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# REPORT

# Monitoring of the pilot sites on $CO_2$ reduction and Carbon storage:

# Installation of instruments for site monitoring

*Deliverable T3.3.1*

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# Introduction and overview of monitoring programme

During the Care-Peat project the knowledge partners have implemented a monitoring programme designed to both inform restoration practice and to monitor progress. The programme consists of baseline vegetation surveys together with soil and soil solution analysis, alongside earth observation (EO) data from drone and Sentinel 2 satellite imagery. Further surveying and EO data collection is planned during and at the end of the project to evaluate change. Meteorological and environmental monitoring has been established in France, Ireland and the UK and this, together with regular greenhouse gas (GHG) data collection, will enable modeling of GHG emissions and the calculation of a GHG budget. This work will then underpin the Decision Support Tool.
Restrictions due to COVID-19 have meant that GHG monitoring has not yet taken place in Belgium and The Netherlands, however, campaigns are planned for when restrictions are eased. As a contingency, a protocol for soil core sampling and measurement of baseline carbon stores has been developed.

# 1. Installation of instruments

## 1.1. Meteorological and environmental monitoring at each site

Weather stations and environmental monitoring equipment are installed in France, Ireland and the UK. In France and Little Woolden Moss (UK), this equipment was already installed from previous projects. In Ireland and WInmarleigh Moss (UK) equipment was funded from Care-Peat. Weather stations are not installed in Belgium and the Netherlands, however, appropriate data for modelling to be resourced from the closest weather stations, although at both these locations localised water table monitoring is in place. Full details of equipment installed at each site and the variables recorded at each site are in Table 1.

*Figure 1: a) Meteorological station installed at Winmarleigh Carbon Farm and b) V notch weir installed with dipwell logging and autosampling to monitor DOC losses.*

Typical data recorded includes air and peat temperature, rainfall, relative humidity, water table depth and photosynthetically active radiation (PAR).
Recording intervals are 10 -15 minutes. Similar variables are recorded when GHG monitoring is undertaken which allows extrapolation and modelling of GHG data to produce annual carbon budgets.

*Table 1. Meteorological and environmental monitoring equipment installed at each site with environmental variables recorded.*

| Site | Instrument | Variables recorded (Frequency) | Date logging started |
|---|---|---|---|
| Cloncrow Bog (CB), Ireland | 3 x Campbell 300 series data loggers | Air and soil temperature (@ 5 cm), rainfall, relative humidity, photosynthetically active radiation (PAR) (15 minutes) | November 2019 |
| | 5 x Hobo MX2001 and 2 x Hobo U20 Water table logger | Water level is monitored every 15 minutes at each site ( each site has a group of 3 collars) | |
| Black Creek (BC), Belgium | 35 divers installed as a network | Water table depth across a hydrology measurement network. | Spring 2021 |
| | | Nearest weather station located 20 km from site, soil temperature by EO. | ongoing |
| De Wieden (DW), The Netherlands | n/a | Nearest weather station is Royal Dutch Meteorological Survey station situated at about 10 km from the site, measuring precipitation, temperature, radiation, wind speed, air humidity, cloud cover | ongoing |
| La Guette (LG), France | | Weather station and water table piezometers installed | ongoing |
| Little Woolden Moss (LWM), UK | Delta-T GP2 data logger | Air and soil temperature (@ 5cm), rainfall, relative humidity, and photosynthetically active radiation (PAR) (15 minutes) | October 2018 |
| | 1 x Hobo MX2001 Water table logger | Water table on companion planting plots (15 minutes) | August 2020 |
| Winmarleigh Carbon Farm (WCF), UK | Delta-T GP2 data logger | Air and soil temperature (@ 5cm), rainfall, relative humidity, and photosynthetically active radiation (PAR) (15 minutes) | August 2020 |
| | 3 x Hobo MX2001 Water table logger | Water table monitoring on pasture and carbon farming; depth at V-notch weir (15 minutes) | August 2020 |

## 1.2. Greenhouse Gas (GHG) monitoring

### 1.2.1. Experimental set-up at each site and monitoring equipment

GHG data is collected from at least three replicate locations on both treated and control areas with measurements made in full sunlight, partial shade and complete darkness. Full details of the protocol for this and supporting rationale are supplied here.

Typical experimental layouts are illustrated in Figure 2 showing locations of GHG monitoring collars in control and pilot areas; this contrast enables the GHG benefits of restoration to be validated in the absence of data collected prior to the project.

