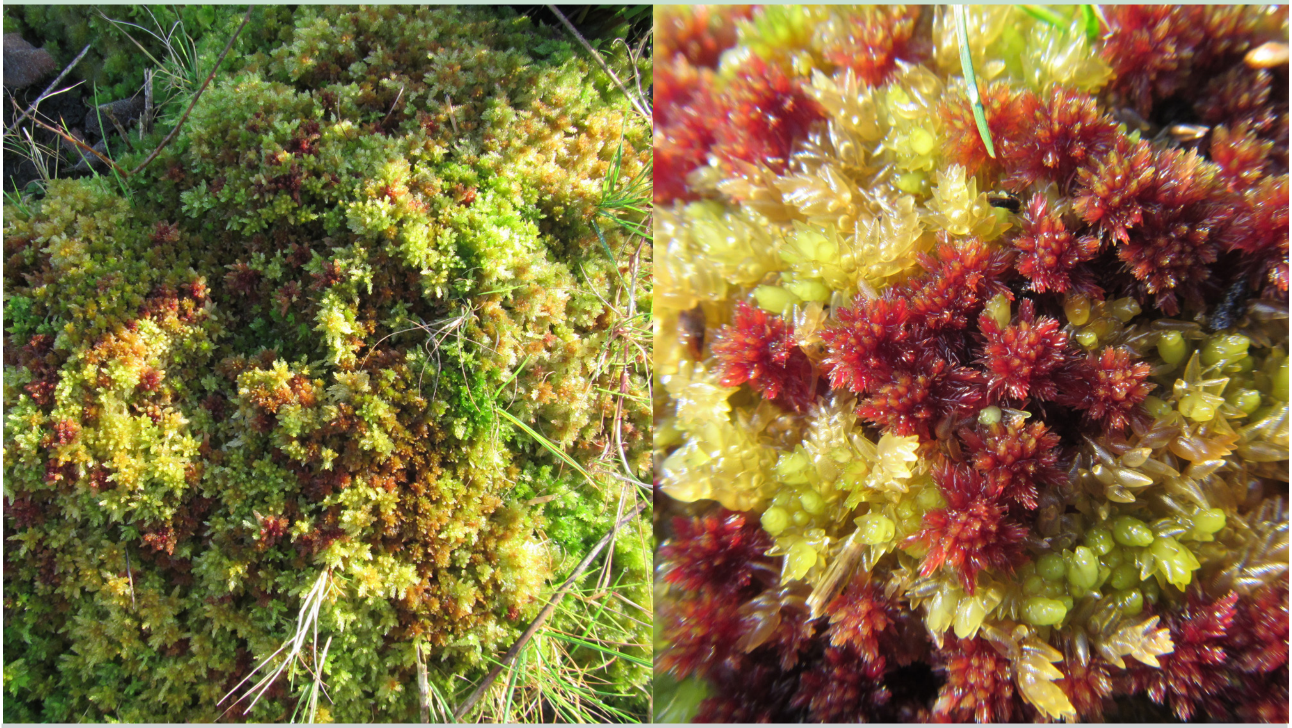


Figure 11. Different *Sphagnum* species are now obvious within the hummocks, as the plugs have grown and spread out

