Interreg
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Care-Peat
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Interreg Care-Peat

Report on deliverable WP T3

Transnational preparation, implementation and demonstration of new techniques and methods to restore C-sequestration in peatlands

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Introduction

Global peatlands contain around 33% of global soil carbon yet occupy only 3-5% of the world's land surface. Many of these peatlands are in poor condition through drainage, conversion to agriculture, peat extraction and historic pollution causing carbon that has been stored over thousands of years to return to the atmosphere, contributing to large-scale Greenhouse Gas (GHG) emissions and increased atmospheric CO_2. These carbon stores are further threatened by climate change which will increase the rate of decomposition. Global annual 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 NWE-region they are approximately 150 MT/year (more than annual GHG emissions of Belgium).

The restoration and rewetting of peatlands are therefore seen as vital in our battle against climate change and key to achieving the EUs aim of carbon neutral by 2050. Care-Peat addresses this goal through the reduction of CO_2-emissions and increased C-storage in several EU peatlands by:

1. Testing innovative technologies and methods at 7 pilot sites across 5 countries to demonstrate and quantify CO_2 emissions and C-storage.

2. Proposing restoration scenarios and solutions for the reduction of CO_2 emissions from peatlands of the NWE-region, using advanced management tools developed from pilot sites.

3. Creating involvement and collaboration of public and private stakeholders associated with peatland restoration to achieve C-sequestration and socio-economic benefits throughout the NWE-region.

In Care-Peat we are restoring and changing the management of seven peatlands across five countries. These pilot sites (Table 1) cover a range of peatland types seen across the EU: raised bog, poor fen, rich fen, extracted peatland and former peatland now managed as agricultural land. The project will share knowledge of best practice restoration techniques developed across the partnership and jointly monitor the success of the restoration programmes at each site. The pilots will act as case studies and demonstrations of restoration techniques and the outcomes of the restoration will be communicated to stake holders, policy makers, peatland managers and owners both locally and across the EU to advise future peatland restoration.

The objective of this joint restoration planning document is to establish the baseline conditions at each site in terms of the hydrological status, current vegetation and notable flora and fauna, any protections afforded to the sites including cultural heritage, peat condition and chemistry, and to match these conditions to the long-term goals for the sites and the design of the practical restoration.

Table 1. Overview of the sites to be restored as part of Care-Peat, with details of their peatland type, current vegetation and desired state, together with pollution information and meteorological data.

Site	Peatland type (size/pilot size)	Current habitat	Current vegetation	Desired state/habitat	Pollution (current/ historic)	Meteorology
Zwarte Beek (Black Creek), Belgium	Iron rich fen peatland (drained) 750/250ha	Wet grassland (D.3.41) Quaking bog and Transition mire (D2.3)	Grass/sedge/ Forb/occasional *Sphagnum*	Quaking bog and Transition mire (7140/D2.3)	N dep: ~20 kg Nearby agriculture, Iron rich	Rainfall: 808 mm Temperature: Jan: -0.5°C, Jul: 22.1°C
Cavemount Bog, Ireland	Raised bog (extracted)	Raised bog degraded (7120/D1.1)	Bare peat	Active raised bog (7110/D1.1)	N dep: ~15-20 kg	Rainfall: 925 mm Temperature: Jan: 2°C, Jul: 19°C
Cloncrow Bog, Ireland	Raised bog (drained) 200/26 ha	Raised bog active (7110/D1.1) + degraded (7120/D1.1)	Bare peat with bog species in active areas/grassland / woodland	Active raised bog (7110/D1.1)	N dep: ~15-20 kg	Rainfall: 925 mm Temperature: Jan: 2°C. Jul: 19°C
De Wieden, Holland	Forested fen 10 ha Foreshore 5 ha	Broadleaved deciduous Forest (T1.5/9080)	Alder woodland with birch, occasional *Sphagnum*, Open water	Pits: quaking mire Foreshore: Reedbed	N dep: ~18 kg	Rainfall: 856 mm Temperature: Jan: 1°C, Jul: 16°C
La Guette, France	Degraded Fen 23/0.12 ha	Wet heath (F4.1/4010) Fen (D2.3/7140?)	*Molinea*/ *Erica* shrubs/ *Sphagnum*	*Sphagnum*/ *Tricophorum* (*Rynchospora*) /Eriophorum (7140/D2.3)	N dep: ~10 kg	Rainfall: 641 mm Temperature: Jan: 2°C, Jul: 21°C
Little Woolden Moss, UK	Raised bog (extracted) 105/~2ha	Raised bog degraded (7120/D1.1)	Bare peat	Raised bog active (7110/D1.1)	N dep: ~20 kg Historic pollution from industry	Rainfall: 929 mm Temperature: Jan: 1°C, Jul: 21°C
Farmland adjacent to Winmarleigh Moss, UK	Raised bog (drained for agriculture) 20/4 ha	Agricultural grassland	Grass/Forbs	Carbon farm	N dep: ~27 kg Nearby agriculture, high ammonia	Rainfall: 1044 mm Temperature: Jan: 5°C, Jul: 19°C

Site descriptions, current status and condition

A brief description of each site, together with current management, any protection afforded to the site and the species within each site is below with summary information presented in Table 2. The condition of the sites varies greatly, from bare peat to organic grassland soil overlaying peat. With the exception of this grassland Winmarleigh Moss, which consists of 30 cm of organic soil over *Sphagnum* rich peat, the peat quality at all sites is poor and highly humified as a result of long-term oxidation. Key to the restoration of peatlands is the rewetting and control of the water table to reduce further oxidation followed by the re-establishment of suitable vegetation capable of future carbon sequestration. All sites have experienced some form of drainage, but all have good potential to reverse this.

Zwarte Beek (The Black Creek), Belgium

The valley (Vallei van de Zwarte Beek – Valley of the Black Creek) stretches out over 30km and consists of a slender ground water fed iron-rich fen peatland over an area of around 750 ha of which 250 ha will be restored in the project. The natural surroundings of the peatland are heathland (with peat bog like situations), grasslands and woodland. There is also farmland and some residential areas where consultation will be needed during the restoration process, and a military domain on the heathland area. Natuurpunt manage the site, with help from volunteers and labour teams, and also work with farmers in the area. The area is designated a 'heritage landscape' which has some protection for cultural heritage.

The habitat at the site consists of European habitat 7140 quaking bogs and transition mires (EUNIS D2.222) and wet grasslands, mostly degraded, with some still in very good wetland condition (EUNIS E3.411). The main vegetation is grassland and small sedges with some alder forest in between and some small areas of *Sphagnum* moss. The site is host to the largest population of Common snipe (*Gallinago gallinago*) in Flanders, the very rare Large marsh grasshopper (*Stethophyma grossum*) and is also important for the occasionally-breeding Spotted crake (*Porzana porzana*). The very rare Corncrake (*Crex crex*) is sometimes present together with other breeding birds including the Curlew (*Numenius arquata*). is

The long-term goal is quaking bog and transition mire throughout the site. This will be achieved through the blocking or suppressing of drains and waterways that cover the site.

