Interreg Care-Peat

Deliverable T1 D1.4

Draft transnational and integrated research program

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Revision history

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16/07/2019	S. Gogo	Integration of all contributions (D1.1, D1.2, D1.3) and the inputs from the workshop during the kick-off meeting in Manchester (June 2019) to make the first draft of the integrated program
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Table of contents

1. Introduction

Peatlands are assuring many ecosystem services such as provisioning (fibre, fuel and genetic resources through their biodiversity), regulating (flood damping, carbon - C - sequestration) and cultural services (recreation and education). The structure and the functioning of peatland are under threat because of local and global disturbances, jeopardizing the realisation of these services. On a local scale, it is possible to act to restore peatland C sink capacity, biodiversity and hydrology. It is to promote such actions that the CARE-PEAT project was built (INTERREG NWE). Specifically, the CARE-PEAT project aims at showing good management practices that would promote the C sequestration into peat (regulating service), through the implementation of 5 pilot sites.

Depending on the characteristics and the management plan specific to each site, restoration activities will be completed in Irish, British, Dutch, Belgian and French peatlands. On the whole, drain blocking works and/or meander installation were or will be done in each site to decrease the potential release of C through oxic decomposition and promote typical peatland vegetation. In addition, to enhance the capacity of peatland vegetation to restore their C sink capacity, *Sphagnum* mosses will be spread using different techniques in 3 out of 5 pilots. *Sphagnum* mosses are typical peatland vegetation that can retain important amount of water (up 30 times its dry weight), acidify the peatland water, sequester nutrient and produce a recalcitrant litter.

Usually, the success of restoration action in peatland is assessed by biodiversity surveys. This is a good technique to show how the provisioning service is recovered, but it tells nothing about the C sink/source functioning of the ecosystem. As in the CARE-PEAT project, the aim is to promote practices that enhance C storing capacity of peatlands, one must be able to estimate whether the actions undertaken indeed stimulate the C sink capacity of the restored site, or not. Furthermore, to disseminate to a large extent the need to take into account the C sink capacity in management practices among the managers community, it would be pertinent to produce a toolkit to assess the C sink restoration actions. To do so, greenhouse gases (GHG) should be measured using different techniques and a model should be developed to produce a decision support tool (DST). In order to produce comparable data between sites and run a model applicable to all sites, a protocol should be written to obtain a coherent data set within the CARE-PEAT project.

This protocol gives the rationales and the practical guidelines to measure GHG fluxes applicable to all sites, including all the ancillary data required to model building. Three scales of measurement will be done: ground, drone and satellite GHG measurement. To make possible the integration of the data into a model (base of the DST), the data format requirements are also specified.

2. Ground measurements for greenhouse gasses

2.1. What do we measure and why

In theory, to know whether an ecosystem functions as a C sink or source, all the different fluxes of C have to be measured. Ecosystem can exchange C with the atmosphere (gaseous form) and with the hydrosphere (soluble or solid forms). These fluxes are:

- 1) Gross CO_2 input from photosynthesis or Gross Primary Production: **GPP**

- 2) CO_2 output from respiration (autotrophs and heterotrophs) or Ecosystem Respiration: **ER**

- 3) CH_4 flux from the balance between methanogensis and methanotrophy or $\mathbf{F_{CH4}}$

- 4) Volatile organic compounds flux other than CH_4 or $\mathbf{F_{VOC}}$

- 5) Carbon monoxide flux or $\mathbf{F_{CO}}$

- 6) Dissolved inorganic C flux or $\mathbf{F_{DIC}}$

- 7) Dissolved organic C flux or $\mathbf{F_{DOC}}$

- 8) Particulate organic C flux or $\mathbf{F_{POC}}$

The CO_2 balance is called net ecosystem exchange or NEE:

$$NEE = ER - GPP \qquad \text{eq 1}$$

NEE was proposed by scientists working on the atmosphere and they took the atmosphere as reference. This implies that when the ecosystem functions as a C sink, NEE is negative (GPP > ER), and when the ecosystem function as a source, NEE is positive (ER > GPP).

The global C balance is called net ecosystem C balance or NECB (Chapin et al., 2006). This time the reference is the ecosystem. Furthermore, other than GPP all other fluxes in peatlands are export of C and are thus noted negatively:

$$NECB = GPP - RE - F_{CH4} - F_{VOC} - F_{CO} - F_{DIC} - F_{DOC} - F_{POC} \qquad \text{eq. 2}$$

All the terms of the NECB are not quantitatively equivalent. GPP and ER are the two greatest fluxes, followed by F_{CH4}, DIC, DOC and POC (in varying proportion depending on the site). F_{VOC} and F_{CO} are generally considered negligible.

The C fluxes have to be monitored at an adequate frequency and at “hot moment” (e.g. flooding events for DOC and POC) to grasp enough temporal variability to assess NECB. Monitoring the 6 most important fluxes requires the deployment of many instruments, needing important maintenance. Thus, a trade-off has to be found between the resources available and the goals that can be achieved.

The CARE-PEAT project aims at showing good management practices leading to increase C sequestration. There are two main issues that have to be dealt: 1) what do we compare and 2) what do we measure?

1) Ideally, we should compare the C balance before and after restoration works. This implies that C fluxes have to be measured many years before the restoration works to grasp how each system behave depending on climatic variations (dry vs wet years, hot vs cold years). This is not possible because C fluxes are not currently measured in all sites, so we do not have the “before restoration” state of the system.

2) Again, ideally, we should measure all the incoming and outgoing fluxes of C to establish a full C balance. This is not possible as all the required equipment is not deployed in each site and the task force required for such a monitoring is not available.

These two issues can be resolved with these two propositions:

1) Instead of comparing C fluxes before and after restoration, we should compare, if it is possible, C fluxes between an area of the site that will not be restored: **CONTROL** area, to an area of the site that will be restored: **RESTORED** area. In such a way, during the time frame of the CARE-PEAT project, we may be able to assess the effect of restoration activities on C fluxes. As vegetation can vary within a CONROL and a RESTORED area (e.g. zones with *Sphagnum* and zones of bare peat within the RESTORED plot) a **nested design** can be applied with sub-areas within each area.
2) Instead of measuring all the C fluxes, we should focus on NEE, ER (both CO_2) and F_{CH4}, because: a) they are 3 of the most important fluxes in terms of quantity and b) they are all greenhouse gases (GHG). Thus, assessing the C balance of the GHG will give a good proxy of the total C budget and valuable informations on the effect of restoration activities on climate change.

2.2. GHG fluxes measurement methods

There are different techniques to measure GHG fluxes. The three most used techniques are: 1) eddy covariance, 2) gradient method, 3) chamber method.

The eddy covariance technique consists in measuring at the same location the air temperature, atmospheric pressure, water vapour, CO_2 and CH_4 concentrations and the wind speed and direction in 3D. Such measurements integrate fluxes over a large area (at least about 1000 m^2). When there is no eddies, the vertical wind component is null and no exchanges can be seen between the ecosystem and the atmosphere with this technique. When eddies are present, the vertical component of the wind is not null. The vertical wind speed informs on the flow rate and the vertical wind direction informs on the direction of the flow between the ecosystem and the atmosphere. When these informations are known, the quotient of the wind speed with, for example, the CO_2 concentration gives a flux. To be able to see small eddies (high speed) the variables have to be monitored at a very high frequency (10 to 20 measurements per second). Then fluxes are calculated and averaged over 30 minutes, for example. Ideally an eddy covariance station should be placed in every plot.

The gradient method consists in measuring the GHG concentration in soil at different depths by burying CO_2 sensors for example. Then, by using physical laws (e.g. Fick law), a flux can be calculated. However, measurements are very local and a spatial analysis requires the installation of many sensors profile. In addition, the method works well for CO_2 because sensors can be placed directly in the soil and the properties of this gas allow the application of relatively simple laws. However, no CH_4 sensors can be buried in the soil and the models to derive a CH_4 fluxes are more complicated than for the CO_2. Finally, the input of CO_2 cannot be assessed with this method.

The most common method is the closed chamber method, which consists in inserting a collar in the peat and then place a chamber on the collars in a way that the system is airtight (no exchange of gas with the exterior). The gas within the chamber is analysed either by a sensor placed in the chamber or by a sensor outside the chamber equipped with a pump that draw air from and put it back to the chamber. Many collars can be installed within a specific plot and the fluxes can be measured one after the other with the same chamber-sensor. Furthermore, automatic chamber are now available on the market that allow more frequent measurement than when the chamber are used manually. Thus, special variation can be easily assessed, with a relatively low cost and easy maintenance.

In the CARE-PEAT project, we want to know the amount of CO_2 absorbed by the peatland. Furthermore, different plots will be studied, that may be composed of different vegetation, so we need a good spatial integration. Thus the gradient method is not appropriate. The academic teams involved in the project are already equipped with chambers, whether with sensors inserted in the chamber or with outside analyser with a pump system. In addition, since the Care Peat project aims to demonstrate carbon reductions, it appears that pragmatically, the chamber method is the most appropriate technique to be used in the CARE-PEAT project.

2.3. From the flux measurement to the GHG budget

The aim is to assess the GHG budget in different plots using the in situ measured fluxes and controlling variables (Fig. 1 a). Whatever the technique used, the data sets need to be gap-filled. This is usually done by establishing relationships between the low frequency measured GHG fluxes and controlling factors, based on models (Fig. 1 b). The controlling variables are measured at a much higher frequency than fluxes and with much less data loss (Fig. 1 c). These data are injected in the models to calculate high frequency GHG fluxes time series (Fig. 1 d). Finally, the flux time series is integrated over a year to obtain the yearly GHG budget (Fig. 1 e).

The most common controlling factors used in such statistical models are abiotic and/or biotic variables such as: air temperature, soil temperature, water table depth, soil water content, photosynthetically active radiation or photosynthetic photon flux density (PPFD), leaf area index, green area index, vegetation index (based on percentage cover). Any biological activity will increase with temperature. Furthermore, the water content will determine the metabolic pathways (aerobic versus anaerobic), which rate proceeds at different rates at a constant temperature. Photosynthetic activity varies with the amount of light available and the photosynthetic rate can vary between species and with biomass.

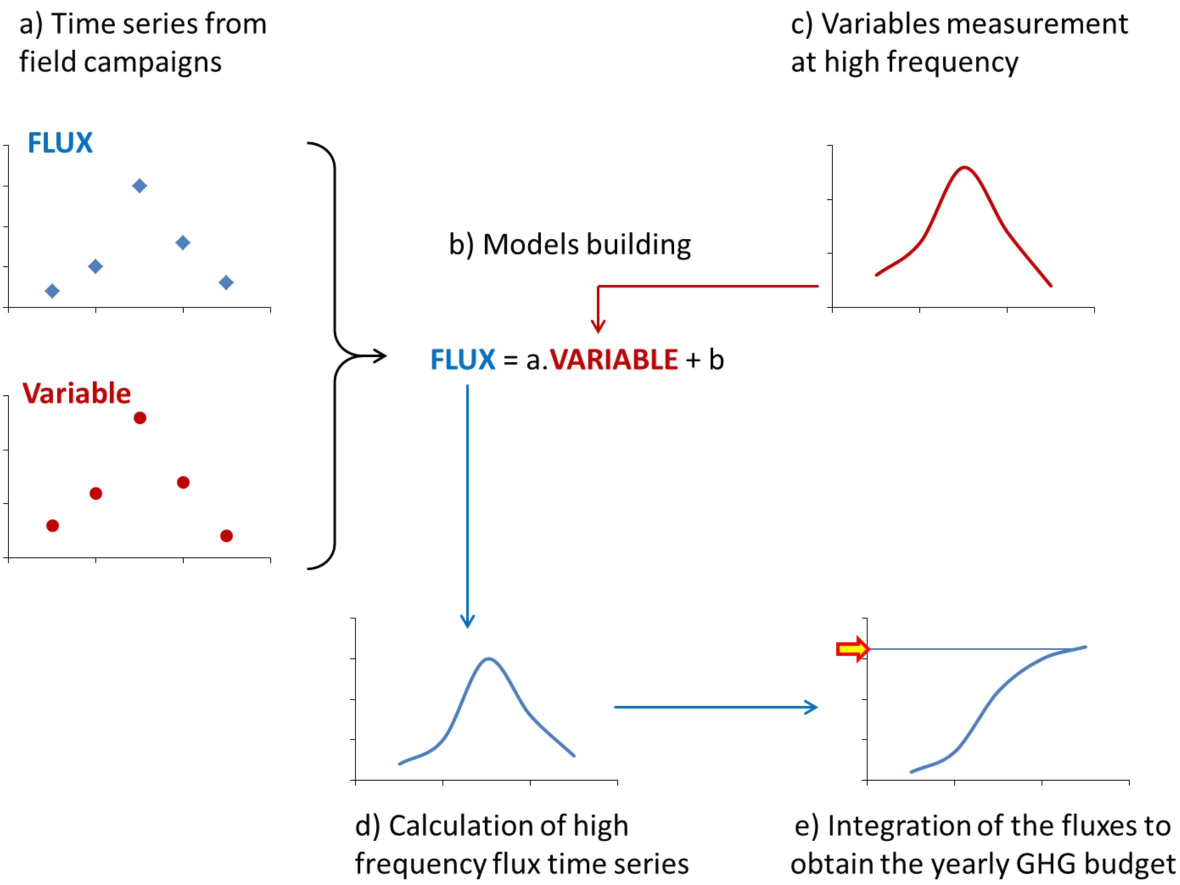

Figure 1. Schematic view of the GHG budget calculation from the flux and the controlling factors measurements (in blue: fluxes, in red: controlling factors; dots: punctual measurement, lines: complete time series).