Figure 12. In the areas of best growth the *Sphagnum* hummocks are joining up

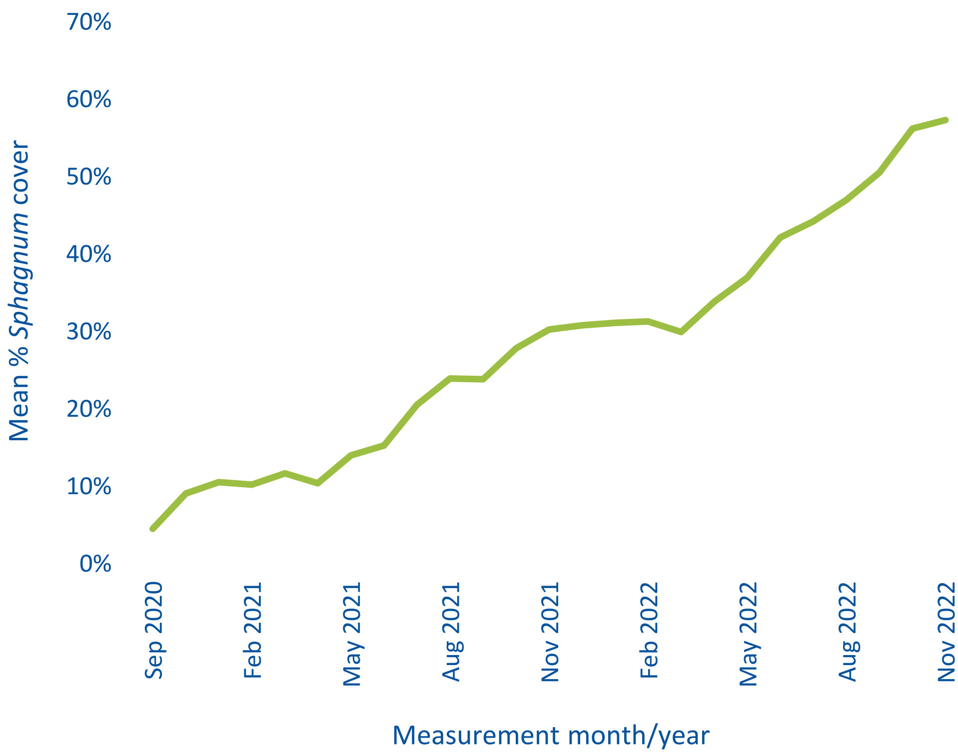


Figure 13. Mean Percentage ***Sphagnum*** cover in CGHG monitoring collars from planting to end of second monitoring year

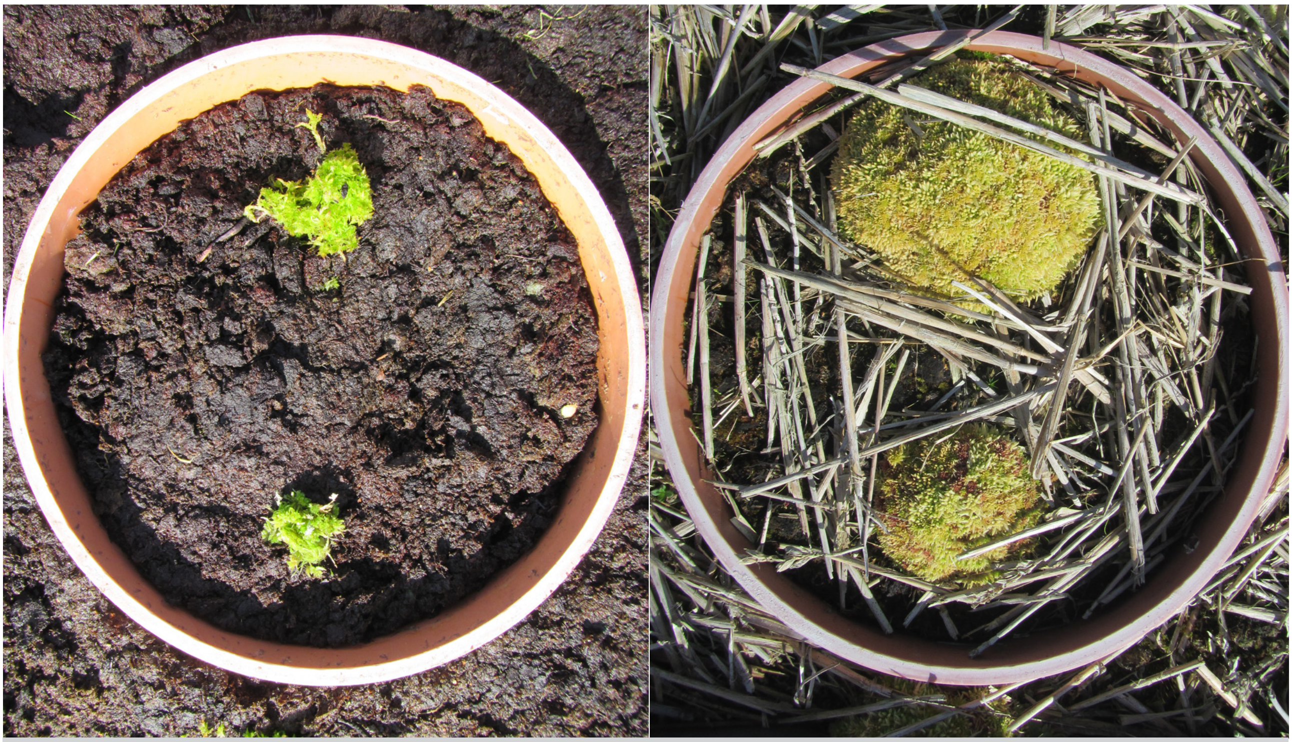


Figure 14. Examples of *Sphagnum* plugs within a collar in September 2020 (top left; at planting), September 2021 (top right) and August 2022 (bottom; light straw cover applied post-planting to protect plugs during establishment).