De Wieden, Netherlands

The De Wieden peatland is the most unusual in Care-Peat. It consists of two main areas:

1) 10 ha of forested fen on terrestrialised former peat pits, formed after historic peat excavation. These fens will be excavated again to re-start the process of terrestrialisation;

2) 6 ha of foreshore in a lake ~1.5 m deep where the excavated peaty material will be stored underwater or close to the surface; the latter would afford further terrestrialisation.

The area is within a Nature reserve and National Park comprising peat pits, fens, lakes, reed lands, marshes, shrubs, forests, quaking bogs, transitional fens and terrestrialising fens. It is managed by Natuurmonumenten although the forested fens in the pilot area are not actively managed currently.

The surface water levels are managed by the waterboard so conventional rewetting through raising the water table is not possible.

The habitat is deciduous broadleaved forest, commonly dominated by alder (*Alnus glutinosa*) on non-acid peat (EUNIS T1-5) with some cover of *Betula pubescens*. Common ground species include *Phragmites australis*, *Thelypteris palustris*, *Juncus subnodulosus* and *Typha angustifolia* with occasional *Menyanthes trifoliata*, *Cladium mariscus*, *Carex diandra* and *Carex lasiocarpa*. There are a few *Sphagnum* species present in the general area. Most common is *S. palustre*. Less abundant are *S. fimbriatum* and *S. squarrosum*. The site is home to a variety of common birds, including the Willow Warbler (*Phylloscopus trochilus*), Blackcap (*Sylvia atricapilla*), Garden Warbler (*Sylvia borin*), Chiffchaff (*Phylloscopus collybita*), Treecreeper (*Certhia familiaris*), Great Spotted Woodpecker (*Dendrocopos major*) and Chaffinch (*Fringilla coelebs*). The rarest species are Spotted Flycatcher (*Muscicapa striata*) and Willow Tit (*Poecile montanus*), although there are no rare or threatened species.

The peaty material will be shredded and transported through pipelines to the foreshore, in a mixture with water (1/3 peat, 2/3 water). After excavation in the new peat pits terrestrialisation should start and in the foreshore a marsh situation is aimed for. The long-term vegetation plans are for species-rich mire in the peat pits and, depending on the depth of the soil beneath the surface, *Phragmites*-dominated vegetation is expected to establish in the foreshore area. The idea is to create two areas of rich fen peatland from one, that are both in a high carbon-building stage of development and richer in biodiversity than the existing area.

La Guette Peatland, France

La Guette Peatland is a degraded fen dominated by *Molinia caerulea* with *Erica tetralix* in wet heathland areas. The area is around 23 ha in size with smaller pilot areas of around 0.12 ha. It is situated in a generally wooded area consisting of *Betula* spp. and *Pinus nigra* plantation with some dry heathland. There are many small water bodies and the peatland was formed in a former meander of a nearby river.

Current vegetation is dominated by *Molinia caerulea* (~90%) and Ericaceous shrubs (*Erica tetralix* ~60% and *Calluna vulgaris* ~ 20%). Locally, in the wettest areas and in numerous trenches dug by boars (population growth stimulated in the region for hunting), *Sphagnum* species can be dominant and the site hosts 11 different *Sphagnum* mosses with *S. palustre*, *S. rubellum* and *S. cuspidatum* most common. Rare species for the region are: *Rynchospora alba*, *Eriophorum angustifolium*, *Gentiana pneumonanthe*, *Drosera rotundifolia*.

The site is currently degraded and drained by a nearby road which drives the vegetation succession towards a *Molinia* and *Erica* heathland that is progressively invaded by trees. There is potential to raise water tables at the site and this combined with the removal of *Molinia* and a small amount of peat from some areas; the translocation of *Sphagnum* from other areas will produce a site rich in *Sphagnum* with *Eriophorum* and *Rynchospora* over the longer term.

Table 2. Summary of site protection status, rare species, cultural heritage and stakeholders.

Site	Designation	Rare/protected species	Cultural/Historic	Nearby habitats/ land use	External stake holders
Zwarte Beek (Black Creek), Belgium	Heritage landscape	Common Snipe population, Marsh grasshopper, occasional Corncrake, Curlew	Partly protected landscape for cultural heritage	Heathland, Grassland, Woodland/agriculture, residential, military	Small, private landowners on land that could be restored
Cavemount Bog, Ireland	None	Bare peat	None	Lowland raised bog, woodland	Bord na Mona (land owner), IPCC – Irish Peatlands Conservancy Council
Cloncrow Bog, Ireland	Natural Heritage Area (NHA)	Good mix of wetland species and several bog mosses	Nearby earthwork and souterrain. Peat cutting.	Peat cutting/bare peat. Forestry (on peat). Agriculture, grazing (on peat)	Coillte (Forestry authority), Local landowners/farmers
De Wieden, The Netherlands	National Park	None in wooded area, some flycatcher and willow tit. The wet areas support rare birds – Bitten, Snipe	Peat extraction/pits. Water courses.	Wet heath, bog. Open water, reed beds (some farmed), marsh, forest, peat pits, residential	Water board, Farmers, Land leasers
La Guette, France	None	Locally rare: Rynchospora alba (Trichophorum cesp.), Eriophorum ang., Drosera rot., Gentiana, 11 Sphagnum spp.	None	Woodland in private ownership and local authority.	Little agriculture or industry in surrounding area.
Little Woolden Moss, UK	None – but forms an important stepping stone site between sites in the Manchester Mosses Special Area of Conservation and the Great Manchester Wetlands Nature Improvement Area	Currently bare but rare species in local area: willow tit, adder, water vole, hare, lizard	None known. Bog oaks and other historic finds in local area and potentially on site.	Bare peat, Agriculture – grazed livestock, winter feed, arable.	Local farmers. Tenant farmer, land owners. Salford City Council
Winmarleigh, UK	None but borders Winmarleigh Moss SSSI	Agricultural grassland. Water voles in ditches.	None	Agriculture – grazed livestock, winter feed, arable. Woodland	Local landowner and tenant farmers. Natural England.

Winmarleigh Moss, UK

Winmarleigh Moss is a former lowland raised bog that was drained in the 1970s and converted to agricultural land used for livestock and winter feed crops. It borders Winmarleigh Moss SSSI which is a lowland raised bog. A large drain between the sites removes water from the farmland and, despite piling and other water retention measures, causes water loss on the SSSI raised bog. Lancashire Wildlife Trust (LWT) has owed most of the SSSI since 2012 and in 2019, LWT purchased the remaining part of the SSSI along with 20 ha of the neighbouring farmland, part of which will be used for the current pilot.

The main objective for this pilot is the change in management of 4 ha of this farmland to a 'Carbon Farm' planted with *Sphagnum* moss and designed for the long-term storage [sequestration] of atmospheric CO_2. This will be achieved through raising the water table by blocking drains, and the removal of the nutrient and seed-rich, organic topsoil that has formed over the peat. The site will then be planted with *Sphagnum* moss species. It is also hoped that the rewetting of this buffer farmland will improve conditions and reduce GHG emissions on the adjoining SSSI.