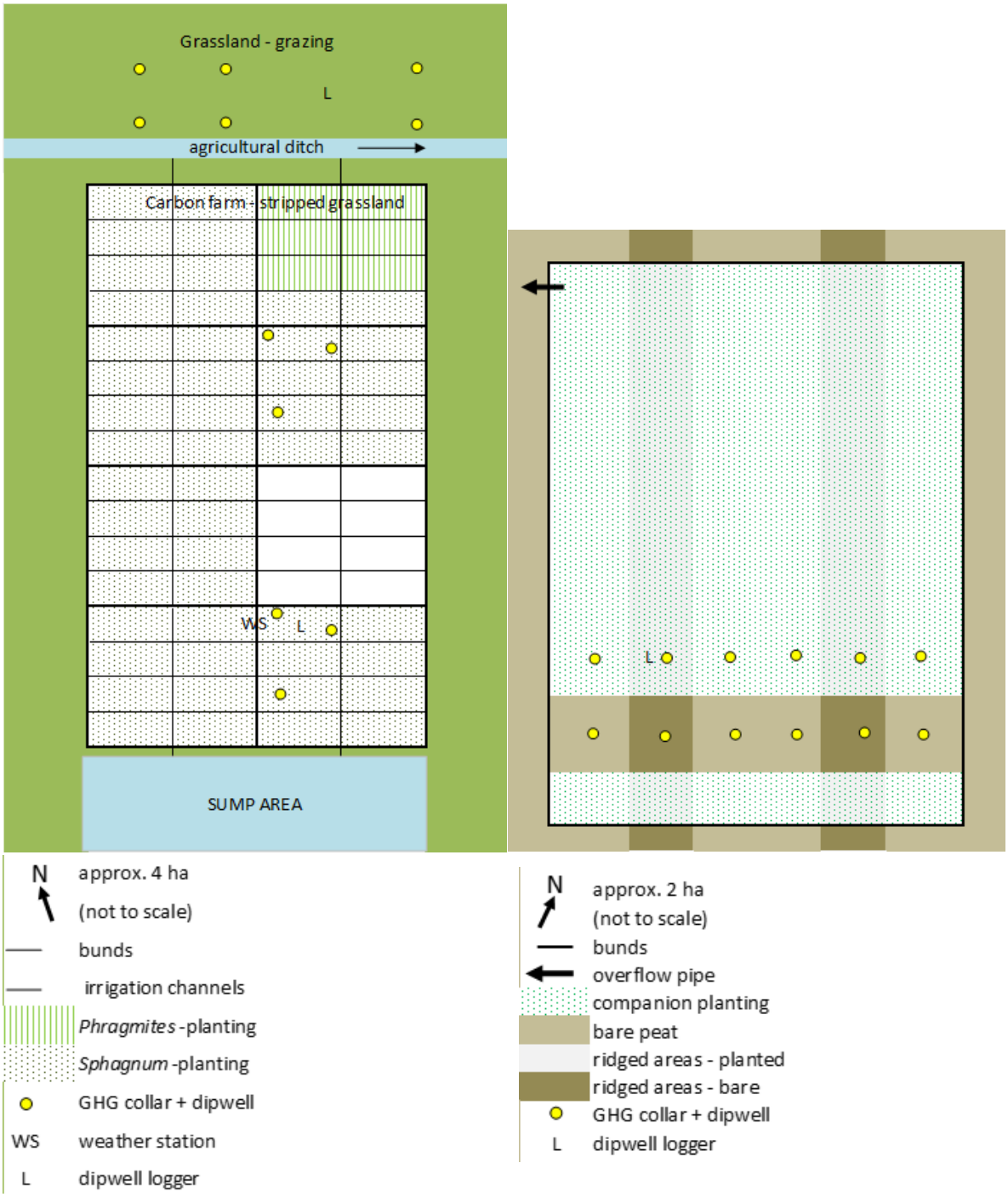


*Figure 2: Experimental design at a) Winmarleigh Carbon Farm (WCF) pilot site and b) LWM companion planting pilot showing arrangement of irrigation, planted cells, GHG monitoring collars, dipwells and weather station.*

Greenhouse gases (GHG) are being monitored at pilot sites using dynamic, closed -chamber systems which pump and return sample gas from a sealed chamber of suitable size to a GHG analyser (Figure 3, Table 2). When a GHG measurement is being captured, key environmental variables such as air temperature, soil temperature, PAR and water table depth are also recorded.