5.3 Carbon emissions

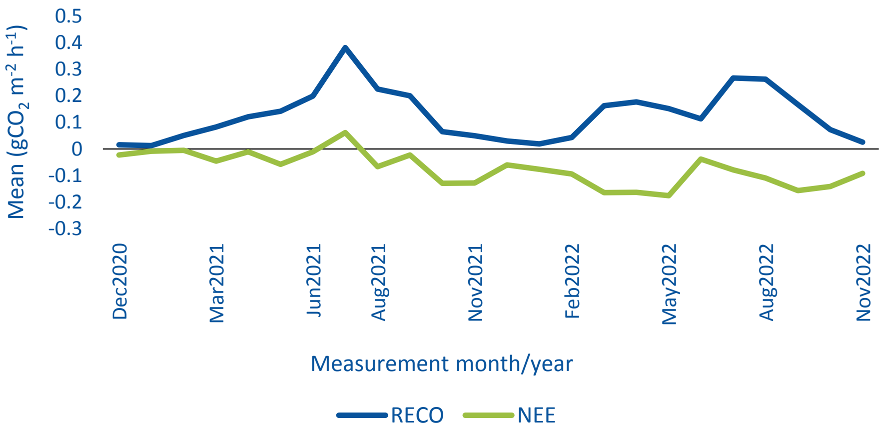
Growing-season drought conditions over the project period hampered progress in restoring the carbon storage function (which is not yet achieved at this stage of development of the site) and highlight the urgent need for improving resilience to climate change in peatland restoration projects. Conversion of drained, grazed pasture to re-wetted bog has reduced emissions hugely and appears likely to deliver good climate-action outcomes.

The monthly measured CGHG flux data for both the Carbon Farm and the grazed pasture show an expected increase in both CO_2 emissions and uptake in warmer, drier, sunnier months, and a reduction in cooler, wetter, low-light months of the year (Figure 15 a and b). The daytime net CO_2 uptake Net Ecosystem Exchange; NEE) on the carbon farm is larger overall in the post-establishment year as there is a greater cover of *Sphagnum*, providing higher levels of photosynthesis and more moisture at the peat surface. On the grazed pasture, the generally drier second/post-establishment year resulted in a more variable, reduced uptake of CO_2. The fluxes on the Carbon Farm are a tenth of those on the grazed pasture. When the larger night-time ecosystem respiration (RECO) measurements for both treatments are included in the overall carbon gaseous budget, there is an overall emission on both, but far greater on the grazed pasture.

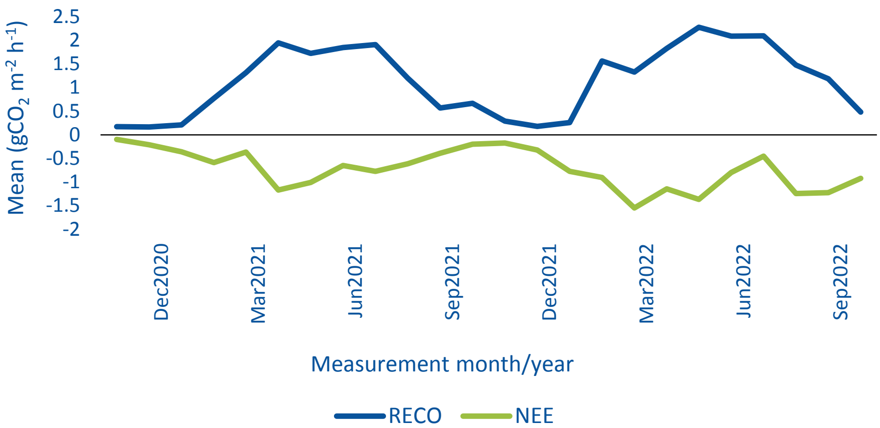
The flux data from each CGHG monitoring collar was modelled, and incorporated environmental variables of WTD, peat temperature and photosynthetically active radiation (PAR). Mean carbon gaseous budget data gives the following results showing that both sites are net emitters of CGHG in both years (note that these are still provisional figures, and hence subject to change):

Grazed Pasture:	Year 1: 20.76 ± 8.43	Year 2: 41.30 ± 10.61 ($tCO_2eq\ ha^{-1}\ yr^{-1}$)
Carbon Farm:	Year 1: 2.40 ± 2.25	Year 2: 3.85 ± 1.49 ($tCO_2eq\ ha^{-1}\ yr^{-1}$)

This gives a Carbon GHG emission-saving from converting grazed pasture to the Carbon Farm of 88.4% in Year 1 and 90.7% in Year 2. Mean measured methane (CH_4) fluxes were very small and highly variable (i.e. negligible) overall (Figure 15 bottom graph).