Almost all the immediately surrounding land is owned by LWT including the SSSI which is owned and managed by LWT, and the majority of the remaining surrounding land, which is currently used for grazing/winter feed, is owned by LWT and managed by a tenant farmer (with input on management by LWT). Stakeholders include the tenant farmer and private landowner and Natural England due to the surrounding area's SSSI status. Other stakeholders could include residents and local businesses/land owners who may be impacted or interested.

Current vegetation at the site is that of agricultural grassland, although the neighbouring SSSI is rich in bog species and 11 different *Sphagnum* mosses have been recorded including *S. palustre*, *S. fimbiatum*, *S. fallax*, *S. capillifolium*, *S. cuspidatum, S. papillosum* and *S. magellanicum*. This highlights the suitability of the site to grow *Sphagnum*. There are no protected species on the farmland, but ditches are inhabited by water voles (*Arvicola amphibious*), a priority conservation species. Water supply at the site is plentiful and it is anticipated that rewetting will be achieved through drain blocking. A small reservoir will be created to store a water supply for irrigation and maintenance of the water table during dry periods.

Little Woolden Moss, UK

Little Woolden Moss (LWM) is a 107 ha lowland raised bog that was extracted for peat until 2012 and in parts as recently as December 2017. The site is wholly owned by LWT and large-scale re-wetting and re-vegetation restoration works are ongoing. As part of the Care-Peat project, a 2 ha area of bare peat will be revegetated by a combination of *Sphagnum* mosses and sedges designed to promote rapid colonisation with vegetation and minimise the time taken to return the site to a CO_2 sink. This work applies research findings on the C benefits of specific plant mixes.

LWM sits within the Great Manchester Wetlands Nature Improvement Area and is considered an important linking. The site is home to over 100 species of birds including the internationally endangered Curlew (*Numenius arquata*) and the locally rare Willow Tit (*Poecile montanus*) as well as the Lapwing (*Vanellus vanellus*), Skylark (*Alauda arvensis*), Short-eared Owl (*Asio flammeus*), Hobby (*Falco subbuteo*) and Merlin (*Falco columbarius*). Black darter dragonflies (*Sympetrum danae*), Common Lizards (*Zootoca vivipara*), brown hares (*Lepus europaeus*) and the rare Bog Bush Cricket (*Metrioptera brachyptera*) also inhabit the site.

Cloncrow Bog, Ireland

Cloncrow Bog is a 200 ha lowland raised bog with a mix of active and degraded bog areas that have been subjected to drainage and in parts afforestation, peat extraction (and burning) and agricultural grassland used for grazing. The active areas of the bog have good hummock/hollow microtopography, some bog pools and quaking areas, a swallow hole, a small flush and forestry on high bog. The drier, cutover area supports humid grassland, improved grassland, small areas of Downy Birch (*Betula pubescens*) woodland and scrub, and forestry. The Care-Peat pilot is 26 ha and will undergo drain blocking to reduce water losses and the transplantation of *Sphagnum* mosses.

The site is primarily owned and managed by the National Parks and Wildlife Service (NPWS) of Ireland, although Coillte (State owned forestry) owns a portion of the site in the southern end of the NHA, while the north eastern section is comprised of degraded cut over bog in private landownership. The NPWS has been negotiating with the landowners for purchase of the lands and Care-Peat will purchase 13.5 ha of private land to include in the restoration of the bog.

Much of the high bog has vegetation typical of an Irish Midlands Raised Bog and supports such species as Ling Heather (*Calluna vulgaris*), Common Cottongrass (*Eriophorum angustifolium*), White Beak-sedge (*Rhynchospora alba*), Bog Asphodel (*Narthecium ossifragum*) and a range of bog mosses including *Sphagnum imbricatum*, *S. pulchrum*, *S. fuscum* and *S. cuspidatum*. Midland Raised Bog indicator species include Bog-rosemary (*Andromeda polifolia*) and Cranberry (*Vaccinium oxycoccos*).

The northern half of the bog is firm but wet and with a hummock/hollow microtopography, while in the southern and eastern sections the bog is wetter and spongy with good hummock/hollow microtopography, pools, inter-connecting pools, quaking areas and a flush. The pools and channels are filled with the aquatic bog moss *Sphagnum cuspidatum*, White Beak-sedge, Common Cottongrass and Bog Asphodel. The hummocks are composed of the bog mosses *Sphagnum fuscum*, *S. imbricatum*, *S. papillosum* and *S. capillifolium*. The tops of the hummocks support Ling Heather, Common Cottongrass, the moss *Hypnum jutlandicum* and lichens (*Cladonia* spp.) The bog moss *Sphagnum pulchrum* has been recorded in the far east of the site.

Cloncrow Bog is part of a Natural Heritage Area (NHA) and although there are no records of cultural at the site there is an earthwork near the southern border of the site (red) and a Souterrain (mostly destroyed) in the northeast area outside of the NHA.

Restoration to active raised bog will be achieved through drain blocking and *Sphagnum* transfer from the adjacent raised bog area.

Cavemount Bog, Ireland

A further site in Ireland is associated with the project and will be used for measurements, validation of restoration benefits and modelling scenarios. Cavemount Bog is a 503 ha bare-peat former extracted peatland owned by Bord na Móna. No restoration works are planned for this site.

Peat condition and hydrology

The condition of the sites varies greatly, from bare peat to organic soil overlaying bare peat. With the exception of the agricultural grassland at Winmarleigh Moss, which consists of 30 cm of organic soil over *Sphagnum* rich peat, the peat quality at all sites is poor and highly humified. All sites have experienced some form of drainage and therefore the peat is oxidised, but all have good potential to reverse this.

In Belgium, the peat has been degraded due to long standing drainage for agricultural use, although in areas upstream there is much better preservation and some very wet areas. Restoration is needed because of ditches and the sites are losing water. A good depth of peat (formed mainly from sedges) remains across the site ranging from 2-3 m downstream to 6-8 m upstream, representing a large carbon store. The peat, topped by 30-50 cm of organic soil, is highly humified reflecting long-term oxidation from drainage. Some consideration should be given to effects on nearby land and water quality of the main waterways.

In the Netherlands, a detailed peat depth survey has not been completed although depths are expected to range from 0.5 to 1.5 m, with some areas deeper. The peat at the site is compacted and again well humified. Water is plentiful at the site although little independent hydrological control is possible as control is managed regionally by the water board. At La Guette, France the physical condition of the peat is good, but it is also highly humified reflecting long-term drainage. Peat depth is between 0.4 and 1.8 m formed mainly from sedges, although some surface peat contains *Sphagnum*. The site is a mix of wet and drier areas with further rewetting planned through blocking the drain near the road that runs alongside.