2.4. Data acquisition

The below protocol present the minimal data set that can be obtain in the worst possible case: a single person using one manual chamber with equipment able to measure CO_2 and CH_4 at the same time (e g. Los Gatos Research analyser). Any situation with more fluxes is of course encouraged.

Nested design

A trade-off has to be found between 1) having many data on few vegetation types, which will allow a good modelling exercise, but a poor representation of the field variability, and 2) few data on many different vegetation types, which will give account of the vegetation variability, but with too few data to have robust models for each vegetation type. The CARE PEAT project will adopt a nested design, where fluxes can be measured in the two dominant representative vegetation types in each area (2 sub-areas within each area, Fig. 2).

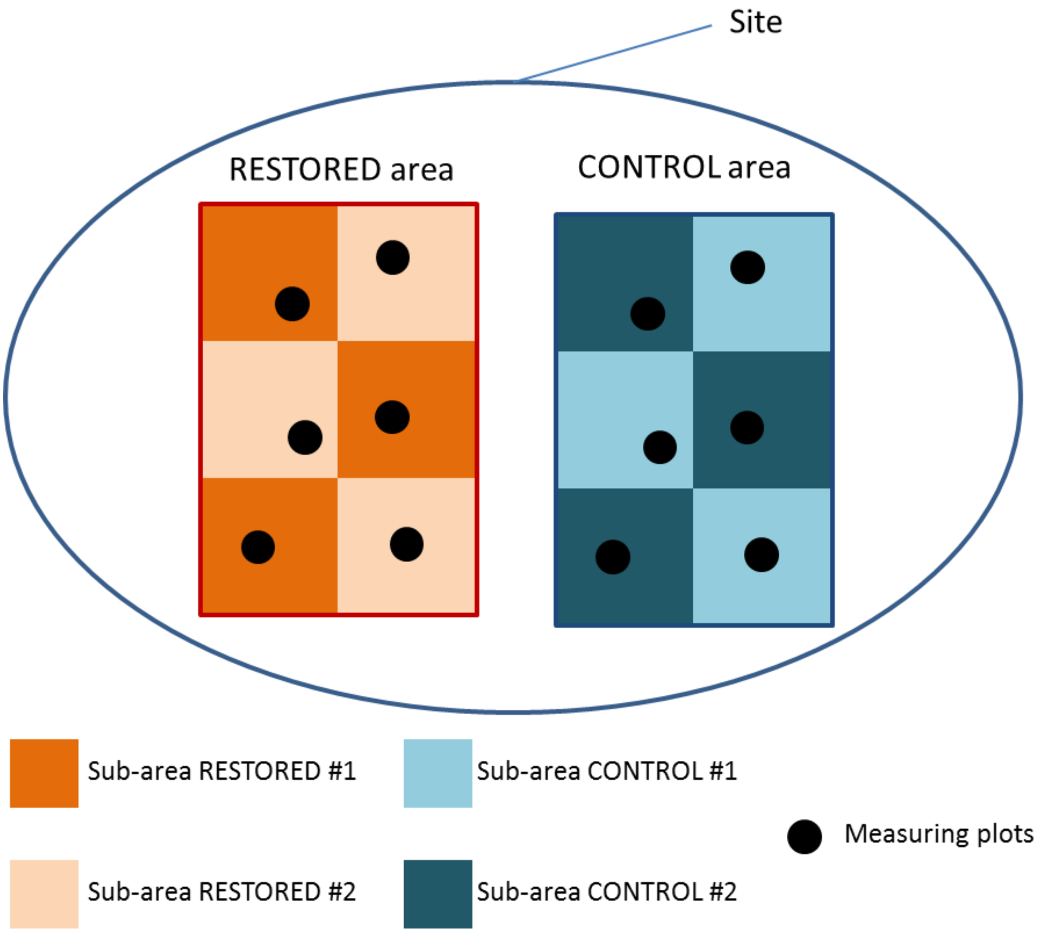

Figure 2. Schematic representation of the nested design adopted in the CARE-PEAT project.

GHG fluxes variables and materials

3 variables will be monitored:

- Net Ecosystem Exchange or NEE,
- Ecosystem Respiration or ER,
- CH_4 flux from the balance between methanogenesis and methanotrophy or F_{CH4}.

NEE is measured with a transparent chamber to allow solar radiation to activate photosynthesis (Fig. 3 a).

In each plot, NEE will be measured in saturated radiation condition for the day of measurement with no nets on it (Fig 3 a) and with nets of different meshes (1 coarse, 1 intermediate, 1 fine). ER will be measured with an opaque chamber or by using a cover that is placed on the transparent chamber (Fig. 3 b). This will make data sets composed of 5 different fluxes. As F_{CH4}. Is measured at the same time as the CO_2 fluxes, 5 fluxes of CH_4 will be obtained.

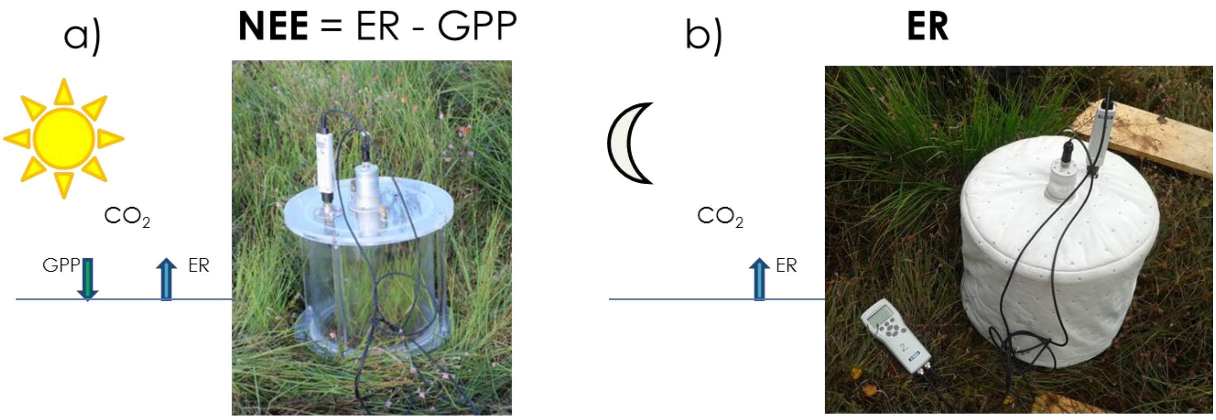

Fig. 3. Example of a transparent chamber to measure NEE (a) that can be covered to measure ER (b).

With such a design, we can assess the response of the system to varying light (e.g. Fig. 4). The 5 fluxes will be used to calculate the different parameters of the model for 1 specific plot.

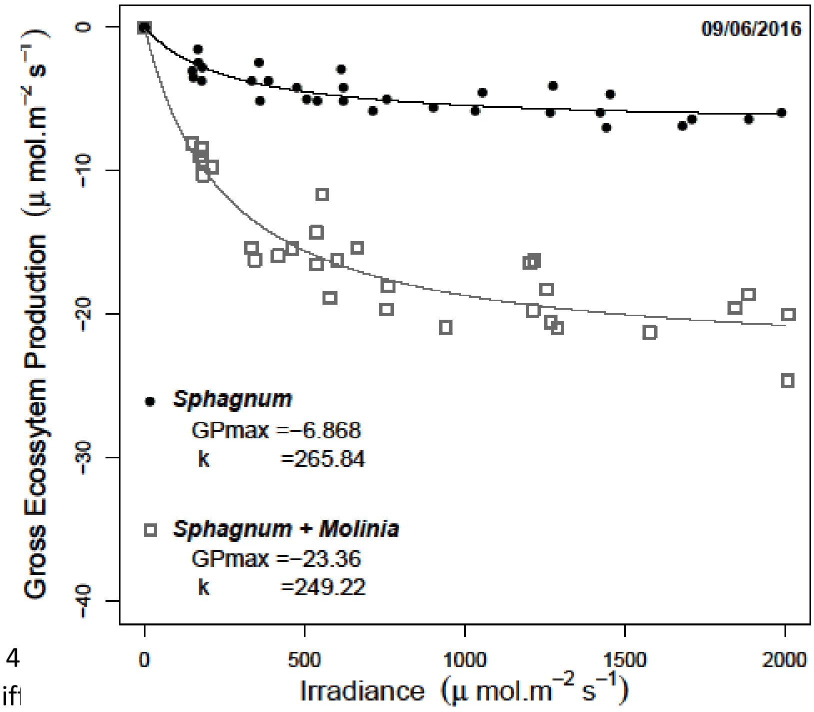

Figure 4 … nsity simulated by nets with dif … y et al., in prep). From this dat

The chamber can be either manual or automatic. Automatic chamber allow the acquisition of a large number of fluxes. In any case, the chamber is fitted on a collar that is inserted into the soil to assure airtighness of the system. Measurements can be done with equipment available on the market or self-made, with different geometry. In the CARE-PEAT project, a common type of chamber will not be recommended because each site may require different type of chamber depending on the height of the vegetation. To assess how the chamber type affects the measurement, at least one inter-comparison campaign will be done during the course of the project.

Manual chamber CO_2 and CH_4 fluxes will be measured with Los Gatos Research analysers. Vaisala probes mounted on manual or automatic chamber or Licor automatic chamber will be used for CO_2 alone when possible.

Ancillary variables and materials

The most important forcing variables are:
- a) Air and soil temperatures => determine the rate of biological processes,
- b) Light intensity => determine the amount of light available for photosynthesis,
- c) Soil water content => determine 1) the amount of water available for biological processes, 2) the metabolic pathways as it affects the amount of available oxygen,
- d) Photosynthetically active biomass => determine the maximum rate of photosynthesis,

Some variables are relatively easy to monitor and most the national weather station do measure these variables. Other are much more complicated to measure and proxies are most of the time used to give account of the effect of these variables.

In the CARE-PEAT project we propose the relative high frequency monitoring of the following minimum data set of forcing variables:
- Air temperature (if possible *in situ*, but if not from the closest national weather station),
- Soil temperature (*in situ*, no alternatives) to be measured at approximately 10cm depth. If possible one plot should have soil temperatures at a minimum of three depths (10, 20, 30 cm).
- Photosynthetic Photon Flux Density (PPFD) directly or calculated from total radiation (if possible *in situ*, but if not from the closest national weather station),
- Automatic piezometer (at least 1 per site) and 1 manual piezometer per measuring plot (associated to a collar) to measure water table depth as an integrated value for soil water content: the highest the level, the lower the oxygen availability (*in situ*, no alternatives),
- Vegetation index calculated from the plant species percentage cover => the highest the percentage, the highest the biomass, interpolation will be used to adjust the data to the same frequency as the other variables (*in situ*, no alternatives).

GHG measurement location and replication

Area. It is proposed that each site has at least 2 areas: 1) **CONTROL** area not affected by the restoration activities that is to be tested, and 2) **RESTORED** area initially similar to the CONTROL area, which has been restored.

Sub-area. To take into account the variability of the vegetation, 2 sub-areas can be chosen in each area. Typically, when *Sphagnum* will be added, a first sub-area will be composed of *Sphagnum*, but sub-areas without *Sphagnum* (bare peat) may remain. In the CONTROL plot, the 2 main vegetation types can be chosen and they will be site specific. Each sub-area will have to be defined by the pilot manager.

Measurement plots. In every sub-area, 1 collar will be installed in 3 replicate plots spread over the whole studied area. It is preferable that every year the collar location will be changed to avoid any bias caused by the collar.

Plot code. Each plot of the CARE PEAT project will have a code associated to GPS location details. The code will be as follow (example for the La Guette pilot):
Country_Site_Year_Area name_Area number_sub-area number_plot number
FR_lgt_2020_C_1_1_1

The area number allows different study area within 1 site. This is an example for the Little Wooden Moss:

UK_lwm_2020_C_1_1_1 (control area)

UK_lwm_2020_R_1_1_1 (*Eriophorum* + *Sphagnum*)

UK_lwm_2020_R_2_1_1 (Mixed grass + *Sphagnum*)

UK_lwm_2020_R_3_1_1 (Bog in a box)

The country code will be: BE, FR, IE, NL, UK. Each pilot manager will give a 3 letter code (lower case) for their pilot. Then, each flux will be associated to a code. This is made to facilitate the data treatment and integration into a database.

Measurement conditions: flux and field campaign

For the estimation of 1 flux, concentration of GHG within the chamber should be done at the minimum frequency of 1 measurement every 5 seconds. The time length of the measurement that can be used to calculate a flux should be as short as possible, between 1 to 2 min, to prevent heating within the chamber. 1 min is often required to stabilize the system so the total length of a measurement should be between 2 to 3 min. One measurement has to be done with cover (ER), without cover (NEE in light saturated condition) and with the 3 different nets (NEE with varying light intensity. Measurements have to be done when light is not limiting (e.g. > 1000 µmol of photon m^{-2} s^{-1}) to be able to assess the maximum GPP. The measurement should be carried out at constant PPFD (± 10%), and the chamber has to be ventilated between each measurement.

At the minimum, it is expected that 1 set of fluxes (with different radiation intensity, see the following section) should be measured in each replicate plot in 1 campaign. A minimum of 12 campaigns pear year is required to catch the whole range of air temperature and water table depth. These 12 campaigns can be spread over the year or can be combined to avoid too much field trip (6 field trips combining 2 campaigns at each time or 4 field trips combining 3 campaigns). More campaigns can be undertaken during the growing season when the largest range of all the forcing variables is expected.