Carbon Farm (Restoration)



Grazed Pasture (Control)

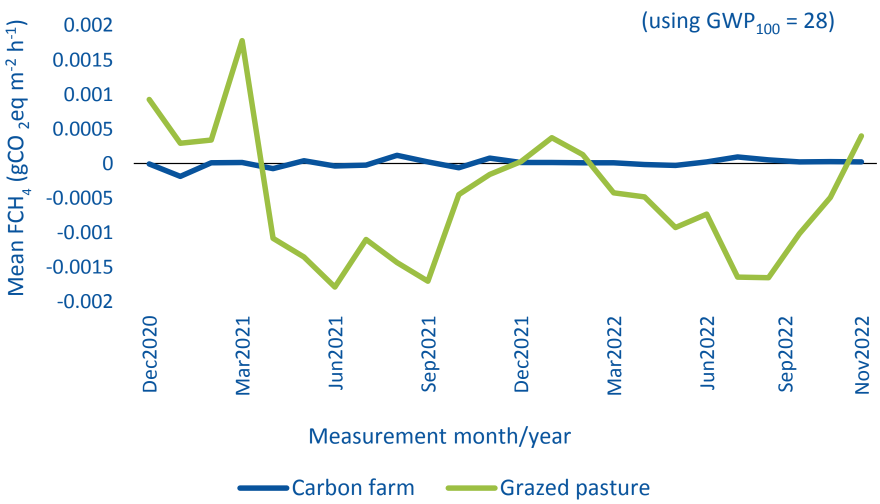


Figure 15. Measured CGHG data on the Winmarleigh Carbon Farm pilot. Top) RECO and NEE (full light only) on Carbon Farm, Middle) RECO and NEE (full light only) on Grazed Pasture; Bottom:methane (CH_4) flux on both treatments, converted to CO_2 equivalents. Note the scale on the CH_4 graph is of a factor of 1000 lower than that of the CO_2.

It is recognised that various aspects of the Carbon Farm creation and operation, e.g., peat removal and relocation, bunding, creation of water bodies, and grazing and lime application on the grazed pasture, are not included in the carbon budget figures. Bare peat areas emit CO_2, water bodies may emit CH_4 and the pasture may emit nitrous oxide (N_2O). These have not been measured and so their influence on the overall GHG budget of both treatments is unknown.

While the principles of carbon farming are to safeguard peat carbon stores, and facilitate carbon sequestration in the long term, we acknowledge that the required intensity of the creation of the Carbon Farm for this project has had associated, unmeasured carbon emissions which may well increase the length of time for the pilot site to achieve positive outcomes. However, it is hoped that demonstrating the difference in annual emissions between these two land uses on peat helps to promote further adoption of more carbon friendly land management. Adoption of Carbon Farming using lower intensity approaches would avoid these sources of emissions.

5.4 Earth Observation

Earth observation analysis was undertaken for the Winmarleigh Carbon Farm pilot site, to investigate the benefits of remotely sensed optical satellite imagery to monitor environmental change from peatland restoration. Initial observations were generated from time series (May 2018 – June 2023) Sentinel-2 image data (European Space Agency, Copernicus programme) for sample points located on farm cells, and across the adjacent grazing control areas. To provide a consistent time lag for further analysis, index values for cells and grazing areas, along with overall on-site measurements, were aggregated to quarterly averages.

WTD (monitored between December 2020 and October 2022) exhibits a strong positive correlation to the Normalised Difference Moisture Index (NDMI) which indicates water content in vegetation. This relationship was consistent for uncorrected, and trend corrected values (Figure A). Given correlation in NDMI values to vegetation growth, patterns between the two variables exhibit greater similarity with continued vegetation development. In contrast, Sphagnum growth (September 2020 to Nov. 2022) exhibited strong relationship to upward trends in the Normalised Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) respectively. However, in contrast to WTD, this relationship weakens considerably when detrending the data, with neither index correlating to WTD variation around the overall trend line.