In the UK at Winmarleigh Moss, the top ~30 cm of the site is organic soil, formed from the current agricultural use, which sits over good quality peat with *Sphagnum* rich layers. The peat depth is currently not known – this will be surveyed winter 2019/20. Rewetting here will also be achieved through blocking the drains that run along the edge of the site. At Little Woolden Moss peat depth is shallow ~ 0.5 m but varies up to 1.5 m due to sub-surface fluctuations in the underlying sand and bedrock. Peat quality is again poor, it is highly humified and much surface cracking exists. The site has already been rewetted. In Ireland, Cloncrow Bog peat depth is ~ 4m formed from *Sphagnum* mosses and the pilot site is currently vegetated with a mix of bog and heath species although it is degraded through drainage. This site drainage network will be blocked via peat dams to restore hydrology and some neighbouring buffer land will be purchased and restored to support the rewetting.

Peat Chemistry

Methods

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 μm and a 1:4 dilution with Deionised water (DI H_2O). 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 500^{o}C for 2 hours in a muffle furnace and pH was also measured from 10 g of fresh soil mixed with 20 ml DI H_2O, 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).

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 bare sites, Ellenberg values were not calculated for LWM or Cavemount bogs.

Results and Discussion

Nutrient data presented is total inorganic N summed from NO_3^--N and NH_4^+-N, in all cases NO_2^- was below detection limits. This extractable N is readily accessible for plant uptake. Total extractable N (Figure 1 d) results were highest at Black Creek, De Wieden and Winmarleigh Moss (Figure 2a and b) – these sites have all had recent agricultural uses or in the case of De Wieden, share available water with local and regional agriculture. The lowest available nutrients are at the Irish sites which for comparison sit at the lower end of inorganic N values found in across a UK bog survey conducted by the authors. The data from LWM and La Guette is very variable suggesting some localised enrichment may occur, possibly from bird or other animal faeces or enriched water, however, they do sit within the broad range of UK comparison sites. LWM is also located west of Manchester and may receive elevated atmospheric nitrogen deposition currently and historically, and as formerly drained, bare peat mineralisation and oxidization or organic matter could have occurred. Ellenberg N[1] (Figure 1a) derived from vegetation data is in agreement with the soil N data, with Black Creek, De Wieden and Winmarleigh Moss habitats for plants preferring higher nutrient conditions and Cloncrow and La Guette providing a low nutrient environment (LWM and Cavemount are bare peat sites so this comparison was not possible).

Calcium (Figure 1f) levels appeared elevated at De Wieden and Winmarleigh (not shown), probably reflecting the use of lime in local agriculture. The water level in the water management area of which the De Wieden pilot site is part of, is maintained by inlet of water from outside. This inlet water is partly from brooks and streams which in summertime are fed by calcium rich seepage water, which explains the calcium levels observed. In wintertime the inlet water is dominated by farmland water, containing less calcium and more phosphate. Other soil nutrients were not notable at the sites, with the exception of phosphate at both De Wieden and La Guette where small amounts were observed. NB. A full suite of soil metals was not performed. For a full breakdown of soil nutrients see Appendix 2 and for soil water chemistry see appendix 2.

In terms of moisture and Ellenberg F[2] (Figure 1c), the driest sites are the drained agricultural areas of Black Creek 1 & 2 and Winmarleigh, however, an Ellenberg F of 5 is indicative of a moist site and 7 a constantly damp site, so even these ‘dry’ locations have a propensity for moisture. Black Creek 3, Cloncrow, De Wieden and La Guette all sit within the range of UK Bogs highlighting the likely success of restoration with minor changes to hydrology.

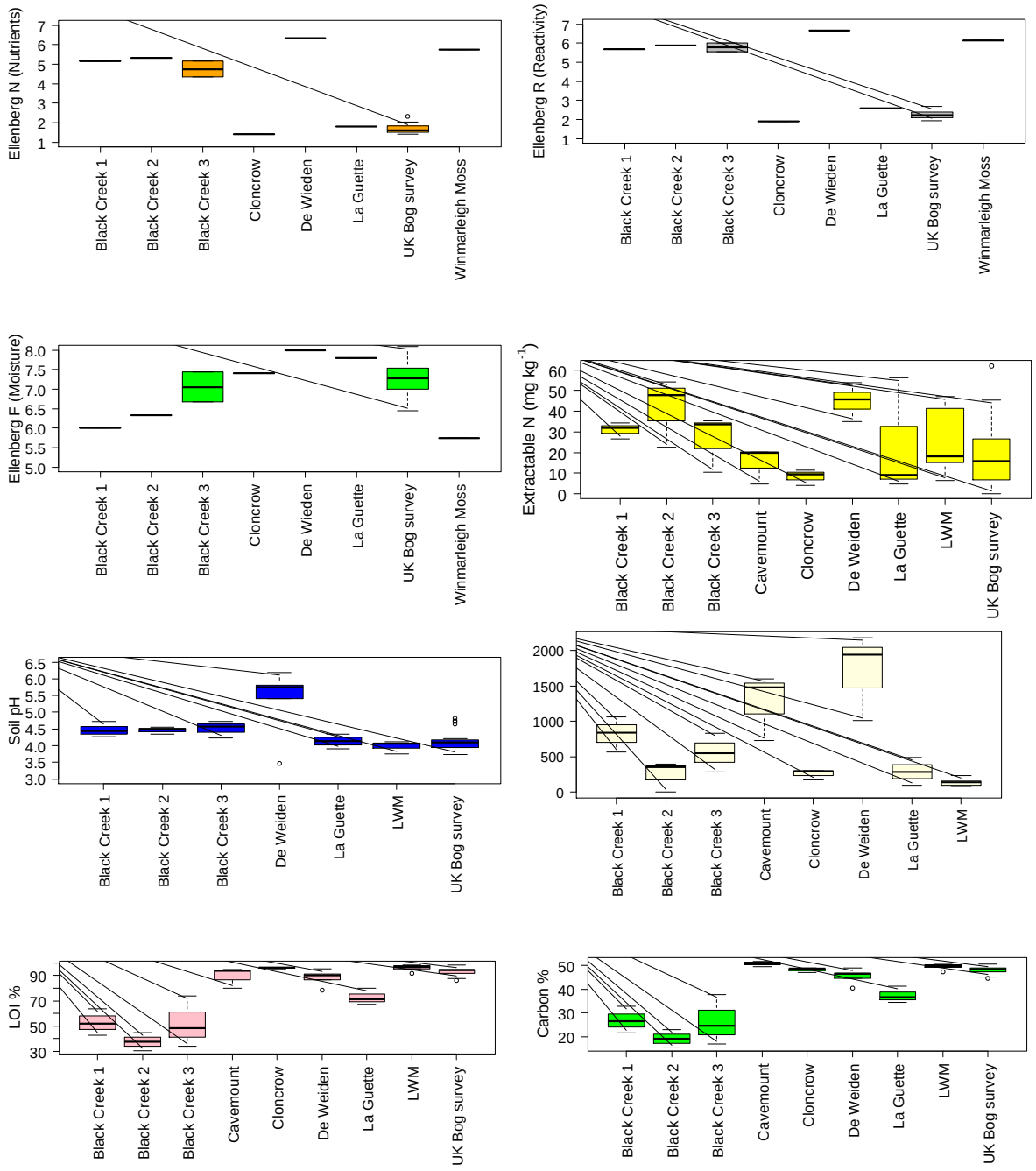


Figure 1. Ellenberg values from vegetation covering Nutrients (N), Reactivity (R- acidity), Moisture (F) alongside extractable total inorganic N (sum of ammonium and nitrate), soil pH, soil Calcium, soil Loss on Ignition % (LOI) and soil C%. The range of values for 29 UK raised bogs sites are included for comparison purposes.