*Table 2. Greenhouse gas monitoring equipment used at each site with environmental variables records and dates of sampling.*

| **Site** | **GHG monitoring equipment** | **GHG monitoring locations** | **Variables recorded** | **Dates** |
|---|---|---|---|---|
| Cloncrow Bog (CB), Ireland | Los Gatos Microportable GHG Analyser | 6 collars in rewetted high bog, 6 collars in control (drained) high bog, with two ecotopes at each site (Submarginal and Facebank). 6 collars in rewetted cutover bog, 6 collars in control (drained) cutover bog, with two ecotopes at each site (Eriophorum and Molinia dominated) .<br>Shallow wells at each site . | CO2, CH4, soil temperature, soil water content, PAR, water table depth. | Monthly from September 2020 |
| Black Creek (BC), Belgium | Los Gatos Ultraportable GHG Analyser | Planned: 6 collars rewetted, 6 collars control with 3 in each area on contrasting vegetation types. | CO2, CH4, air temperature, soil temperature, PAR, water table depth. | Preliminary data March 2020 |
| De Wieden (DW), The Netherlands | Los Gatos Ultraportable GHG Analyser | Planned: Fluxes will be monitored along a circuit of different measuring stations (creeks + lake) | CO2, CH4, air temperature, soil temperature, PAR, water table depth. | Preliminary data March 2020 |
| La Guette (LG), France | Los Gatos Ultraportable GHG Analyser | Planned: 6 collars in restored, 6 collars in control with 3 in each area on contrasting vegetation types incl. bare peat. | CO2, CH4, air temperature, soil temperature, PAR, water table depth. | Monthly from April 2021 |
| Little Woolden Moss (LWM), UK | Los Gatos Ultraportable GHG Analyser | 6 collars on bare peat, 6 collars on vegetated plots with 3 hummock and 3 hollow locations at each site. Dipwell pipes at each GHG collar. | CO2, CH4, air temperature, soil temperature, PAR, water table depth. | Monthly from June 2020 |
| Winmarleigh Carbon Farm (WCF), UK | Los Gatos Ultraportable GHG Analyser | 6 collars on grazed pasture, 6 collars on carbon farm. Dipwell pipes at each GHG collar. | CO2, CH4, air temperature, soil temperature, PAR, water table depth. | Monthly from December 2020 (+ Sept 2020) |

In France, Ireland and the UK measurements commenced in summer 2020. Initial site visits and preliminary data were collected in De Wieden, the Netherlands and Black Creek, Belgium to design sampling protocols, however, due to COVID19 travel restrictions sampling has not yet been possible. It is hoped that measurement campaigns can be undertaken at a later stage in the project. A carbon storage protocol has been designed as an alternative (see 1.3 below). In the UK GHG fluxes above standing water in ditches are also captured and this is also planned for Ireland from Autumn 2021.