Thus, for 1 person with 1 chamber and 1 sensor measuring both CO_2 and CH_4, a minimum total of 24 CO_2 light response curves and CH_4 fluxes in each vegetation type (sub-areas) will be measured over the 2 years of measurement of the CARE-PEAT project.

In each pilot data-set, the time-zone will have to be explicitly mentioned to avoid any errors based on timestamp.

2.5. Data formatting and information system

A file format to compile all the data will be used by all partners. In this way the data from any site will be processed in the same way and more easily integrated into the information system. Such a file is available at the following url:

{to be done}

2.6. Data processing/modelling

For CO_2, the models parametrisation will proceed in three steps. The models are empirical and thus they are specific to each site. The equation proposed here are from Bortoluzzi et al. (2006), but other equation can tested and compared (e.g. with less parameters), without changing the logic behind the parametrisation described below.

The first step consists in modelling ER. It can be modeled with the following equation:

$$ER = \left(a \times \frac{WT}{WTref} + c\right) \times \left(\frac{Ta - Tmin}{Tref - Tmin}\right)^{b} \qquad \text{eq. 3}$$

ER is ecosystem respiration, a, b and c are empirical parameters (b is the temperature sensitivity parameter), WT is the water table depth, WTref is a reference water table depth (e.g. a value just below the lowest water table depth recorded), Ta is the air temperature, Tmin is the minimum temperature at which a respiration occurred, Tref is a reference air temperature. As Ta and WT will be measured at a high frequency, a modelled ER can be calculated and the modelled values can be fitted to the measured values by adjusting the 3 parameters a, b and c. *The results of this first modelisation step will be : a value for a, b and c and statistics describing how well the model fits to the data.*

The second step will be the calculation of the GPP light-response curve parameters for each set of CO_2 fluxes. The average air temperature of all the NEE measurements (with nets and full light) will be calculated and ER will be calculated with this temperature and eq. 3. The eq. 4 will be fitted to measured data at each plot:

$$GPP = NEE - ER = \left(\frac{k \times PPFDin \times GPPmax}{GPPmax + k \times PPFDin}\right) \qquad \text{eq. 4}$$

PPFD and NEE are measured, ER is known, GPPmax and k will be adjusted to fit the modelled GPP to the measured ones. The average of the model parameter (2 measured light-response curve measured in 1 hour) will be calculated to obtain a set of parameter the hour of measurement. *The results of the second modelisation step will be: a value for GPPmax and k, and statistics describing how well the model fits to the data.*

The third step will be the modelling of the parameters GPPmax and k. GPPmax can modelled as follow:

$$GPPmax = d \times VI \times e^{-\left(\frac{Ta - f}{g}\right)} \qquad \text{eq. 5}$$

VI is a vegetation index, d (gross photosynthesis at saturation PPFD at optimum temperature and vegetation index), f is the optimum temperature and g is a temperature sensitivity factor[1]. The eq. 5 will be adjusted to the calculated GPPmax from the previous step. The same process will be done with k, but the equation remains to be found. If no trend of k with time is found, the average k will be used. *The results of the third modelisation step will be: a value for d, f, g, average k (minimum) and statistics describing how well the model fits to the data.*

The fourth step of the modelisation will be the calculation of a high frequency NEE time series. With high frequency time series of PPFD, air temperature, water table depth and vegetation index, and eq. 3, eq. 5 and average k values, a high frequency time serie of NEE can be calculated:

$$NEE = \left(\frac{k \times PPFDin \times GPPmax}{GPPmax + k \times PPFDin}\right) - ER \qquad \text{eq. 6}$$

Then, by integrating the NEE over a year, the CO_2 annual budget can be estimated.

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[1] No parameters are identified with an « e » as it stands for exponential

As CO_2 and CH_4 will be measured at the same time, the effect of light on F_{CH4} can be assessed. If no relationship is found, then the same type of equation as eq. 3 can be used to model F_{CH4}.

The annual CO_2 budget and cumulated F_{CH4} are added to obtain the annual GHG budget.

2.7. Data promotion

To ensure the visibility, transparency and durability of the CARE-PEAT results, the data-sets from the measurements undertaken during the project will be published in a data paper (e.g. Pangeae), along with scientific articles that will be written to address the specific issues that the CARE-PEAT project aims to tackle.

2.8. Specificities of the Weerribben – Wieden National Park pilot

In the Dutch pilot, the restoration action consists in rewetting a current "dry" site by cutting the trees and digging superficial peat (relative increase of the water table) and brings these materials to a second site. This second site is a lake and the peat will be deposited in the foreshore to form a peatland by articficial terrestrialisation. At the end the forest site will become a wetland with peat below the water surface and with floating mats, and the lake site will become a wetland with the water level just at the top of the peat surface (Fig. 5).

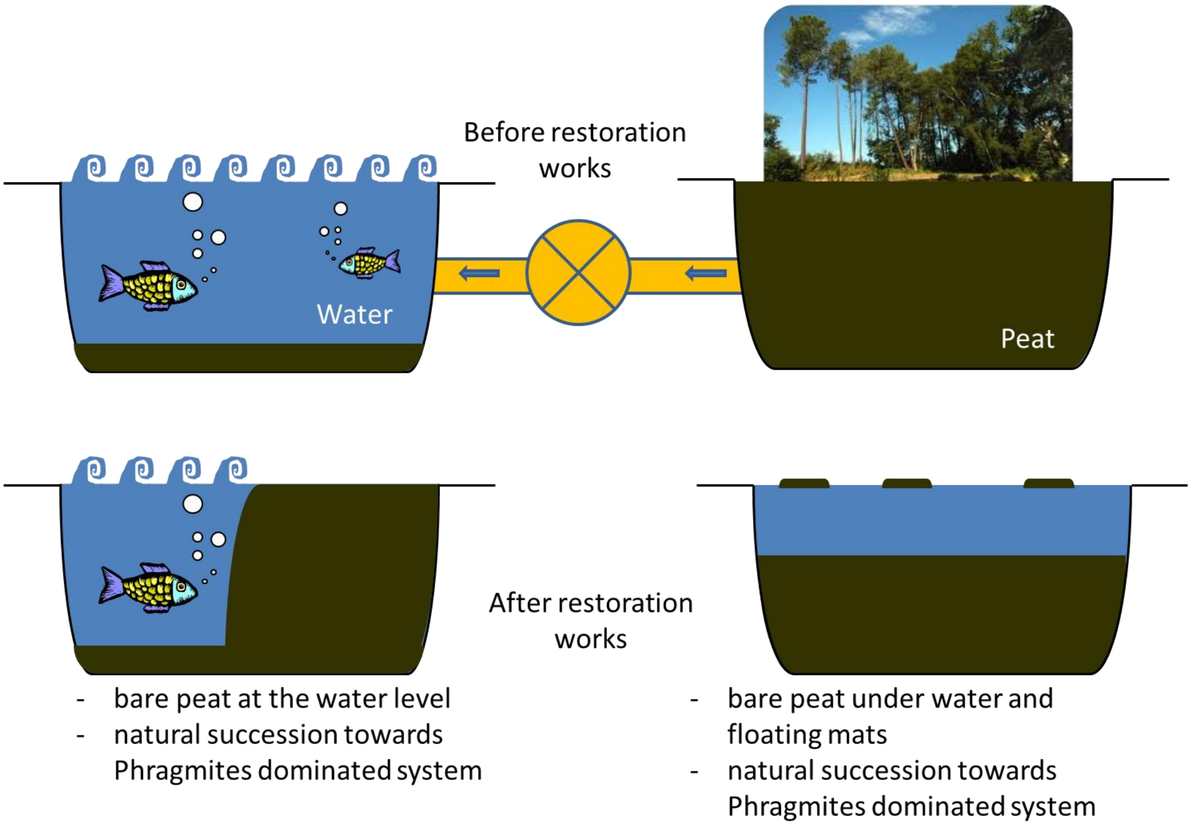


Figure 5. Schematic representation of the states of the ecosystems before and after restoration works undertaken at the Weerribben-Wieden National park site.

Because it is not possible to apply the method presented here (chamber method and nested design) when trees are present, an alternative method will be used:

1) Before the restoration works:
    a. the ecosystem C stock will be estimated by assessing the tree height and sampling peat cores to the mineral layers that will be analysed in the laboratory
    b. fluxes can be measured to assess the soil respiration
    c. fluxes can be measured on the water surface of the lake
2) During the restoration work:
    a. the amount of organic material brought from the peatland site to the lake should be estimated
3) After the restoration works
    a. fluxes measurements on the water surface of the paludified site (former treed area)
    b. fluxes measurements on the water surface of the terrestrialised site (former lake forehosre)
    c. peat cores will be taken just after the restoration works and every 6 months thereafter to assess the evolution of soil C stock.

Flux measurements will be done during the day at different time of the year to assess the effect of season temperature variations of the fluxes at the water-atmosphere interface. Some night fluxes will also be measured.

2.9. Site specific informations/recommendation

Belgian pilot: Vallei van de Zwarte Beek, 250ha

The restoration actions will consist in hydrological restoration and vegetation cutting to open the ecosystem. The hydrological restoration may take place on the whole site, but some areas in the pilot are isolated and will not be affected by raised water levels.

Suggestions for ground GHG measurements: one of these isolated areas can be used as CONTROL area. Such area could be an open area containing Phalaris arundinacea and Juncus effuses. A nearby area affected by the restoration can be used as RESTORED area. The choice of these areas will be done with the pilot managers and the teams in charge of the GHG measurements. Peat cores can be taken in different other parts to assess the C stock variations.

Ancillary data may be available from a weather station located 20 km from the site (to check if data are available).

The fluxes will be measured in different vegetation of the CONTROL and RESTORED areas (Figure 6).

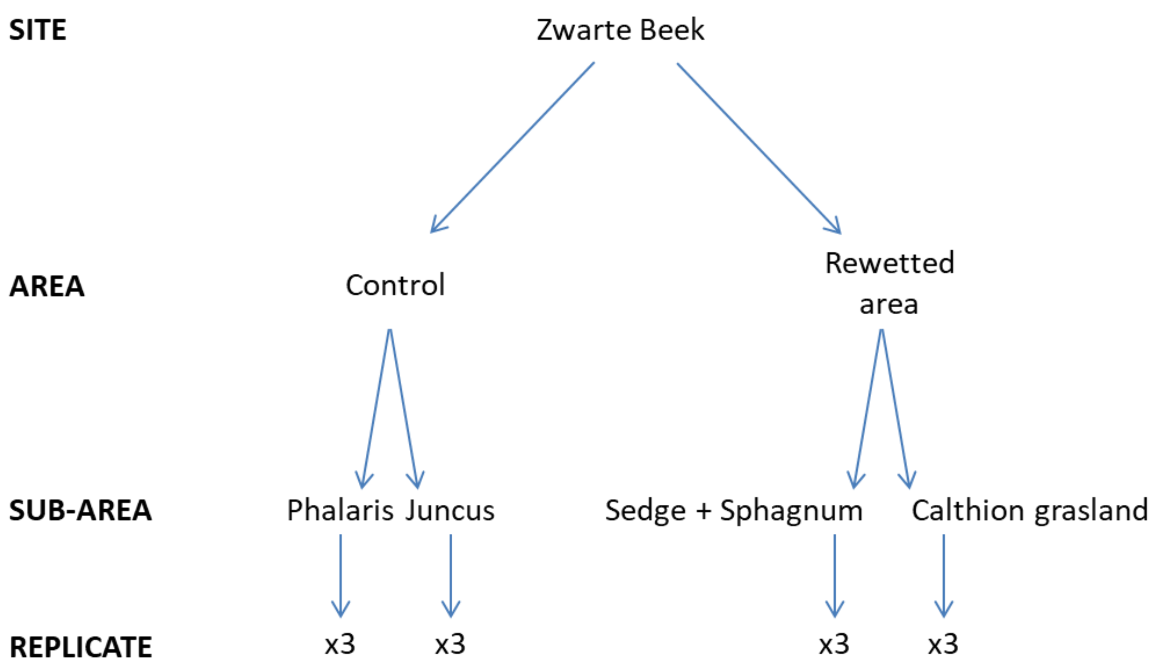


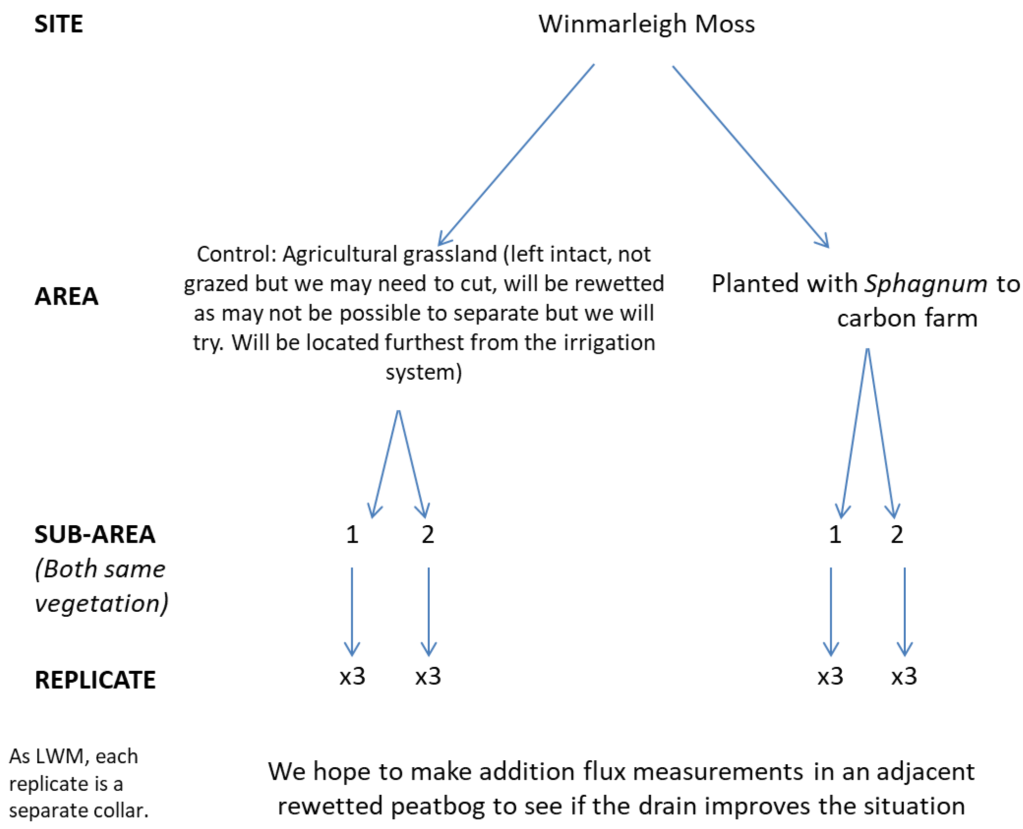
Figure 6. Schematic plan of sampling at the Belgian pilot

British pilots: Winmarleigh Moss (89 ha) and Little Woolden Moss (107 ha)

Winmarleigh Moss: this site contains a Sphagnum farm (at Birch House Farm). The farmland is 20.6 ha and the Sphagnum farm will be on 4 ha of this. Removal of the top soil, bunding, ditch blocking, installation of water control pipes, surface preparation, installation of solar panel and irrigation pumps, sphagnum planting. Monitoring of the main restoration site, Winmarleigh Moss, may be carried out in order to assess the benefit from raising the water table/blocking the drains on the buffer farm land.