Different peatland types can be characterised by their pH. In the Care-Peat sites, soil pH at La Guette, Cloncrow and Little Woolden Moss (LWM) fits well with the UK bog survey comparison indicating a raised bog habitat (usually pH<4.2). Black Creek pH is indicative of poor fen (range pH 4.5-5.5) as is Cavemount (pH=4.97) which perhaps reflects a history of peat extraction bringing the peat surface close to the underlaying mineral layer. De Wieden is in the rich fen range (pH 5.5-6.9). Some overlap does exist between these categories. , However, current vegetation does support the soil pH data (Ellenberg R, Figure 1b) with values of 1.9 at Cloncrow and 2.6 at La Guette suggesting very acidic sites with ~5.7 at Black Creek and 6.7 at De Wieden indicative of more alkaline conditions.

Peat soil is also characterised by Loss on Ignition (LOI) values of greater than 80% and C% of around 50%. De Wieden, Cavemount, Cloncrow and LWM can all be clearly defined as peat (Figure 1g and h). La Guette is marginally less peaty and probably more peaty-organic, perhaps reflecting some recent oxidation from drainage, and whilst there is some variability in the data, the surface soil at the Black Creek sites is not classified peat by most literature and is probably organic rich soil (see Rydin and Jeglum, 2006). However, there is no clear consensus on this definition. This probably reflects the land use and soil formation at the site over the last century and the oxidation of historic peat.

Soil extractable nitrogen at Winmarleigh (Figure 2a and b) and pH (Figure 2c) was also analysed by profile as topsoil stripping is likely to take place at this site to remove nutrients and the agricultural weed seed bank. As can be observed, soil N falls rapidly below 20 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 (not shown) suggested this was also higher in the upper horizons. Following topsoil removal a full nutrient analysis will be reperformed to determine if any remediation of the calcium levels is needed before *Sphagnum* is introduced to the site in Spring 2020 – very high levels of calcium is thought to be toxic to *Sphagnum* moss. Soil C% at Winmarleigh is organo-peat in the upper profile and peat from around 20 cm down.

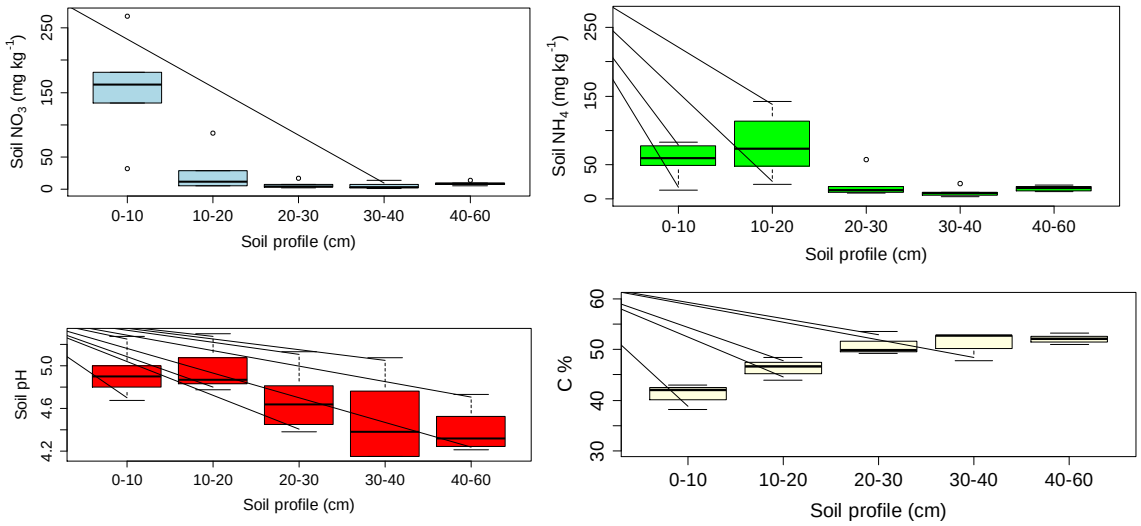


Figure 2. Soil extractable NO_3, NH_4, pH and C% by soil profile at Winmarleigh Moss, UK.

Summary

Overall, the site survey data collected during summer 2019 supports the main intended restoration plans at each site and highlights the suitability of the sites to reach their desired states over time.

The data confirms Black Creek as a suitable poor fen, which should be achieved following rewetting. The third location in Black Creek in particular has vegetation indicative of a wetter site already and supports the most diverse range of plant species. Following rewetting, peat formation processes should restart along the Black Creek and this rewetting will also act to preserve the existing carbon pools at the site. As the most minerotrophic site, De Wieden is a suitable rich-fen habitat. Although local control of the water table is not possible, peat translocation will enable the site surface to be taken down below the water table. Some consideration should be given to the peat depth extracted and the area of foreshore that is being created to ensure that the peat is close enough to the surface to maximise future carbon storage from vegetation colonisation alongside stabilisation of the existing C store. La Guette is classified as a fen, although its oligotrophic nature and soil chemistry, acidic pH and vegetation gives it many characteristics of a lowland raised bog. It is likely that this habitat is a transition habitat between poor fen and lowland raised bog. The site is peaty although some oxidation has occurred, however, following further rewetting further peat should form and as this elevates the bog surface above the ground water table the site should transition to a raised bog.

Of the existing bog sites, Little Woolden Moss (LWM) is a lowland raised bog that is currently bare following peat extraction. Site drains have already been blocked and a high-water table already achieved and it is now ready for reintroduction of suitable *Sphagnum* mosses and cotton grasses. Cloncrow bog is a lowland raised bog in varying condition. It is mostly vegetated with bog species throughout and it is likely that following drain blocking, natural recolonisation of the site will occur from local sources. At Cave-Mount, some hydrological works have taken place and the site is now suitable for revegetation if desired. Winmarleigh Moss is currently managed as agricultural grassland. However, the soil is highly organic and below 20 cm is good quality peat, following rewetting the site should effectively sustain the *Sphagnum* moss carbon farm.

Bibliography

This planning document has drawn heavily on the information provided by the texts below, these may prove useful for other projects when planning their own restoration works:

Field, C.D et al., 2014. The role of nitrogen deposition in widespread plant community change across semi-natural habitats. Ecosystems, 17(5), pp.864-877.