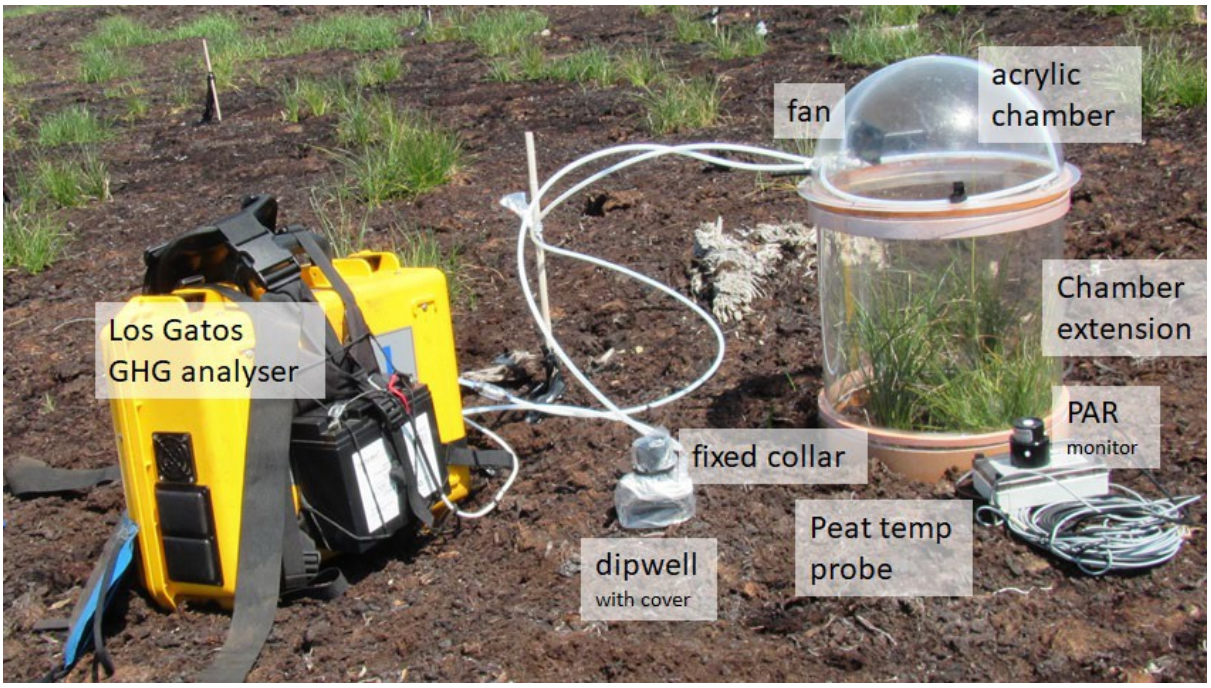


*Figure 3: GHG monitoring system used on Little Woolden Moss and Winmarleigh carbon farm pilot sites.*

Vegetation in GHG monitoring collars is photographed and recorded at each measurement visit to be incorporated as an environmental variable in GHG flux modelling. For example, on the Little Woolden Moss (LWM), UK companion planting area, cottongrass growth and Sphagnum cover within GHG monitoring collars is assessed monthly using a 'pin -touch' method, and vegetation cover across the pilot site is estimated annually. Similarly, in Ireland, the vegetation in each GHG was surveyed in September 2020 and photos of each collar are taken when GHG data is collected.

*Figure 4. a) Monitoring of aquatic GHG fluxes and b), c), d) example photo record of Sphagnum pulg growth in WCF GHG Collar number 6S from September 2020, January 2021 and June 2021 respectively.*

## 1.3. Carbon Storage

Carbon storage measurements have been undertaken or are planned at CB, LG, LWM and WCF in spring 2021. These will provide baseline data before restoration work is undertaken and allow future comparisons of carbon storage to be made.

Each peat core was then cut into segments then dried and incinerated to determine bulk density and Loss on ignition (LOI) organic content. Carbon percentage was allocated from LOI using the procedure described by Bojko and Kabala (2014)[1]. At LWM and WCF, 3 peat cores were sampled to full depth on each treatment (i.e., 6 cores per site) in spring 202. AT CB, this work is planned for summer 2021. Visits have not yet been possible to BC or DW, however, Rotterdam University researched the carbon stock in the peat pits at DW in summer 2020.

[1] Bojko, O. and Kabała, C., 2016. Loss-on-ignition as an estimate of total organic carbon in the mountainsoils. *Polish Journal of Soil Science*, *47*(2), p.71.

# 2. Vegetation surveys and soil sampling

## 2.1. Baseline vegetation surveys

At each site vegetation was recorded and Ellenberg F (moisture), R (Reactivity) and N (Nutrients) calculated based on presence of a species and presented as one value per site. As a bare site, Ellenberg values were not calculated for LWM. For more information on these please see the report on restoration planning.

## 2.2. Ongoing vegetation monitoring

Ongoing vegetation monitoring is to be undertaken at all sites. On the Winmarleigh Moss carbon farm, 20 permanent vegetation monitoring plots of 1m 2 were established and first surveyed in April 2021, it is planned that Sphagnum plug size and any other vegetation within the plots will be measured seasonally i.e. 4 times per year (Figure 5). In Ireland, a detailed site survey was undertaken in summer 2020, and in France a bryophyte inventory was carried out in May 2020.