A weather station may be installed to monitor in situ ancillary data.

The fluxes will be measured in different vegetation of the CONTROL and RESTORED areas (Figure 7).



As LWM, each replicate is a separate collar.

We hope to make addition flux measurements in an adjacent rewetted peatbog to see if the drain improves the situation

Figure 7. Schematic plan of sampling at Winmarleigh Moss, UK pilot

Little Woolden Moss

The overall site is 107 ha but the pilot area will be 2 ha where we are doing the species mix planting – we can establish some plots including controls/what would be done normally to see if we can positively influence.

A weather station is already installed to monitor in situ ancillary data.

The fluxes will be measured in different vegetation of the CONTROL and RESTORED areas (Figure 8).

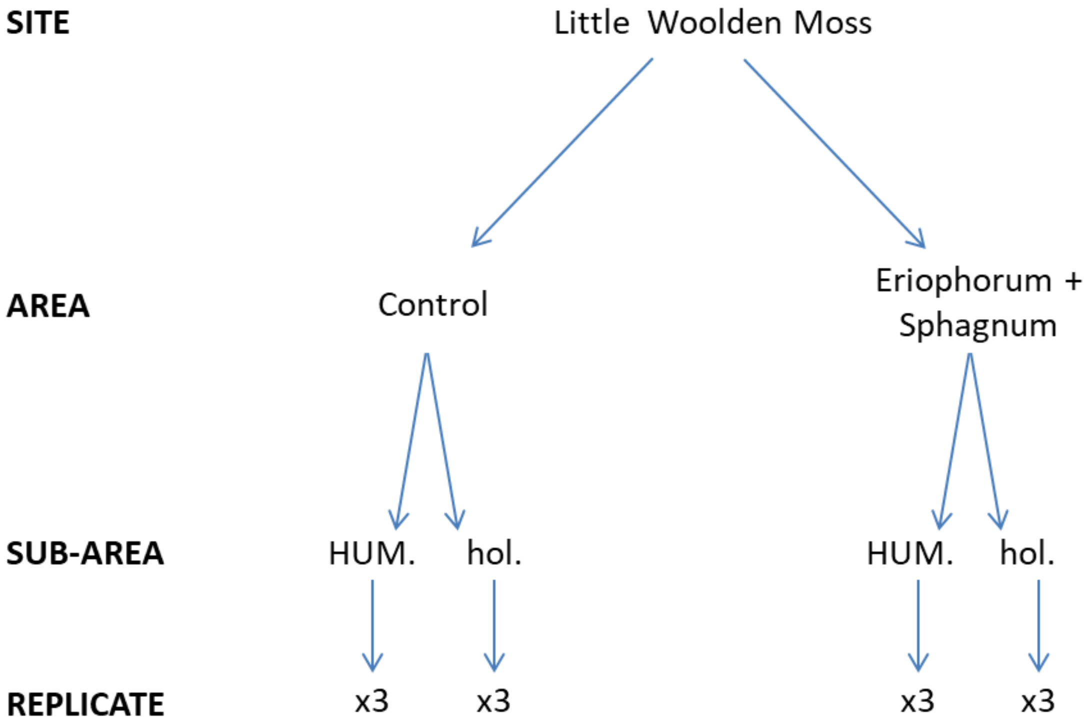


Figure 8. Schematic plan of sampling at Little Woolden Moss, UK pilot

Dutch pilot: Weerribben – Wieden National Park (10000 ha)

Peat pits will be dug, in which there will be more space for growing water plants. This should stimulate the process of terrestrialization. These plants sequestrate carbon and in the pits new peat-layers can grow and retain carbon. The peat that comes from the pits will be used to raise one of the foreshores. So the carbon of the excavated peat is prevented from oxidation and will stay in the submerged peat on the foreshore. By raising the foreshore, more water plants will grow on the foreshore due to better light conditions in the growing place and even more carbon will be stored in the waters of the foreshore. On the whole, 9.5 ha will be restored and CONTROL area will be available. The RESTORED area will consists in excavated area.

There is no in situ weather station but there is a Royal Dutch Meteorological Survey station situated at about 10 km from the site, measuring precipitation, temperature, radiation, wind speed, air humidity, cloudiness.

French pilot: La Guette peatland (25 ha)

In the French pilot, two set of restored and control areas will be design. Only the wettest set of area (the two on the left in the map below) will be monitored for GHG fluxes. However, peat core will be taken in each set of area regularly to assess the C stock changes.

In situ ancillary data are available (weather station and automatic piezometers).

The fluxes will be measured in different vegetation of the CONTROL and RESTORED areas (Figure 9).

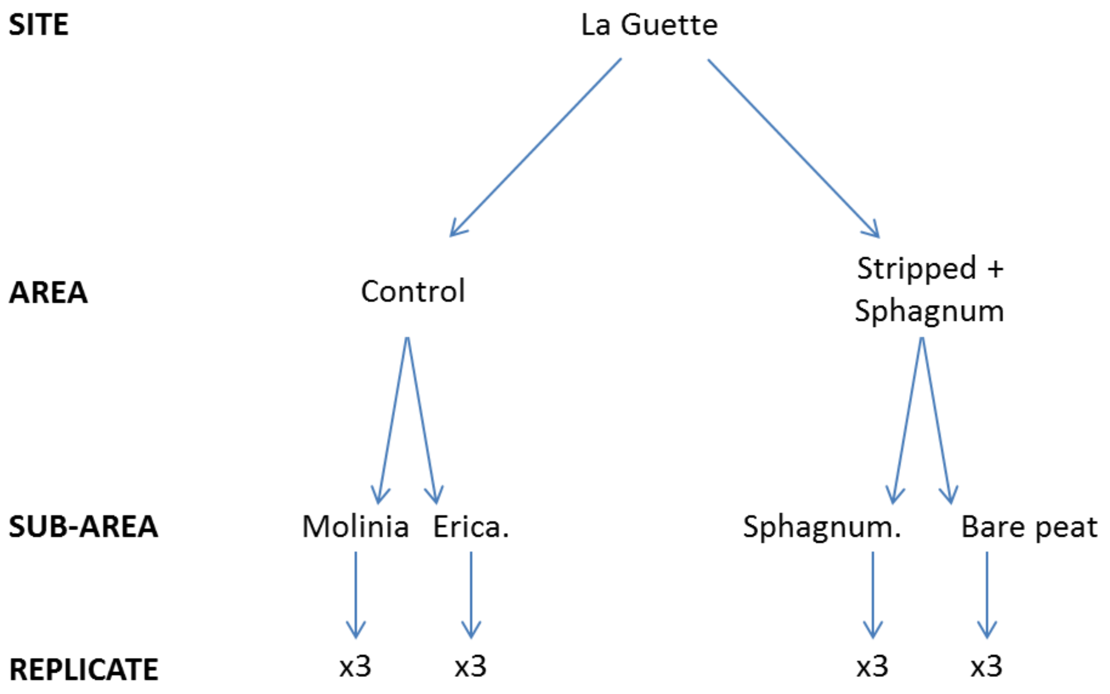


Figure 9. Schematic plan of sampling at La Guette peatland, UK pilot

Irish pilot: Cloncrow bog (28ha), Cavemount bog (218 ha).

Cloncrow bog: the restoration will consist in drain blocking and Sphagnum transfer. Choosing to keep an area with drains as a control will not be effective. But we can contrast the *Sphagnum* transfer area to a non-transfer area(s). A total of 24 ha will be restored with addition of *Sphagnum* (RESTORED), leaving 4 ha where a CONTROL area with no *Sphagnum* addition can be chosen.

Ancillary data may be available as a weather station may be installed in situ. In any case a weather station is situated 15 km away from the site.

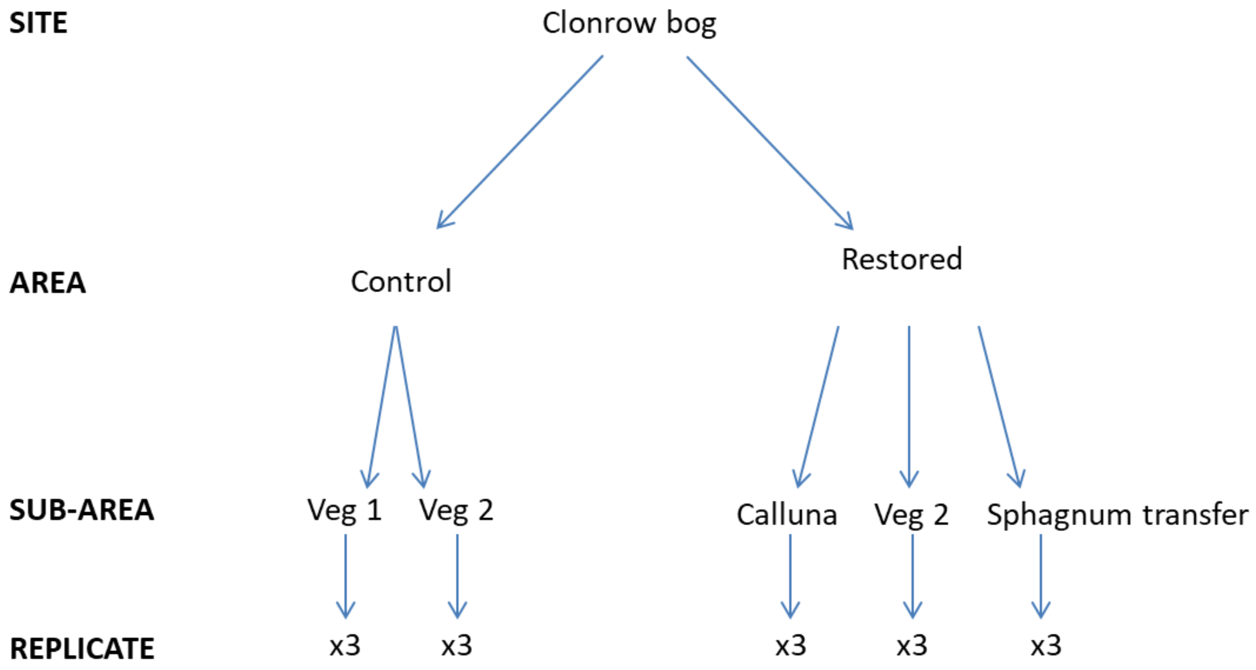
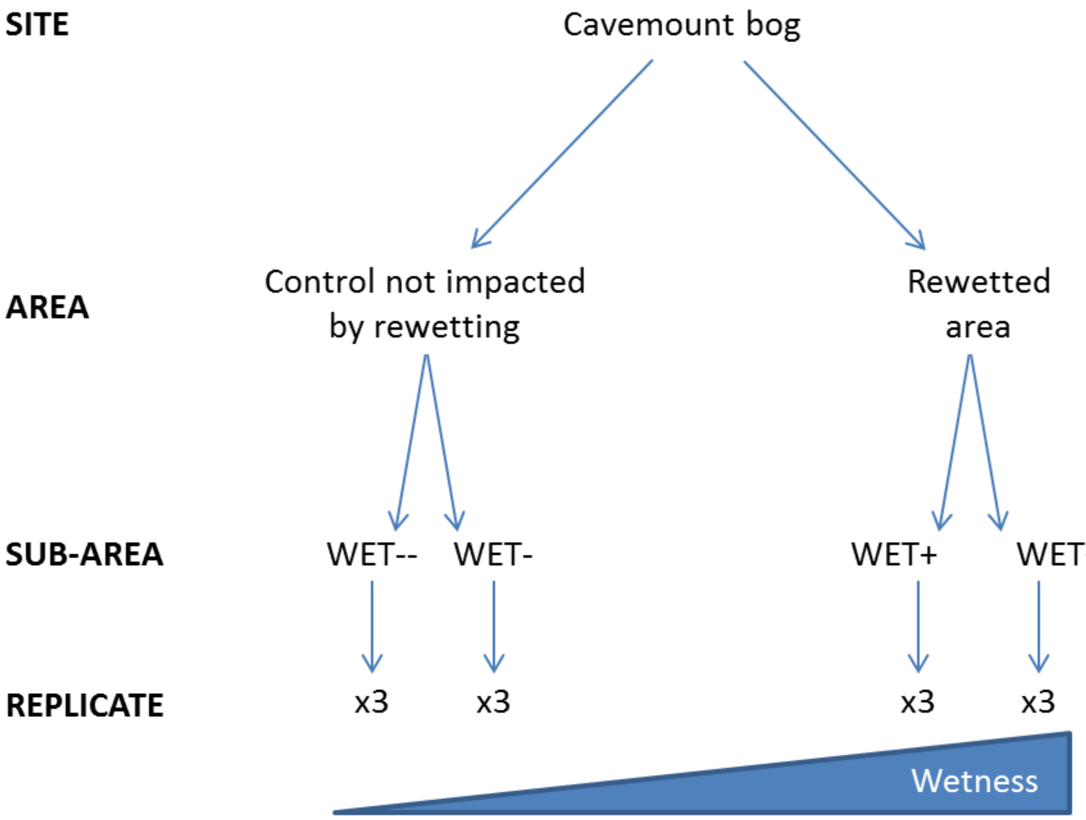


Figure 10. Schematic plan of sampling at Cloncrow bog, Irish pilot

Cavemount bog: this is a very large peatland, where no works are planned. Thus, the NUIG team will likely monitor a section of it for groundwater and soil temp and make GHG measures.