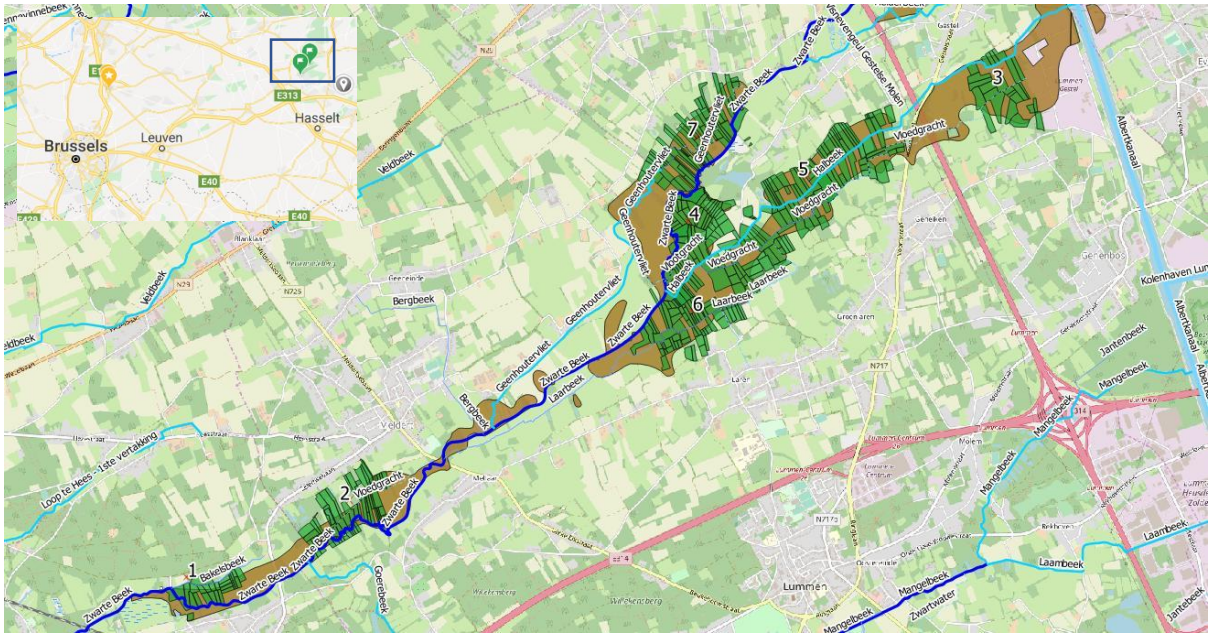
Peatlands and Uplands Biodiversity Delivery Group (2010) Guidelines for Peatland Restoration. http://www.qpani.org/documents/PeatlandRestorationguidelinesfinal.pdf

Quinty, F. and L. Rochefort, 2003. Peatland Restoration Guide, second edition. Canadian Sphagnum Peat Moss Association and New Brunswick Department of Natural Resources and Energy. Québec, Québec. http://tourbehorticole.com/wp-content/uploads/2015/07/Peatland_Restoration-e.pdf

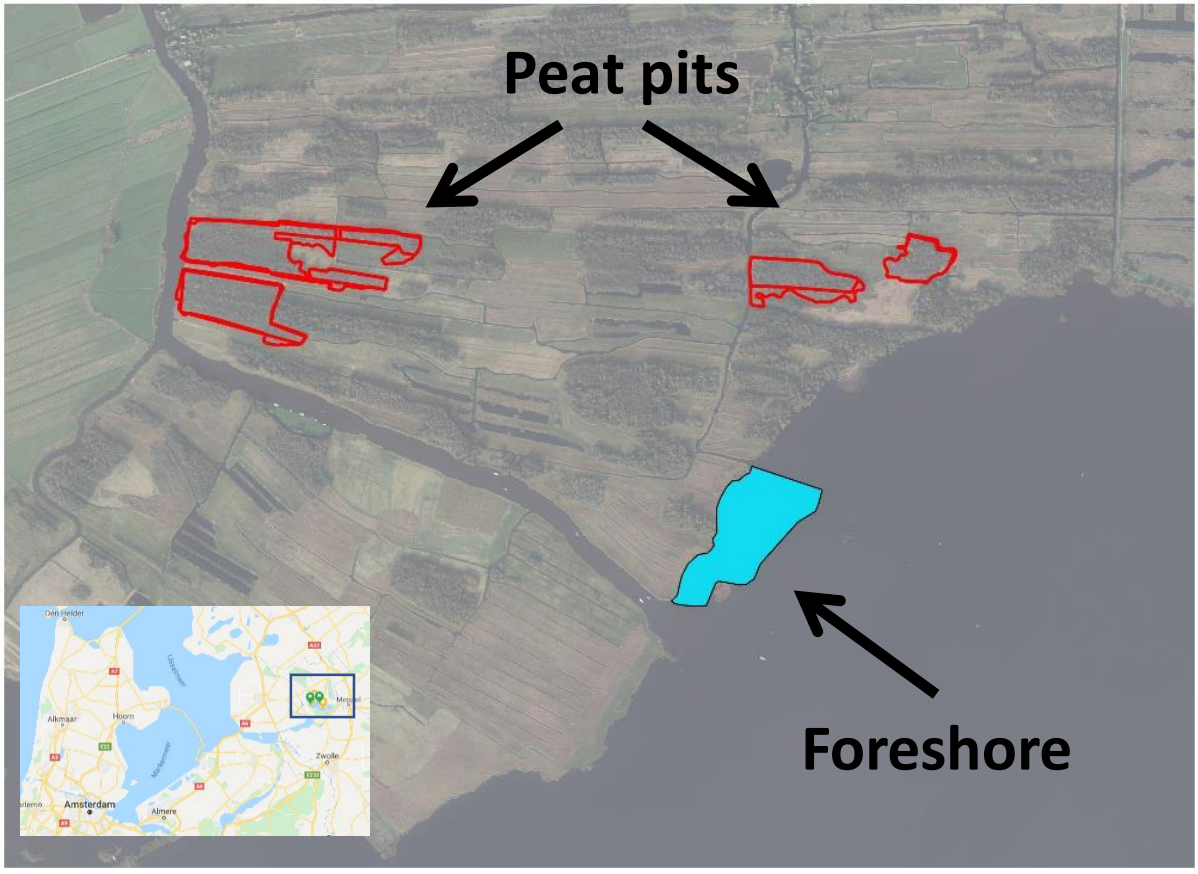
Rydin, H. and Jeglum, J.K., 2013. *The biology of peatlands, 2e*. Oxford university press.