*Figure 5: Vegetation monitoring in 1 m2 plot on Winmarleigh carbon farm site.*

## 2.3. Baseline soil and soil solution sampling

Three replicate soil cores were sampled from the top 15 cm of each site in the summer of 2019, they were refrigerated upon collection and frozen later that day. For La Guette, De Wieden, Cavemount and Cloncrow replicate samples were taken from one location . In Belgium, samples were taken from 3 locations along the Black Creek. For Little Woolden Moss, three replicate samples were taken from a series of Hummocks (Hk) and Hollows (Hw). At Winmarleigh Moss, UK, deeper 60 cm cores were taken and sectioned into 0-10, 10-20, 20-30, 30-40 and 40-60 cm profiles to study the influence of recent farming practices and determine the extent of topsoil removal needed. Available nutrients were extracted from 5 g of fresh soil samples using a 1% KCl solution and shaken for 30 minutes on an orbital shaker. The extractant was then centrifuged for 5 minutes before filtering to 0.2 m and a 1:4 dilution with Deionised water (DI H2O). This was then analysed for anions and cations using a Dionex ICS5000 Ion Chromatograph (Thermo Scientific). For Carbon (C) and Nitrogen (N) % soil was first dried, then fine ground using a ball mill before analysis using an Elementar vario EL CUBE. Loss on Ignition (LOI) was measured by combusting dried soil samples at 500oC for 2 hours in a muffle furnace and pH was also measured from 10 g of fresh soil mixed with 20 ml DI H2O, left to stand for 20 minutes before stirring and recording pH when the reading was stable. Surface soil water was also sampled, refrigerated upon collection and frozen later that day. That was then analysed for anions and cations using the ion chromatograph and for available metals using ICP-OES (Thermalox). For more information on these and the data obtained from them please see the report on restoration planning.

# 3. Earth observation monitoring

## 3.1. Sentinel 2 satellite data

Cloud-free images were taken from different seasons prior to the project start to make 'average' image, with further images taken as restoration progresses and after the project ends. From each image three indices were generated: 1. Normalised Difference Vegetation Index (NDVI; see example in FIgure 6), a proxy of greenness or photosynthetic activity; 2. Normalised Difference Moisture Index (NDMI), a proxy for vegetation water content or the spongy mesophyll structure within the canopy; and 3. Normalised Difference Water Index (NDWI), an indicator of surface water coverage. These indices enable a broad overview of site productivity and wetness conditions and allow us to monitor these parameters seasonally and over the course of the project. They can be particularly useful to monitor landscape changes in moisture of restoration sites and effects on neighbouring sites.

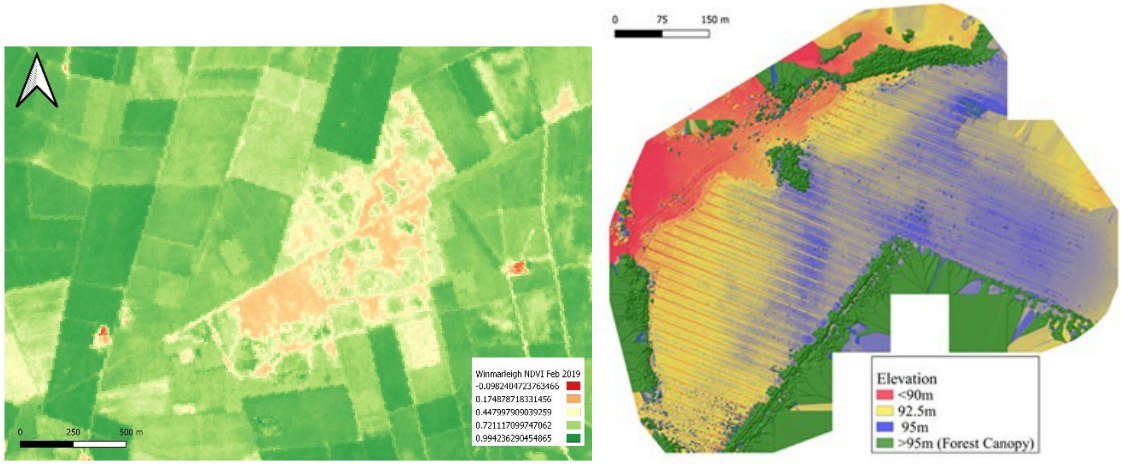


*Figure 6. a) Example Winmarleigh Moss, UK NDVI derived from Sentinel imagery from Feb 2019 and b) Digital Elevation Model (DEM) of Cloncrow Bog, Ireland from Drone imagery from August 2019. Hyperspectral drone data*

The project is also undertaking UAV (Unmanned Aerial Vehicle) surveys: one prior to the restoration works (also in 2019) and the second at the end of the project. Imagery from these surveys were standardised by a pixel resolution of between 2 cm and 10 cm and by using similar drone multispectral cameras to provide vegetation indices NDVI, NDWI, NDRE (Normalised Difference Red Edge). As a result of each drone survey, an orthographic, DEM (georeferenced raster images, Figure 6)) and multispectral imagery are also generated. This will allow the identification and monitoring of vegetation change and the health of each pilot site. It will also support the scaling up of our carbon measures to larger areas as well as to reduce uncertainties with up-scaling carbon flux measures.