Ancillary data may be available via Wunderground and a weather station of NUIG will be instaleld



Rewetting of the site, no restoration works.
Monitoring along a wetness gradient

QUESTION/REMARKS:

Please check, correct and precise the sampling plan for both sites

3. Drone measurement

3.1. Protocols for UAV multispectral measurements and data treatment

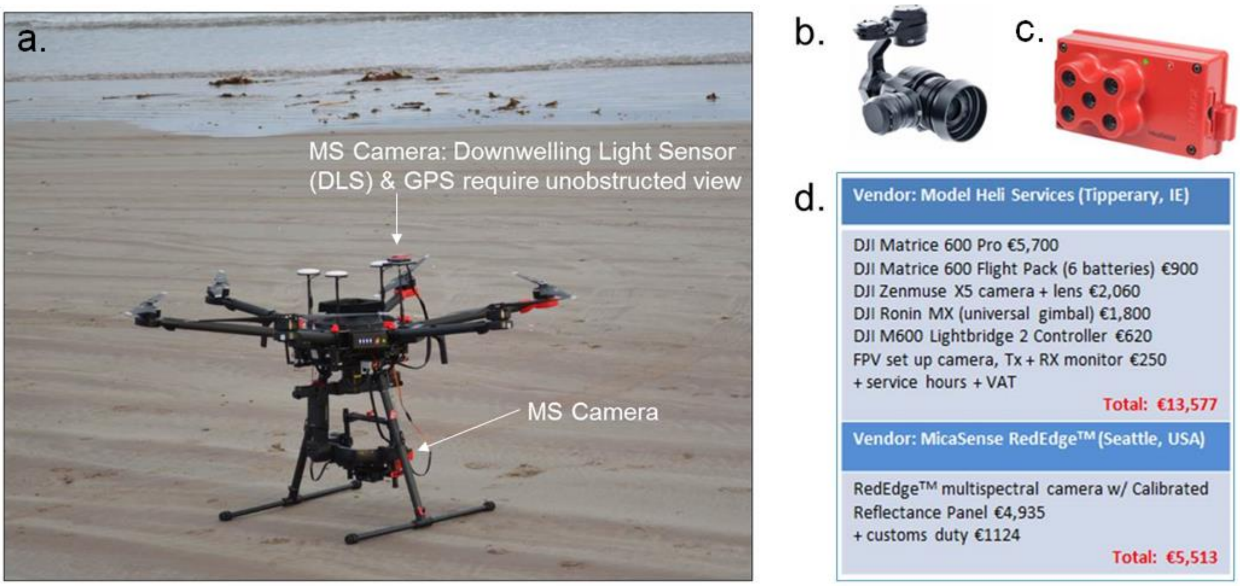
In the Care Peat project we will utilize unmanned aerial vehicles (UAVs) to provide high quality orthographic imagery of each pilot and an assessment of vegetation cover and reflectance using state-of-the-art technologies. Specific outputs of the project are to produce two sets of imagery during the lifetime of the project, one before works have started (2019) and a second survey at the end of the project. Surveys will allow for creation of digital elevation models of each pilot while a multispectral camera will identify and monitor vegetation change and health. The latter will be important to allow us to scale-up our carbon measures to larger areas.

3.2. Required Infrastructural elements for the Care Peat project.

1) Drone specs and capabilities: UAV aircraft must be able to support the weight of the camera and any additional payload required to support the operation. It should have enough power to fly an entire mission with the full payload, but multiple flight missions are also common (where batteries are exchanged). Both fixed-wing and multirotor options work well for this type of data collection. Another factor to consider is how easy it is to integrate the camera onto the aircraft (see below).

   Additional Payloads: In addition to the standard high resolution photogrammatic setup, this project will carry an additional payload via multispectral camera.

2) Multispectral Camera: This mapping platform requires high levels of expertise to modify to carry the multispectral sensor. For example, a DJI Matrice 600 Pro requires building a custom plate to carry a Micasense RedEdge^{TM}-3 camera connected to a universal type gimbal. With the GPS receiver and the Downwelling Light Sensor (DLS) (both included in the kit), the whole system weighs c.170 grams. The camera does not have an internal power source and thus requires a platform to (i) connect to the camera to maintain sensor power and (ii) build a platform system on top of the UAV to attach the DLS and GPS antenna so they are unobstructed (Figs. 5 and 6).



Vendor: Model Heli Services (Tipperary, IE)

DJI Matrice 600 Pro €5,700
DJI Matrice 600 Flight Pack (6 batteries) €900
DJI Zenmuse X5 camera + lens €2,060
DJI Ronin MX (universal gimbal) €1,800
DJI M600 Lightbridge 2 Controller €620
FPV set up camera, Tx + RX monitor €250
+ service hours + VAT
Total: €13,577

Vendor: MicaSense RedEdge™ (Seattle, USA)

RedEdge™ multispectral camera w/ Calibrated Reflectance Panel €4,935
+ customs duty €1124
Total: €5,513

Figure 5. a) DJI Matrice 600 Pro + MicaSense RedEdge-3 camera with DLS & GPS; b) X5 Zenmuse RGB camera; c) MicaSense RedEdge^{TM} multispectral camera (+DLS & GPS); d) overview of costs.

MicaSense RedEdge^{TM}-3 I camera with 5 discrete bands: R, G, B, NIR, Red Edge. (requires unobstructed view - downward)

Camera Downwelling Light Sensor (DLS) (requires unobstructed view - upward)

Camera GPS (requires unobstructed view - upward)

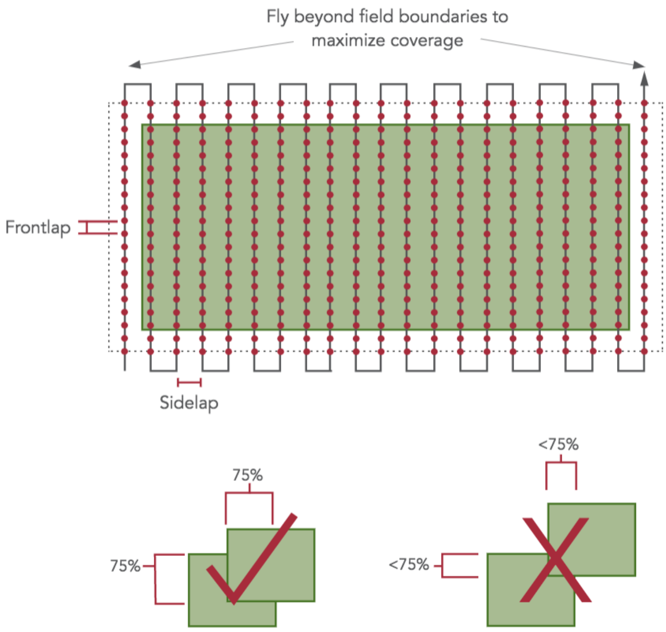
Figure 6. MicaSense RedEdge^{TM} -3 camera components.

The following guide available online will be used to insure the best practices for vegetation monitoring using multispectral sensors:

https://support.micasense.com/hc/en-us/articles/224893167-Best-practices-Collecting-Data-with-MicaSense-Sensors

3.3. Mission Planning.

The area to be captured should be larger than the actual field of interest so that there is sufficient data all the way to the edges of the field. A grid survey should be established using the system's mission planning utility. One additional flight track should be configured on either side of the field. Pilots should ensure a sufficient space is allocated at the end of each flight track for the aircraft to re-align for the next pass. This is particularly important for fixed-wing aircraft platforms.



Overlap.

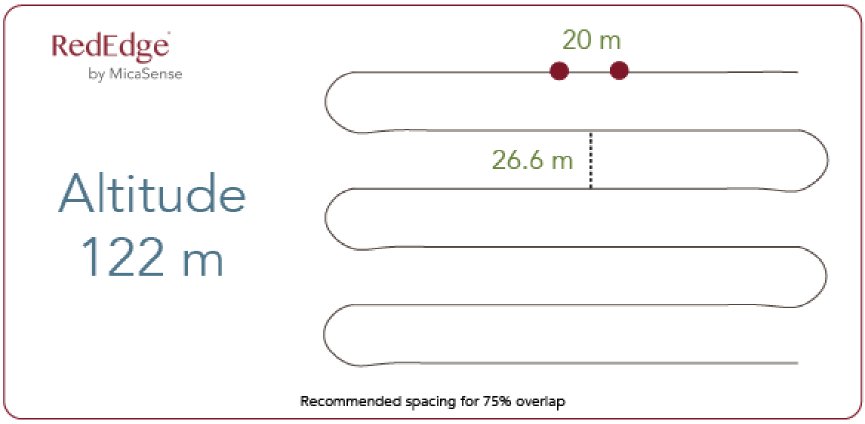
Mission pre-planning should be set with the distance between tracks (**sidelap)**, and the distance between successive captures (**frontlap)** to yield a **75% overlap**. Thus as the aircraft travels along a flight track, each following image overlaps the previous by 75%, both in the forward direction as well as the side direction on the parallel track.

Flight Planners and Camera Parameters

The system's mission planning utility must be set up to establish the flight plan at 75% overlap. **It is essential that the mission planner you use supports your camera's specific parameters.** While the specific method will vary depending on the system, pilots should need to select RedEdge as the camera type, and ensure proper configuration of the camera's overlap mode as the trigger.

The **camera parameters are available on our knowledge base for RedEdge**. The parameters are set up for a camera that is positioned horizontally (landscape), so if the camera is positioned vertically (portrait) in your integration, pilots will need to reverse the width and height specifications.

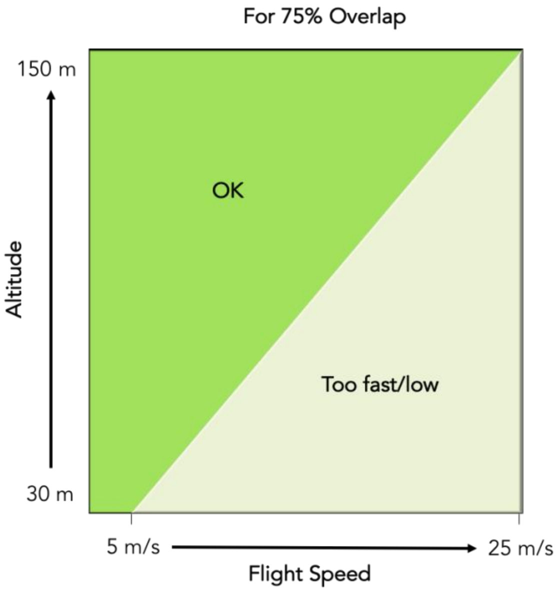
During the pre-survey pilots should check that the mission planner has the correct parameters for the sensor by comparing it to the example flight plan below, which is set up for an altitude of 122 meters and 75% overlap. If you create the same flight plan, the front-lap spacing should be 20 meters and the track spacing should be 26.6 meters:



Speed and Altitude

The frontlap along the flight direction also depends on the flight speed and altitude above the ground. MicaSense Sensors can capture images quickly, as fast as once a second. However, there are combinations of flight altitude and flight speed that will not yield proper frontlap. As this graph shows, slower speeds should be used at lower flight altitudes.

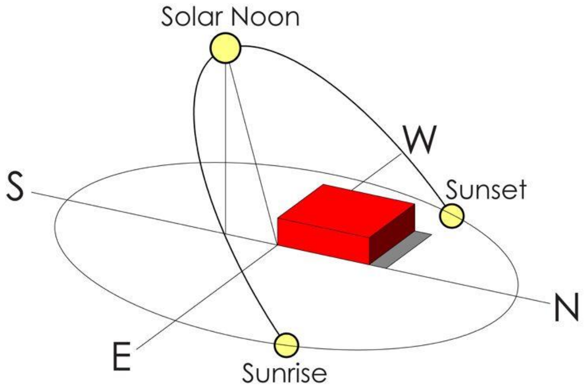
Sample overlap chart for MicaSense Sensors



Proper overlap is extremely important for good quality data. If the overlap is insufficient, the outputs are likely to have defects such as blotchy artifacts or errors in the image alignment. As you create a flight mission, if the field to be mapped requires more than one flight to fully cover, the flights should overlap by at least one pass. When setting up a flight mission over fields that have rows planted in a specific direction, the flight tracks should be oriented such that they are perpendicular to the rows if possible. This will provide the most consistent data output for this type of field.