Thom et al. (2019) Conserving bogs the management handbook – IUCN http://www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/Conserving%20Bogs%20the%20management%20handbook.pdf

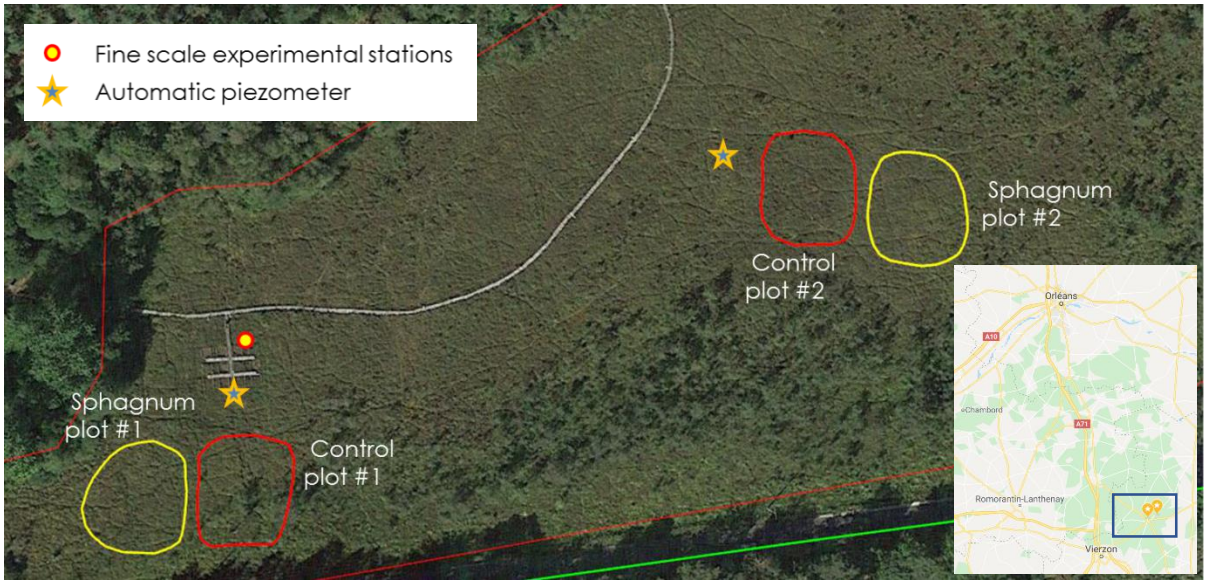
Appendix 1 Site maps and digital surface models



Black Creek, Belgium: 51.014454, 5.176953



De Wieden, Netherlands: 52.714, 6.018

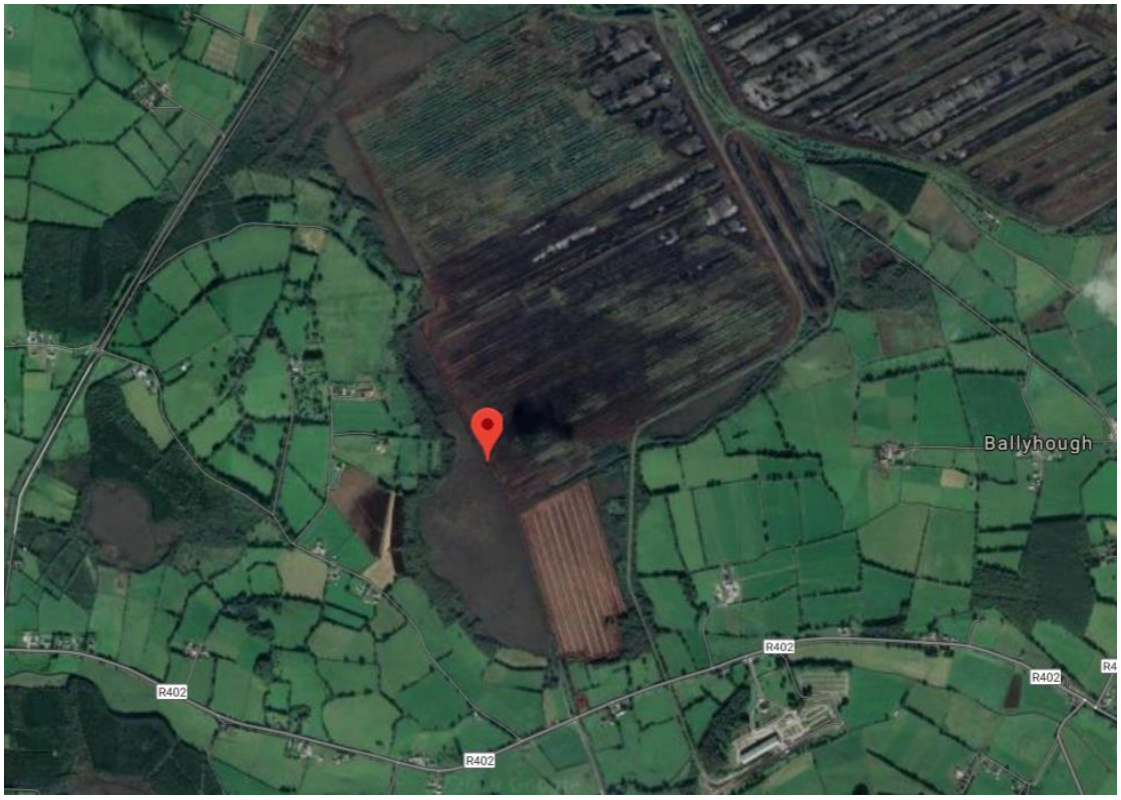


La Guette Peatland, France: 47.321, 2.278

Winmarleigh Moss, UK: 53.926, -2.851

Little Woolden Moss, UK: 53.446, -2.466

Cloncrow Bog, Ireland: 53.395, -7.416



Cavemount Bog, Ireland: 53.305, -7.243

Appendix 2 Soil Chemistry NB. Phosphate by KCl is only a guideline, further analysis can be undertaken if needed by alternative extract.