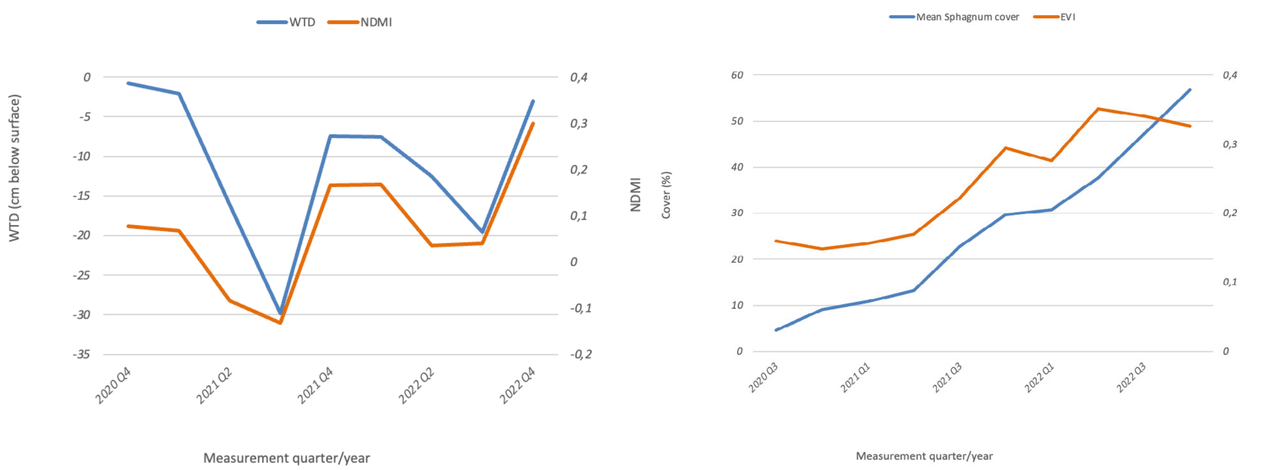


Figure A. Comparison of trends between WTD and NDMI (left), and Mean Sphagnum cover (%) and EVI (right) for Carbon Farm cells

When contrasting control and cell areas, the difference in spectral response is clear. Response in the vegetation and moisture indices drops off substantially following the start of restoration, with turf stripping and irrigation works for cell areas (Figure B). Grazing control areas in contrast record general consistency in overall trends pre and post restoration with a slight upward trend in recent quarters. While the nature of on-site works currently limits the amount of data available for more advanced soil moisture indices, the results here currently indicate limited restoration impacts upon surrounding agricultural land. Overall relationships between on-site observations and remotely sensed indices indicate potential benefits of earth observation for monitoring conditions in peatland restoration areas.

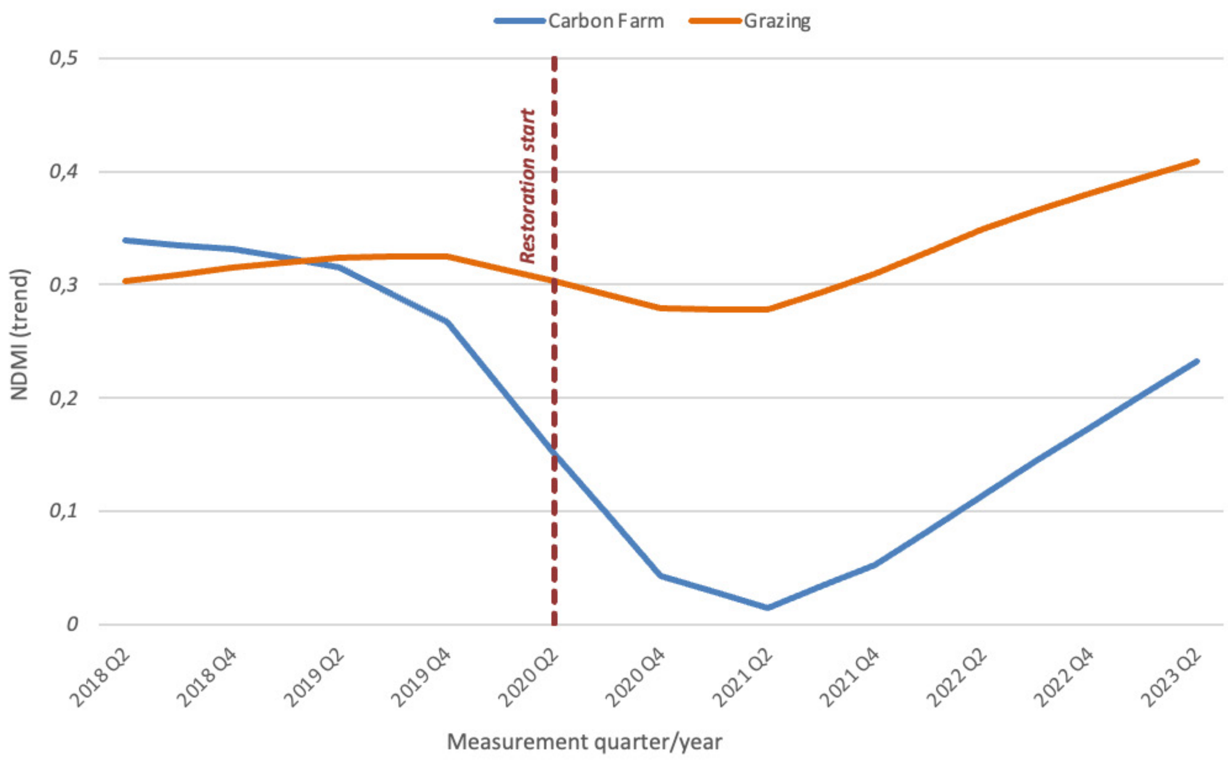


Figure B. Comparison in NDMI trends (2018 – 2023) between Carbon Farm and Grazing