3.4. Best Time for Capture

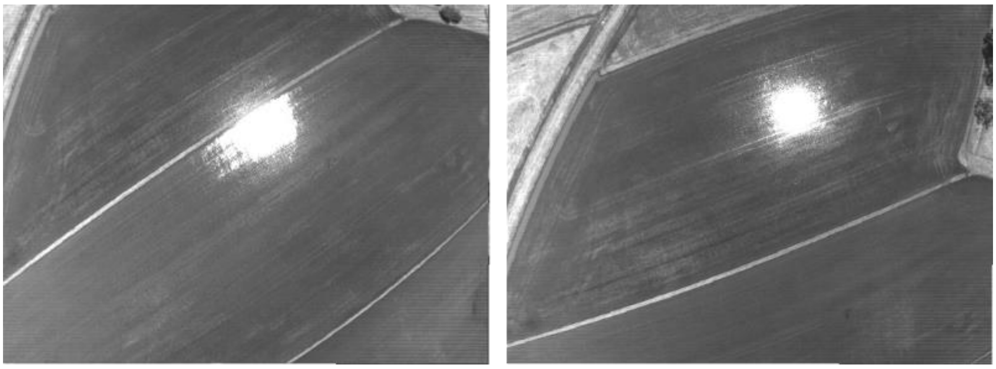
Flights should be performed within two and a half hours of local solar noon.



By doing this, the output does not suffer from deep shadows, which can significantly affect the multispectral results. Shadows not only obscure some vegetation but can also affect values of vegetation indices over areas that are fully or even partly shaded.

Avoid sunspots

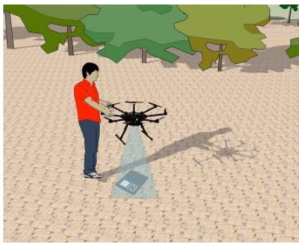
The only exception to flying at solar noon would be if you were to fly in very sunny conditions where, if the sun were directly overhead, it would produce bright sunspots in the data you capture. In cases like this, we recommend flying while the sun is at a lower angle.



3.5. Calibrated Reflectance Panels

To create reflectance-compensated outputs, an image of a calibrated reflectance panel should be captured immediately before and immediately after **each and every** flight. This applies even if a single field is covered in multiple flights – that is, always capture a panel image before and after each flight for that field.

Before capturing the panel, **ensure that the camera has a good GPS fix** so that the panel images will contain appropriate location and time information. This is important for post processing.



The panel should be placed flat on the ground, far away from any objects that could affect the light that illuminates it. Stand in front of the panel such that the sun is at your back. Then take a large step to the left or to the right. Hold the aircraft at chest level and point the camera such that the panel is centered in the field of view and such that there are no shadows on the panel. The camera should be directly overhead the panel if possible, or offset slightly to prevent shadows. Shadows on the panel will invalidate the reflectance compensation readings. Also, if light is reflecting onto another object and then onto the panel, the readings will be inaccurate. In this example, light is reflecting off the clothing of the person holding the aircraft and then onto the panel.

When capturing the panel image using your sensor, use either the Capture button in the camera's WiFi interface page or push the physical button on the front of the camera. **External trigger mode, timer mode, or overlap mode should not be used for panel captures.** These modes will cause saturation of the panel images. **Ensure that the light sensor has full view of the sun. Do not cover the light sensor while taking a panel capture.** This could cause faulty reflectance calibration in image processing software.

Capture mode

QR Mode

The best way to capture a reflectance panel is via the Automatic Panel Detection/ QR Mode. For more details on this mode, please see the MicaSense Sensor. Alternatively, the sensor has a physical trigger button as well as a capture button in the web configuration page.

Ensure that the panel takes up at least one third of the image width, and that the QR code and serial number label are visible in the image.

Ambient Light Conditions

In order to collect reflectance-compensated results, the light conditions at the time of capture should be consistent throughout any one flight. Clear sunny days as well as light overcast days in which the ambient light is not changing are best. Avoid capturing data in partly cloudy days with rolling clouds. Data captured in cloudy conditions, where the sun is partly or fully obscured for portions of the flight, will suffer from anomalies.

The accuracy of the reflectance values for data captured in these conditions is questionable. Additionally, these defects not only affect the colour image but can also affect the vegetation indices. If capturing data in partly cloudy days is unavoidable, make sure that at least one reflectance panel image is captured in bright conditions.

Feature Variability

Including unique features and variability in your captures helps increase the accuracy of your output mosaic. While it may not be feasible to place unique features everywhere throughout your field, there are other positive actions you can take. One simple way to include variability in your data would be to make extra passes beyond your field, as outlined in the overlap section.

Nadir

It is extremely important to ensure that the camera is pointing at nadir (straight down) or as close to nadir as possible (even if flying over sloped terrain). There are several gimbal options available from integrators. If not using a gimbal, the pilot will need to account for the tilt of the aircraft as it flies forward and adjust the camera's position accordingly.

Sloped Terrain

If flying over sloped terrain (such as a vineyard), the pilot should maintain an altitude constant relative to the slope/ground, and fly perpendicular to the field. If "terrain following" is not possible, split the field into multiple flights, choosing an altitude above the highest elevation. Also, choose a time of day to minimize shadows (this may be different than solar noon).

3.6. Processing Sensor Data

Partners or subcontractors collecting UAV imagery as part of the Care Peat project are expected to follow the manufacturers protocols for post-processing sensor data. NUI Galway uses RedEdge sensors thus we follow the following guidelines :

Video guide: https://www.youtube.com/watch?v=yLdbMRD9wyc

Step by step guide:https://support.micasense.com/hc/en-us/articles/115000831714-How-to-Process-MicaSense-Sensor-Data-in-Pix4D

A detailed methodology is included below to provide to subcontractors as an example of imagery taken with a MicaSense sensor with Pix4Dmapper**.**

Importing the Data

Imagery taken with MicaSense sensors will be automatically recognized since the camera is in the Pix4Dmapper camera database. RedEdge is supported by both Windows and Mac versions.

3 Create a new project.

4 Import all of the images for each band

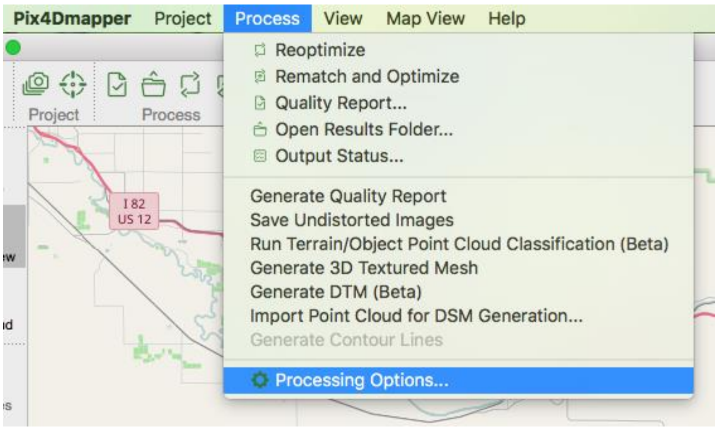
  4.1 RedEdge: Blue, Green, Red, Red edge, and NIR

5 In the Edit Camera Model window, ensure the Global Shutter model is selected.

6 Choose the Ag Multispectral processing template.

Radiometric Processing and Calibration

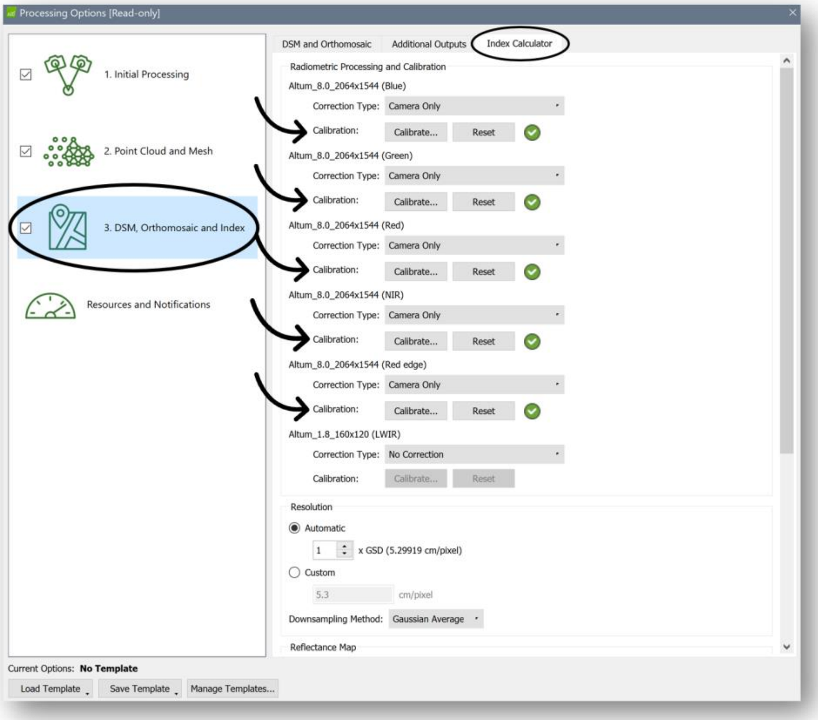
On the Menu bar, click **Process > Processing Options...**



the *Processing Options* pop-up appears.

Press **3. DSM, Orthomosaic and Index**

Select the **Index Calculator** tab



Radiometric Processing and Calibration

Altum_8.0_2064x1544 (Blue)
Correction Type: Camera Only
Calibration: ✓

Altum_8.0_2064x1544 (Green)
Correction Type: Camera Only
Calibration: ✓

Altum_8.0_2064x1544 (Red)
Correction Type: Camera Only
Calibration: ✓

Altum_8.0_2064x1544 (NIR)
Correction Type: Camera Only
Calibration: ✓

Altum_8.0_2064x1544 (Red edge)
Correction Type: Camera Only
Calibration: ✓

Altum_1.8_160x120 (LWIR)
Correction Type: No Correction
Calibration:

Resolution
● Automatic
1 x GSD (5.29919 cm/pixel)
○ Custom
5.3 cm/pixel
Downsampling Method: Gaussian Average

Reflectance Map

Current Options: **No Template**

Under **Radiometric Processing and Calibration**, you can choose the following options:

- **No correction**: no radiometric correction will be done
- **Camera only**: corrections will be applied for the parameters that are written in the EXIF metadata and relate to the camera (vignetting, dark current, ISO, etc...).
- **Camera and Sun Irradiance**: corrections will be applied for the camera parameters from the point above as well as for the sun irradiance information written in the XMP.Camera.Irradiance EXIF tag.

- **Camera, Sun Irradiance and Sun angle**: corrections will be applied to take into account the sun position, as well as the camera information and the irradiance data. This option should only be chosen for flights that were done in clear sky conditions.

The camera used is displayed. Users can calibrate the sensor to perform an illumination adjustment in order to obtain more accurate reflectance values.

Using the Calibration Panel

The **Calibrate** button allows users to take into account the information from a picture with radiometric calibration target if such a target was used during the project.

Obtaining your panel's reflectance values

If you have a MicaSense Reflectance Panel, make sure you obtain the reflectance values for your panel.

Note. If you have a newer panel with a serial number that begins with RP04 (or higher), you can find the reflectance values printed on the panel. The values are in percentages and typically need to be written as decimal fractions when inputting into software like Pix4D or Agisoft. For example, a printed reflectance value of 51.3 would become 0.513 when inputting into your photogrammetry software.

Blue: 475 (20)

Green: 560 (20)

Red: 668 (10)

NIR: 840 (40)

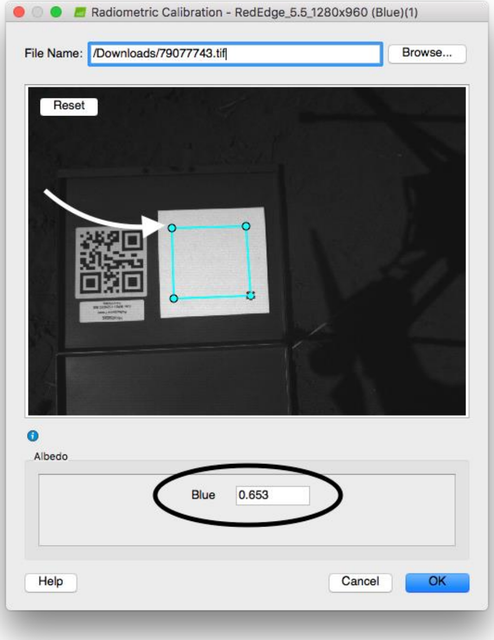
Red edge: 717 (10)

RP04-1824239-SC

475-20	560-20	668-10	840-40	717-10
51.0	51.0	51.0	50.7	50.9

This procedure will need to be done for each of the five bands, with the corresponding "albedo" value provided for each band. Please note the band order (Blue, Green, Red, NIR, Red Edge) and ensure you are entering the appropriate value for each band.

After clicking **Calibrate** for a camera model, the *Radiometric Calibration* pop-up appears.


Radiometric Calibration - RedEdge_5.5_1280x960 (Blue)(1)

File Name: /Downloads/79077743.tif

Albedo

Blue 0.653

If a radiometric calibration target is used, make sure that the radiometric target data is taken into account by ensuring the symbol in the Processing Options is a green checkmark.

In *File Name*, the **Browse** button, opens the *Select a radiometric calibration image* pop-up. This pop-up allows the user to select the image in which the radiometric calibration target appears.