Site	pH	LOI %	C %	N %	C/N	Ammonium (mg/kg)	Magnesium (mg/kg)	Calcium (mg/ kg)	Nitrate (mg/kg)	Phosphate (mg/kg)	Sulphate (mg/kg)	Total inorganic N (mg/kg)
De Wieden	5.41	90.91	45.45	3.23	14.09	52.83	0.29	1471.88	0.57	0.00	0.97	41.22
De Wieden	5.75	86.54	44.8	3.13	14.31	58.77	0.00	1937.73	0.76	0.00	1.88	45.89
De Wieden	5.81	78.57	47.12	3.2	14.7	63.16	52.93	2176.30	0.47	19.57	11.58	49.23
De Wieden	6.18	90.00	45.86	2.6	17.62	68.91	15.03	2041.26	0.99	13.60	8.69	53.82
De Wieden	3.47	95.10	48.57	2.79	17.4	44.56	5.69	1009.92	1.51	0.00	5.09	35.00
Black Creek 1	4.73	42.68	27.21	1.98	13.74	44.25	18.77	842.85	0.16	0.00	60.09	34.46
Black Creek 1	4.43	63.82	27.85	1.74	16.05	34.25	31.48	1064.74	0.33	0.00	67.63	26.71
Black Creek 1	4.26	51.82	25.29	2.04	12.4	40.93	3.96	562.89	0.10	0.00	108.83	31.86
Black Creek 2	4.49	30.77	9.45	0.81	11.68	27.68	0.00	349.56	4.42	0.00	0.00	22.53
Black Creek 2	4.35	45.00	18.08	1.23	14.75	69.14	0.00	393.20	1.95	0.00	34.97	54.22
Black Creek 2	4.55	*37.88*	20.41	1.5	13.61	61.47	0.00	0.00	0.30	0.00	0.00	47.88
Black Creek 3	4.72	33.94	16.51	1.11	14.87	43.13	0.00	552.03	0.14	0.00	24.47	33.58
Black Creek 3	4.22	73.65	18.29	1.07	17.17	13.24	0.00	281.81	0.17	0.00	49.69	10.33
Black Creek 3	4.58	48.39	19.52	1.25	15.62	45.31	17.84	827.79	0.14	0.00	97.92	35.27
La Guette	4.14	67.39	43.07	2.1	20.52	5.98	0.00	284.26	0.30	5.46	37.68	4.72
La Guette	4.35	71.08	31.1	1.83	17.02	10.86	0.00	96.19	3.49	0.00	15.98	9.23
La Guette	3.9	80.00	42.08	1.76	23.9	66.26	0.00	485.88	20.78	11.53	20.72	56.23
LWM Hummock 1	3.93	97.56	53.94	1.08	50.04	59.77	0.00	234.33	2.19	0.00	6.21	46.98
LWM Hummock 2	4.05	95.28	51.03	1.29	39.51	18.51	0.00	158.40	3.34	0.00	0.17	15.15
LWM Hummock 3	4.06	97.35	50.57	1.02	49.63	24.87	214.50	128.87	2.57	0.00	0.15	19.92
LWM Hollow 1	4.08	98.47	54.05	1.03	52.71	53.10	105.57	99.26	1.10	0.00	0.68	41.55
LWM Hollow 2	4.12	95.72	51.96	1.1	47.15	20.25	50.65	77.63	2.36	0.00	0.92	16.28

LWM Hollow 3	3.76	91.76	49.17	0.96	51.33	7.29	2249.68	145.90	3.62	0.00	0.14	6.49
Cavemount	3.63	80.00	49.58	1.36	36.57	6.09	144.26	727.39	0.48	0.00		4.85
Cavemount	5.53	93.55	50.91	1.54	33.1	25.56	56.63	1479.01	0.40	0.00		19.97
Cavemount	5.76	94.59	51.8	1.11	46.79	25.89	79.72	1600.93	0.90	0.00		20.34
Cloncrow	4.71	96.43	48.67	1.29	37.83	5.08	104.60	173.82	0.83	0.00		4.14
Cloncrow	4.09	95.00	48.93	1.58	31.04	12.00	154.99	302.61	0.59	0.00		9.46
Cloncrow	4.10	96.15	46.98	1.81	25.92	14.42	133.52	293.83	0.66	0.00		11.36

Winmarleigh soil profile data

Sample	Profile	soil NO3 mg/Kg	soil NH4 mg/Kg	pH	C%	N%	CN
A1	0-10	32.14	58.72	5	42.04	2.17	19.33
A1	10-20	8.37	47.99	4.83	46.66	1.84	25.30
A1	20-30	8.24	18.72	4.67	49.22	1.71	28.74
A1	30-40	7.43	22.45	4.76	47.74	1.89	25.30
A1	40-60	8.06	20.40	4.52	51.05	1.71	29.83
A2	0-10	148.53	48.80	5.27	43.01	2.07	20.82
A2	10-20	29.38	83.16	5.3	43.92	1.76	24.97
A2	20-30	4.58	8.66	4.81	53.55	1.49	35.83
A2	30-40	2.83	3.21	4.48	52.82	1.11	47.69
A2	40-60	9.80	17.94	4.36	53.20	0.93	56.94
A3	0-10	268.25	12.78	4.84	38.25	1.66	23.04
A3	10-20	5.32	21.48	4.88	48.38	1.29	37.38
A3	20-30	3.34	9.53	4.45	49.85	1.37	36.32
A3	30-40	3.13	5.29	4.15	52.78	1.51	35.02
A3	40-60	14.43	11.45	4.21	52.05	1.24	41.82
A4	0-10	175.14	77.21	4.67			
A4	10-20	5.85	142.47	4.85			
A4	20-30	4.78	15.82	4.6			
A4	30-40	4.79	9.84	4.28			
A4	40-60	7.63	13.85	4.24			
A5	0-10	181.80	59.70	4.8			
A5	10-20	16.52	62.95	4.77			
A5	20-30	2.34	10.18	4.38			
A5	30-40	1.62	7.62	4.15			
A5	40-60	8.51	17.85	4.27			
A6	0-10	134.02	83.23	4.96			
A6	10-20	87.54	113.60	5.07			
A6	20-30	17.32	57.65	5.13			
A6	30-40	13.65	9.28	5.07			
A6	40-60	5.29	10.57	4.73			

Appendix 3 Soil water analysis

Soil water nutrients measured using Ion Chromatography, all units mg/l.

	Chloride	Nitrite	Sulphate	Nitrate	Phosphate	Ammonium
Cave Mount	4.97	0.26	3.56	2.70	0.01	1.78
Cloncrow	4.36	0.20	0.24	0.44	0.02	0.00
La Guette	12.64	0.13	7.34	0.29	0.26	3.36
Black Creek	40.17	0.23	14.18	0.36	0.02	0.26
De Wieden	62.42	0.25	17.08	4.00	1.02	2.22
Winmarleigh	3.10	0.24	2.04	0.41	2.07	1.81

Soil water metals measured using Inductively Coupled Plasma – Optical Emission Spectrometer (ICP-OES), all units mg/l.

	Na	Mg	K	Ca	Mn	Fe	Ni	Al	P	S	Cu	Zn
Cave Mount	4.16	1.02	0.44	7.18	0.15	0.66	0.00	0.02	0.01	2.15	0.00	0.01
Cloncrow	3.09	0.40	0.79	0.42	0.00	0.07	0.00	0.07	0.01	0.42	0.00	0.01
La Guette	7.51	0.53	7.79	2.83	0.04	0.26	0.00	0.06	0.14	3.34	0.00	0.01
Black Creek	20.91	2.05	4.13	11.02	0.24	0.01	0.00	0.00	0.01	6.01	0.00	0.00
De Wieden	31.20	5.41	9.56	15.82	0.07	0.03	0.00	0.00	0.43	6.96	0.00	0.00
Winmarleigh	5.04	3.11	2.19	27.55	0.01	0.13	0.00	0.07	1.10	2.32	0.01	0.02

No soil water was collected at Little Woolden Moss.

We can't directly measure DOC but can estimate using spectrophotometer as Wallage and Holden 2010 if needed?