5.5 Biodiversity

The focus of Care-Peat has been the reduction of carbon emissions but co-benefits to biodiversity are also sought. Specific monitoring programmes have not been established with Care-Peat but some observations and monitoring have already taken place. The Carbon Farm has begun to be colonised with bog species associated with the adjacent SSSI including *Calluna vulgaris, Polytrichum commune* and *Drosera rotundifolia* (Figure 16) indicating that the surface pH and moisture is becoming more favourable to these species. Bund areas are also being colonised with mosses, grasses and other vascular plants. Several species of butterflies, damselflies and dragonflies (e.g. Figure 16) have also been observed which were not previously found on the grazed pasture, along with amphibians and bird species.

Figure 16. Recently emerged Common Darter and Round-leaved Sundew

5.6 Benefits to neighbouring SSSI

It was hoped to demonstrate that the re-wetting of the directly adjacent Carbon Farm and the work to block ditches and improve water table depths beneficial to Winmarleigh Moss SSSI in terms of hydrology. However, in reality, it has been difficult to assess this within such a short timescale, and also it is not possible to separate the influence of other site improvement works which have been carried out on the SSSI since the Carbon Farm was created.

But the Carbon Farm will be acting as a buffer. The large drain, Crawley's Dyke, between the SSSI and the Carbon Farm site, which removes water from the farmland, despite previous piling and other water retention measures, caused continuous water loss on the SSSI raised bog. Although the Carbon Farm may be hydrologically discrete itself due to the bunding, the works to reduce site water loss via ditch blocking is highly likely to have benefitted the SSSI. Some of the species living on the SSSI are also able to spread out and colonise this new, more hospitable neighbouring area, which reduces the pressure of species isolation and fragmentation and helps them to be more resilient to impacts such as climate change. Creation of this buffer site also now means there is greater distance between the SSSI areas and farmland reducing the impact on the nutrient sensitive lowland raised bog SSSI from nutrient application or livestock runoff.

Engagement

Changing land use to something more sustainable on a large scale can't be done without involving people at each step. Key stakeholders include the local neighbouring landholders who have a good knowledge of the land and its uses, policy makers who shape the land use agenda and payment system, environmental organisations who could play a part in promoting new carbon-friendly approaches and research and knowledge institutions who can help advise, assess and promote. Initially there were some concerns from neighbouring landowners about whether raising the water table on the Carbon Farm would lead to increased inundation of neighbouring farmed land. The intention of the design is to keep water on the site, via the bunding and ditch blocks and to have no impact on drainage of neighbouring fields. Futhermore, *Sphagnum* moss has excellent water retention properties and is able to buffer high-rainfall events, slowing the flow into the drainage networks. Over time, a good working relationship has been built up with local farmers and they have been involved in the restoration process itself and with several targeted events.

Interest in the Carbon Farm has been far greater than expected and subsequently many more stakeholder events were delivered than planned originally, 15 formal tours, presentations and workshops in all, with a number of smaller, more informal visits as well. Audiences are interested in the potential for GHG reductions, provision of alternative income sources for landowners and alternative land uses for lowland peat.

Table 2. A summary of some of the key stakeholder groups who have learned about the Carbon Farm

Stakeholder group	**No. of groups (individual numbers are greater)**
Local and regional authorities	17
National government and agencies	5
Universities and research organisations	12
Conservation and environmental organisations	21
Private companies	5
Local landowners & farmers	44

Visitors include the North West England National Farmers Union (NFU) Crop Board; national bodies working with peatland restoration such as Natural England, the Environment Agency and the Royal Society for the Protection of Birds (RSPB) and other major land owners; policy makers and influencers including the IUCN Peatland Code team, the Department for Environment, Food and Rural Affairs (Defra) Soils and Peatlands team and the local Member of Parliament. The Care-Peat project partners also visited in June 2022.

Figure 17. The Great Manchester Wetlands Land Manager group learn about the Carbon Farm August 2022

An online policy workshop was also delivered in 2020, attended by local politicians and including presentations from a senior government peatland policy maker.

The Carbon Farm, perhaps due to its unique concept, has gained much publicity, having featured in local, national and international media including articles in the Washington Post, television slots on the BBC's Countryfile programme and the regional news and radio slots, including being featured as one of the "39 ways to save the planet" on BBC Radio 4. It was picked as one of only 27 international climate projects to be featured in the "Running out of Time" relay in the run up to COP27 in 2022. Media reach is estimated at over 700,000 regionally, and 3 million nationally with the syndicated Washington Post article having had the potential to reach millions worldwide. The Carbon Farm has had a strong social media presence and Medialife created a short film about the Carbon Farm.