When an image is browsed, the user can draw a region on the image that will define the radiometric calibration. The **Reset** button, resets the area drawn by the user.

Use the left mouse button to draw the first three points, then draw the final point with the right mouse button.

Important: The albedo values range between 0.0 and 1.0.

Processing

After configuring Pix4D to use the calibration data, you can continue to process your dataset. You will need to generate a reflectance map.

Merging the Reflectance Map

The reflectance map generates a GeoTIFF for each band. To combine these into one multi-band image, you can either upload the data to Atlas and download the GeoTIFF, or use external software:

- gdal_merge via the command line
- QGIS Virtual Raster Builder

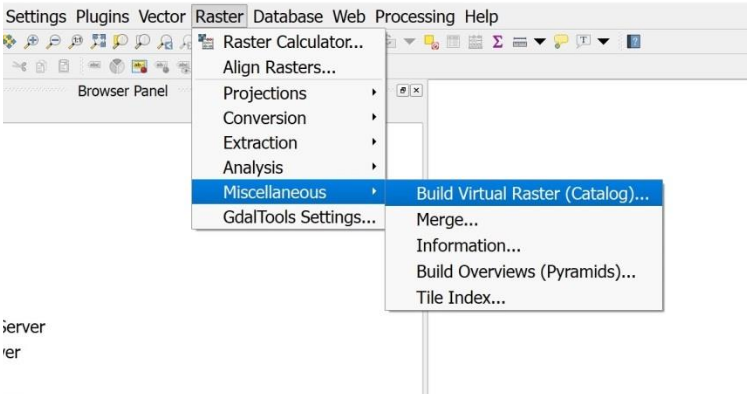
Using QGIS Virtual Raster Builder

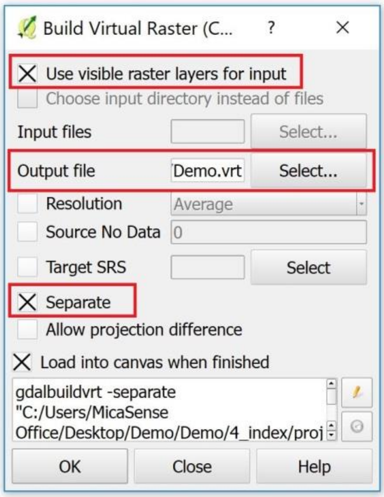
Note: This method does not create a new raster. It is a way to organize your existing rasters into one catalog for easy access and visualization.

Load the GeoTIFFs for each band into the Layers Panel (drag and drop or Layer > Add layer > Add raster layer...)

- Ensure that the individual band geoTIFFs are in the correct order by dragging and dropping
    - Correct order: Blue, Green, Red, RedEdge, NIR
- Select (turn on) all geoTIFFs

Open Virtual Raster Builder from the QGIS menu bar: Raster > Miscellaneous > Build Virtual Raster (Catalog)...





☒ Use visible raster layers for input

☐ Choose input directory instead of files

Input files: Select...

Output file: Demo.vrt Select...

☐ Resolution: Average

☐ Source No Data: 0

☐ Target SRS: Select

☒ Separate

☐ Allow projection difference

☒ Load into canvas when finished

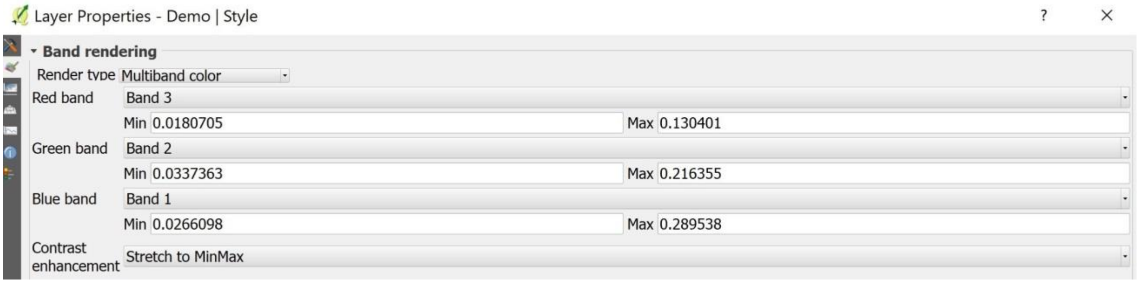
```
gdalbuildvrt -separate
"C:/Users/MicaSense
Office/Desktop/Demo/Demo/4_index/proj
```

The Virtual Raster Builder dialog opens (see below).

- Since all geoTIFFs are activated in QGIS, select the option to use visible raster layers for input.
- Select an output file location for the virtual raster file.
- In order to create a virtual raster with 5 discrete bands in one file, select the Separate option.
- The output file will automatically load into QGIS unless this box is deselected.
- Press OK to build the virtual raster.

The new virtual raster is added to the Layers Panel in QGIS. Now we can move on to editing the layer properties to display properly.

From the Layers Panel, right click on the new virtual raster layer and select **Properties**. Within the Layer Properties, navigate to the "Style" tab. Ensure you are in the "Multiband color" option. Using the drop down menu for each band, you will see that this layer now contains 5 bands. Change the Red band to "Band 3", Green band to "Band 2", and Blue band to "Band 1".


Layer Properties - Demo | Style

Band rendering

Render type: Multiband color

Red band: Band 3

Min 0.0180705 Max 0.130401

Green band: Band 2

Min 0.0337363 Max 0.216355

Blue band: Band 1

Min 0.0266098 Max 0.289538

Contrast enhancement: Stretch to MinMax

Now, copy the smallest "Min" value and paste it into the other "Min" value boxes. Then copy the largest "Max" value and paste it into the other "Max" value boxes. The above example will then look like the example below. This step is not necessary but stretching these values generally helps to create a more visually pleasing image for the human eye.


Layer Properties - Demo | Style

Band rendering

Render type: Multiband color

Red band: Band 3

Min 0.0180705 Max 0.289538

Green band: Band 2

Min 0.0180705 Max 0.289538

Blue band: Band 1

Min 0.0180705 Max 0.289538

Contrast enhancement: Stretch to MinMax

3.7. GROUND CONTROL POINTS (GCP)

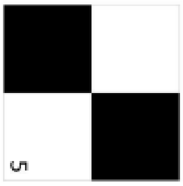
Partners/ subcontractors on the Care Peat project must use ground control points. Two methods for surveying using GCPs are as follows:

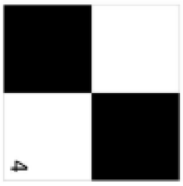
Method 1. Spray paint

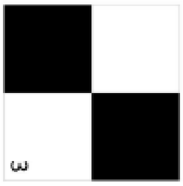
1. Use spray can to paint large crosses on the surface (approx. 40 cm x 40cm)
2. Black colour is recommended
3. This method is cheap and efficient and does not require the GCP to be collected after the mission

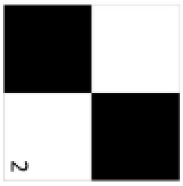
Method 2. Canvas on tile cross hatched patterns

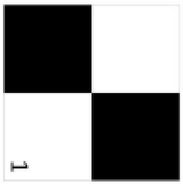
1. Canvas is 60 cm x 60cm; quality was 300gsm
2. Each piece was numbered for management purposes (1 to 5);
3. Each target was mounted (using pins) on simple wooden decking tile (small pallet) purchased in local hardware store
4.











3.8. IN-FLIGHT TARGETS FOR RADIOMETRIC CONTROL

We had good experience in terms of cost / effectiveness with Odyssey sail cloth. Our supplier was Kayospruce in the UK.

We use Odyssey Black (162 cm); Charcoal 162 cm); Silver (162cm) – all 1 meter wide.

Cost £69.37 for 3 (pounds sterling).

We recommend three shades of grey: a black or off-black, dark grey and a medium grey. Light greys might get overexposed, so be careful or test a sample in the field with your RedEdge on a natural background in natural light (other colleagues found that "Indian Birch" did not work for them).

Note. To make sure the surface below does not shine through we mounted our cloth on cheap plastic tables (€40 each). This also prevent them from getting dirty or absorbing moisture from the ground.

If you're really pressed for money, the "mason board and paint" approach by Wang and Myint might be an option, but I have not tried it myself. See:

Wang, C., and S. W. Myint. "A Simplified Empirical Line Method of Radiometric Calibration for Small Unmanned Aircraft Systems-Based Remote Sensing." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 8, no. 5 (May 2015): 1876–85. https://doi.org/10.1109/JSTARS.2015.2422716.

IN-FLIGHT TARGETS BASELINE REFLECTANCE

We recommend measuring them with a field spectrometer in the lab (e.g. an ASD4, but later models should be fine too. Take a minimum of 5 measurements across the targets, then use the average reflectance in your bands. We prefer contact measurements. If you have trouble getting access to a field spectrometer you can contact Andrew Grey or Chris MacLellan at the NERC Field Spectroscopy Facility in Edinburgh (contact details below). We have used this service previously and found it to be very successful and low cost. We obtained (rented for £400, includes 0.5 day of training) a GER 1500 Field Spectroradiometer System which was used to record the spectral reflectance signatures (300 - 1100nm) for a selection of ground cover material types and vegetative species (native and non-native) at our coastal field site.

Equipment: GER 1500 Field Spectroradiometer, GER Standard Lens, Panasonic Toughbook Laptop, Calibrated 10" Reference Reflectance Panel (SRT #039), Tripod, Monopod (Equipment sourced from NERC Field Spectroscopy Facility, University of Edinburgh, fsf.nerc.ac.uk)

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GCPs as inflight radiometric control

It depends on your GSD. We recommend at least 10 x 10 pixels for the radiometry quality control and three shades of grey. For 6-10 cm GSD, we recommend 60-100 cm, as larger is better. If you look for a lighter / cheaper alternative for the GCPs than the vinyl tiles check out https://www.contrado.com/ their prints on “organic cotton canvas 260 g” show up nicely in the near infrared. But canvas might not be as durable as vinyl if you plan to leave them out for longer.

Radiometric Calibration methodology using targets use the empirical line methodology.

Empirical Line method EML:

Conversion of Radiance (Digital Numbers) to reflectance of remote sensed image. Using calibration panels/targets a linear relationship between digital count and reflectance. Linear relationship can be determined if the reflectance of calibration panel/target is known at time of data collection.

Kelcey, J. & Lucieer, A. (2012) ‘Sensor correction and radiometric calibration of a 6-band multispectral imaging sensor for UAV remote sensing’, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXIX-B1*, pp. 393-398.

K and L 2012 – particularly Section 2.6 and 4.2.

Guo, Y., Senthilnath, J., Wu, W., Zhang, X., Zeng, Z. & Huang, H. (2019) ‘Radiometric Calibration for Multispectral Camera of Different Imaging Conditions Mounted on a UAV Platform’, *Sustainability, 11(978),* pp 1-24.

Mamaghani, B.G, Sasaki, G.V., Connal, R.J, Kha, K., Knappen, J.S., Hartzell, R.A., Marcellus, E.D., Bauch, T.D., Raqueno, N.G. & Salvaggio, C. (2018) ‘An initial exploration of vicarious and in-scene calibration techniques for small unmanned aircraft systems’, *SPIE 10664, Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping III, 10664, 1066406-3*

Assman, J.J., kerby J.T., Cunliff, A.M. & Myers-Smith, I.H. (2019) 'Vegetation monitoring using multi-spectral sensors – best practices and lessons learned from high latitudes', *Journal of Unmanned Vehicle Systems, 7,* pp. 54-75.

Smith, G.M. & Milton, E.J. (1999) 'Technical note: the use of the empirical line method to calibrate remotely sensed data to reflectance', *International Journal of Remote Sensing, 20(13).*

Baugh, W. & Groeneveld, D. (2008) 'Empirical proof of the empirical line', *International Journal of Remote Sensing 29(3),* 665{672 (2008).

Von Bueren, S.K., Burkart, A., Hueni, A., Rascher, U., Tuhoy, M.P. & Yule I.J. (2015) 'Deployment of four optical UAV-based sensors over grassland: challenges and limitations', *Biogeosciences, 12,* pp. 163 – 175.

Wang, C. & Myint, S.W. (2015) 'A Simplified Empirical Line Method of Radiometric Calibration for Small Unmanned Aircraft Systems-Based Remote Sensing', *IEEJ Journal of Topics in Applied Earth Observations and Remote Sensing, 8(5),* pp. 1876 – 1885.

3.9. Topography Maps (UAV-RGB) using Structure-from-Motion (SfM) Technology

WP: Topography (DEM, Orthomosaic) from photogrammetry and Structure-from-Motion technology.

WP1.0 – Task 1. Pre-flight planning acquiring relevant permissions, weather planning, definition of flight area and photograph overlap (75%).

WP1.0 – Task 2. Programming of Drone Deploy app (other app's also suitable e.g., Map Pilot).

(i) Licence: pre-design flight missions prior to fieldwork if possible

(ii) Internet: login on site and re-design flight as needed

(iii) Permissions: have all login/passwords on files prior to fieldwork

WP1.0 – Task 3. Flight/raw data collection.

(i) Altitude: 70-100m optimal for coastal surveys

(ii) Speed: 8-12 m/s (depending on wind speed); slower speed for higher wind speeds

WP1.0 – Task 4. Concurrent DGPS surveys will be completed for Ground Control Points.

(iii) Density: 85-130 per km^2 (see **Figure 4**)

(iv) Location: lower beach essential as homogeneous sand surfaces are difficult for SfM due to texture; other GCP's spread randomly to back beach, foredune, backdune areas.