This engagement and publicity programme has led to greater understanding and wider recognition of the Carbon Farm and stimulated much interest in the principles and need for peatland restoration for carbon reduction and how to facilitate adoption of alternative wetter peatland management options.

Economic aspects – costs, income and business case

7.1 Costs to establish

Set up costs for the Carbon Farm through Care-Peat have been relatively high because of the need to set up the pilot in as short a time as possible in order to allow monitoring of impacts within the funded project period. This restricted options, meaning a high intensity capital approach was needed. Establishment costs have an impact on the business case for adopting Carbon Farming as an alternative land use (see secion 7.3). However, it is envisaged that a farmer wishing to set up Carbon Farming on a marginal income area could approach this in a far lower cost manner. For example, a farmer might have the time to plant a nurse crop that would, over a one to two years, reduce the nutrients in the top soil and negate the need to remove top soil (as well as providing a saleable crop). Other methods for sterilising seed banks in the soil, such as steaming, may also develop and become viable, which would result in more confidence in yields. Farmers are also likely to have the equipment and skills in house to carry out works themselves rather than needing to use contractors. Irrigation (which needs to use rain water) may be much more straightforward and farmers may be able to use some of their own equipment, methods or existing water storage.

Purchase and planting of the *Sphagnum* plugs would probably be the most expensive element as well as being labour intensive in terms of planting. However plugs are the most resilient form of *Sphagnum* and planting density could be reduced if longer establishment timescales are acceptable. If the approach is proposed to crop *Sphagnum* for ongoing sales, using plugs might prove a good long term business case. If Carbon Farming is to be adopted, a future approach to minimise set up costs to boost returns may be the use of BeadaGel™. This has been used successfully in other trials and it can be applied easily in bulk, therefore lowering planting costs. It could be better to use overhead irrigation as well as water table raising, but again this might be more easily achieved on operational farms. More research into how to boost establishment success through application timings and site preparation would be required.

7.2 Sources of income

Possible sources of income for carbon farmers are:

- Verifying and selling carbon credits from the carbon emissions reductions of changing the land use from drained, fertilised and grazed peatland to a re-wetted, *Sphagnum*-dominated habitat. Verification could come via the Peatland Code or Wilder Carbon scheme, for example.
- Grant funding
- Corporate support for voluntary, unverified carbon offsets

Sphagnum on the Carbon Farm will not be harvested for a number of years, due to requirements of the grant funding agreement, and in order to fully investigate the Carbon Farming concept, therefore we have not included the potential for income from harvested *Sphagnum* in this report.

7.3 Business Case

Under the Care-Peat project, an economic model and pricing tool was devised for Carbon Farming. This aimed to evaluate the financial feasibility and potential carbon unit pricing options using a number of illustrative examples in order to stimulate discussion. Emerging carbon markets are creating a complex patchwork of financial feasibility so the aim was to create a non-technical and transferable tool that could be widely applied. The tool estimates the financial feasibility of peatland restoration projects and the expected profit from different sale prices of carbon credits. The required input information is the project duration in years, type of restoration, hectares restored, investment amount, whether registry and investment costs are included, and a selling price of carbon credits. Detail of the model and its assumptions is presented in a separate Care-Peat report but summary results for the Carbon Farm are included here (Table 3).

The scenarios shown include Carbon Farm establishment costings of £74,700 per ha (based on ground preparation £17,796; irrigation equipment £4671; moss purchase £41,250 and planting costs £11,000), a more typical lowland peatland restoration figure of £15,000 per ha, and an indicative lower cost intervention of £6,000 per ha. They also consider if a loan is needed to undertake the works assuming a 50 year carbon offsetting agreement is in place. For each initial investment under each scenario the break-even carbon price are shown (Table 3). The break-even carbon price is the minimum each credit must be sold at to cover all costs over the investment period. Then, for each investment scenario, the profit or loss made per hectare per year by selling carbon credits at existing market prices were demonstrated. The carbon credit prices used were £20 per ton of carbon emitted (tCO_2e) (mid-point IUCN UK Peatland Code pending issuance unit prices) and £40, £80 and £120 per tCO_2e (low, central and high forecasted short-term trading prices in UK by 2030). In all scenarios a 20 tCO_2e/ha emissions reduction is assumed.

Table 3. Summary of outputs of economic model for different peatland management approaches. Low cost intervention models the scenario of a farmer taking up Carbon Farming as per the discussion in 7.1

Project length 50 years; GHG reduction of 20 tonnes CO_2e per year; project size 1 ha	**Carbon Farm cost** £74,700 per ha		**Typical peatland** £15,000 per ha		**Low cost** £6,000 per ha	
	without loan	with loan @5%	without loan	with loan @5%	without loan	with loan @5%
Break even carbon price/t	**£128,00**	**£561,00**	**£60,00**	**£147,00**	**£50,00**	**£85,00**
Profit/ha/yr @ £20/t carbon	-£1.897,77	-£9.570,77	-£703,77	-£2.244,53	-£523,77	-£1.140,07
Profit/ha/yr @ £40/t carbon	-£1.543,83	-£9.216,83	-£349,83	-£1.513,63	-£169,83	-£786,14
Profit/ha/yr @ £80/t carbon	-£835,96	-£8.508,96	**£358,04**	-£1.182,72	**£538,04**	-£78,27
Profit/ha/yr @ £120/t carbon	-£128,09	-£7.801,09	**£1065,91**	-£474,85	**£1.245,91**	**£629,61**

The break-even carbon prices are shown in blue, these are the selling prices that cover all costs over the investment period. Whilst the break-even price for the carbon farm pilot is very high (£128.00/t CO_2) without a loan, it is close to the upper end of the 2030 range of £40-£120, with the break-even prices for typical restoration and lower-cost intervention at more realistic prices of £60.00 and £50.00 t CO2e. In all cases the use of investment at 5% has a large impact on feasibility, highlighting that availability of low-rate capital will be important in achieving change for some landowners.

Audit costs also have an impact on feasibility, for example without these the break-even price (without loan) for the different cost scenarios is £85.00/t, £17.00/t and £7/t. For small schemes such as the Carbon Farm audit costs therefore have a large impact, for larger schemes they would represent a lower proportion of total costs highlighting opportunities for neighbouring landowners to form 'Carbon Cooperatives' to share these.

At carbon prices above £80/t, feasibility increases dramatically for the typical restoration and lower cost intervention scenarios, and at higher carbon prices the income per hectare becomes highly favourable in comparison to baseline. As a comparison, income from sheep farming from DEFRA Business Survey 2020 was £586 per hectare including £268 in subsidies. Profitability may not mean a viable income for the landowner depending on circumstances and other factors, however, overall, there is a clear opportunity for 'low income' farm types to fund alternative income from sales of carbon credits.

The future for the Carbon Farm

Further exploration and maximisation of the potential benefits of the Carbon Farm is desirable. For example, to validate more realistic set up and operation costings. It is a new scheme and, whilst early benefits of restoration have been demonstrated, ongoing validation of success will need to continue as the site matures. The site has shown huge early success and further potential for stimulation of engagement, debate, education, policy shaping, investigation and demonstration of the viability of alternative peatland restoration approaches. While LWT have secured a further 18 months of funding after Care-Peat for continuing to operate, maintain and monitor the Carbon Farm, long term funding will be needed to continue to gather the field data to assess the outcomes from the Carbon Farm; to document best practice approaches to operation and to progress inclusion of this land use into carbon credit schemes.

8.1 Recommendations

The following recommendations are made from establishing the Carbon Farm:

- Continued monitoring of GHG fluxes, soil composition, water quality, water table depth, *Sphagnum* coverage etc. It will be interesting to see if the diversity of plant species will continue to increase through natural colonisation from surrounding mossland sites or if additional species need to be reintroduced.
- Continue monitoring both the *Sphagnum* growth and weed encroachment to identify when the *Sphagnum* establishment phase is over.
- Research potential alternative treatments of the weeds.
- Assess at what point irrigation can be dispensed with and at what point the Carbon Farm is considered to be self-sustaining. In the meantime, research into methods of reducing evaporation rates from the irrigation water storage area would be of considerable use as this is a risk to water supply security. Calculation of volumes of water pumped for irrigation would add to the information needed to set up any new Carbon Farm.
- Research into potential methane emissions from the water storage area/irrigation ditches.
- Further understanding of the co-benefits as buffer land to the SSSI.
- Work with local farmers to investigate viability of adopting Carbon Farming e.g. more development work and trials on larger scale use of BeadagelTM or lower planting density approaches, more investigations into set up costs and demonstration of income streams.
- Promote the Carbon Farm approach as a wetter farming technique, demonstrating benefits and progressing inclusion in financing approaches.
- Clarification of Carbon Farming in the context of carbon offsetting schemes and farm grants. It currently falls between traditional restoration and the present definition of paludiculture. More R&D activity and increased data sets to include Carbon Farming as a land use type.
- Develop the site as a teaching/research resource.
- Promote the role and place of Carbon Farming in the wider peat agenda – how to identify when it is the right approach to adopt.
- Further validate and develop the economic model with farmers.

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