(v) Type: A3 laminated cross hatched sheets; spray paint (black) crosses with number also sprayed adjacent to cross

WP1.0 – Task 4. Post processing. The terrestrial topography was generated using standard tools within Pix4D (or Agisoft, also licenced in NUIG Geography). See **Figure 4** for overview of workflow. This is standard in UAV mapping.

WP1.0 – Task 5. Extract shoreline position / cross-shore profiles / blowout or features from DEMs in a GIS.

Note. In reality airborne LiDAR is required to obtain high resolution topography for densely vegetated land such as some peatlands as standard RGB cameras cannot penetrate canopy. The suite of automated filters which post-process LiDAR data to delineate the surface below vegetation makes it a very attractive tool for geomorphic applications. However UAV-LiDAR is not economically feasible due to very high costs of hardware system (>€25,000). Airborne LiDAR also incurs high expense (c.€5000/day).

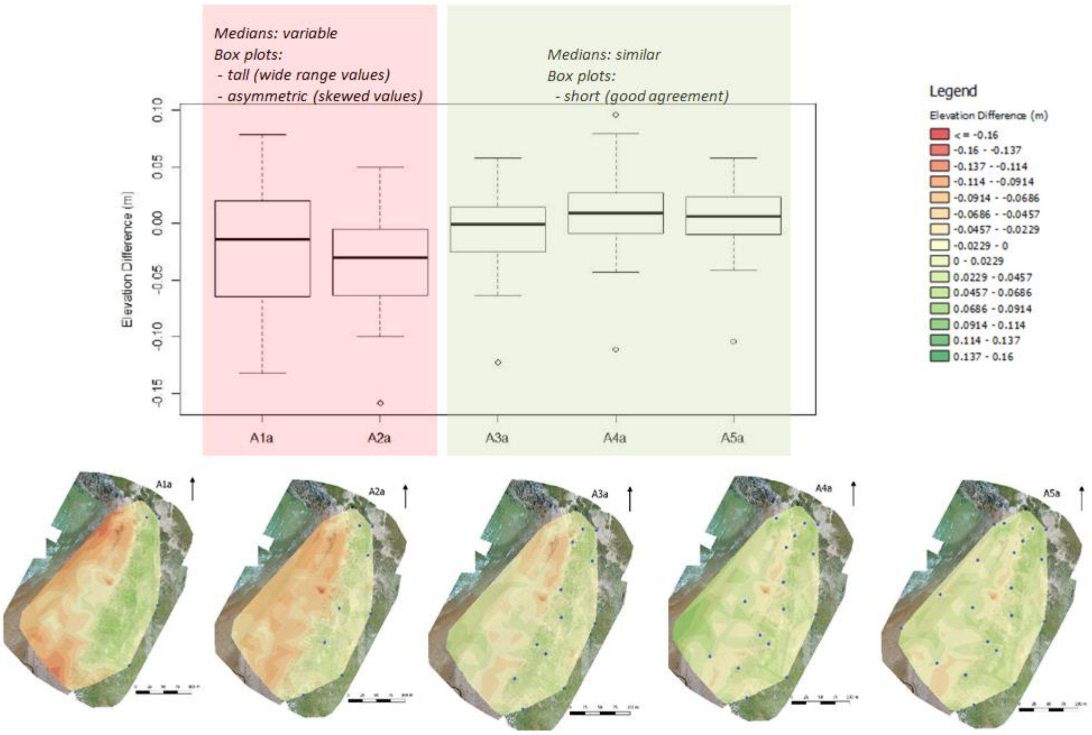

Figure 7. GCP distribution & errors for beach-dune system

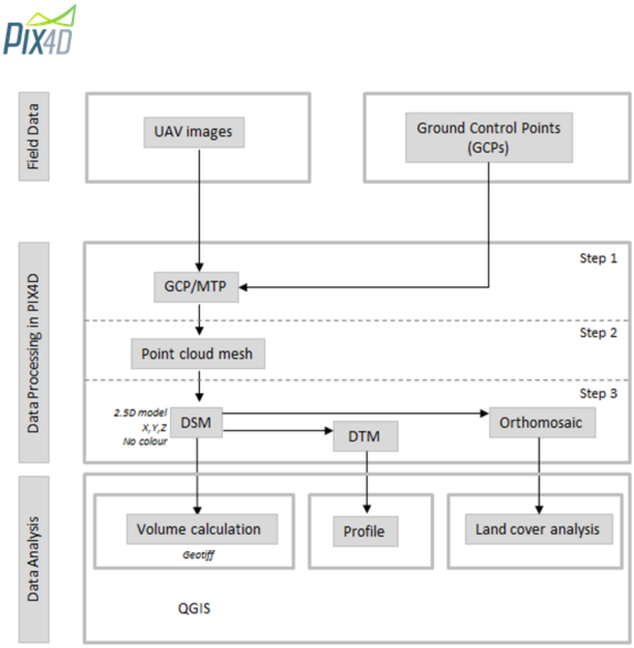

Figure 8. Pix4D workflow

Section of CTI from DTMs below:

The Compound Topographic Index (CTI) is a simple hydrological metric for quantifying the steady-state wetness of an area. For a given area i, it is defined as:

$$CT\,I_i = \ln \frac{a_i}{\tan b_i} \qquad (1)$$

where a is the up-stream contributing area (m/km2) and b is the corresponding slope (radians) (Beven and Kirkby 1979). Hydrologically, this formula relates the potential of an area to receive water (a) against potential loss or retention of moisture (b). By dividing the up-steam contributing area, i.e. the up-slope drainage area, by the corresponding slope CTI values are proportional to the potential wetness and lateral transitivity of a site. The larger the CTI, the greater potential for the landscape to hold water. Although a simplistic metric, CTI values have been shown to be indicative of soil organic matter, erosion potential, and wetland extent (Beven 1997; McKenzie and Ryan 1999; Moeslund et al. 2013). The up-slope contributing area (a) can be weighted according to land cover and soil characteristics. This accommodates varying overland flow and hydraulic conductivity rates present in a region, providing a more realistic representation. A high weighting value will simulate the retention of water, for example due to peaty soil or forest cover. Conversely, low weighting values associated with sandy soils and impervious land cover will encourage the loss of water.

Within Care-Peat, we can use DTM and CTI to prioritise areas for hydrological correction measures such as gully blocking.

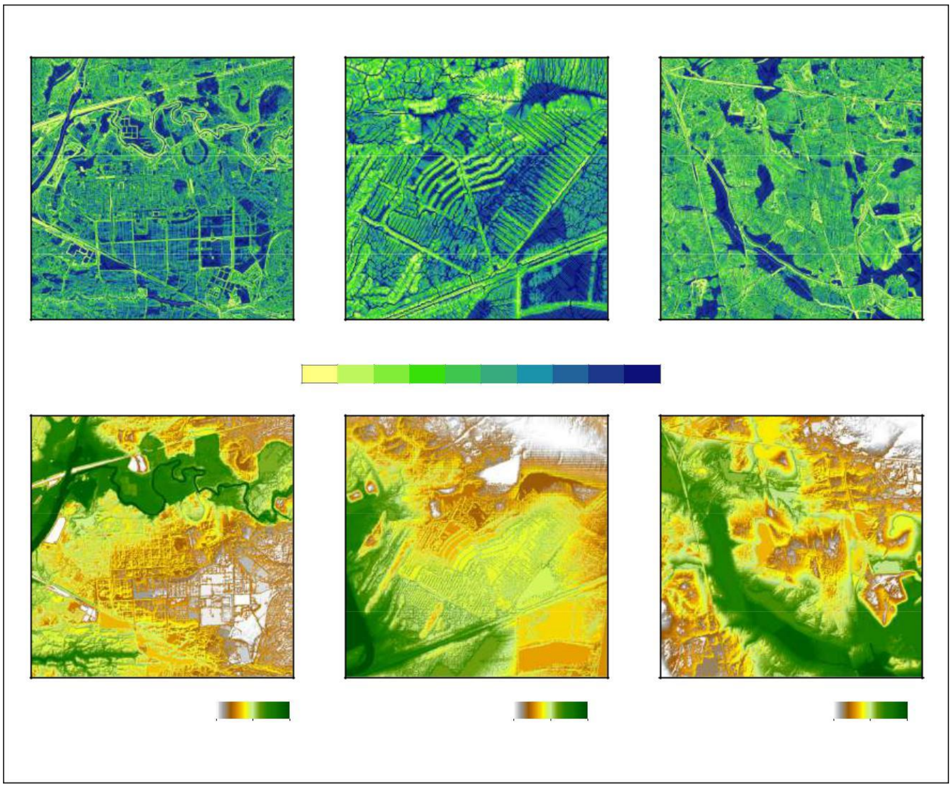

Figure 9. Example CTI (Top row) and DTM (bottom row) maps for arrange of peatland sites, taken from Higginbottom et al. (2018).

4. Satellite measurement

Sentinel-2 is the land monitoring component of the European Space Agency's (ESA) Copernicus programme. It carries a Multi Spectral Instrument (MSI) that captures data across 13 spectral bands. Of these bands, four have a 10 m pixel resolution, six a 20 m, with three 60 m bands primarily for atmospheric applications (Figure 4). There are currently two Sentinel-2 satellites in orbit; Sentinel-2A was launched in June 2015 and was joined by Sentinel-2B in March 2017. Each mission has a 10-day repeat overpass, for the majority of the Earth, resulting in a combined revisit rate of five days.

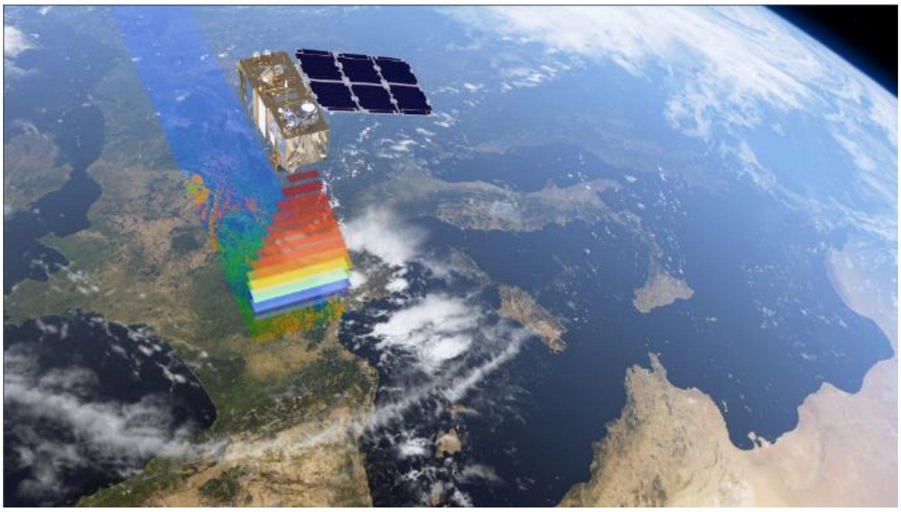

Figure 4a: Sentinel Satellite 2 orbit (ESA medialab)

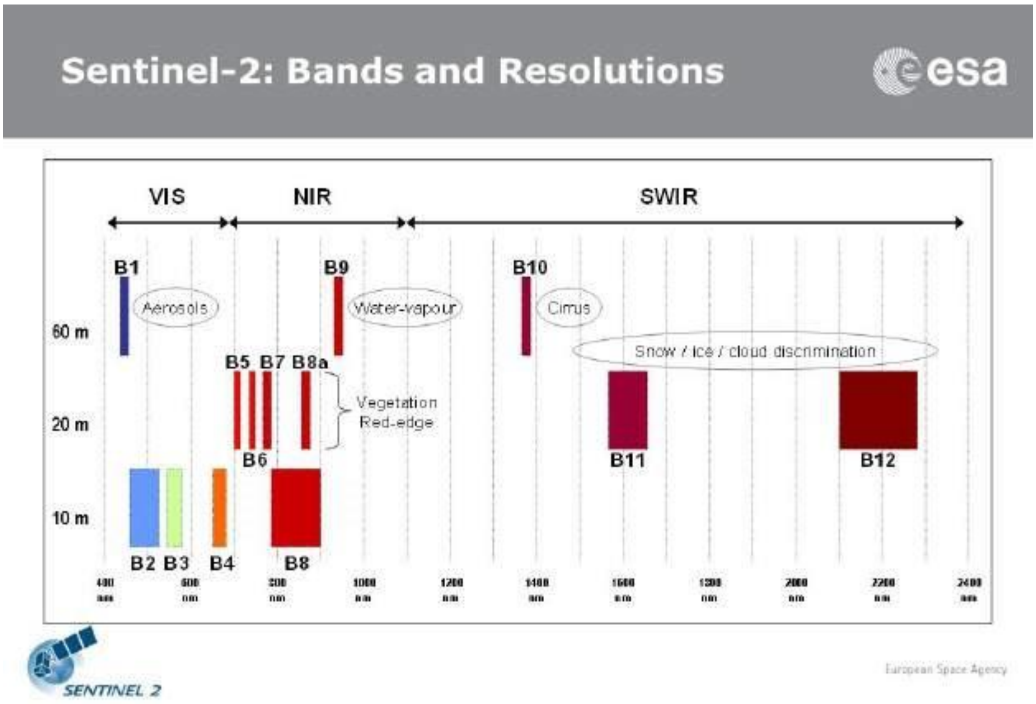

Figure 4b: Sentinel-2 wavebands and resolutions

For each site, we will download Sentinel-2 images at quarterly intervals. Images will be atmospherically corrected using Dark Object Subtraction (DOS) in QGIS, and topographically corrected using cosine correction with an STRM elevation model in SagaGIS.

From each image we will generate three vegetation indices:

1. Normalised Difference Vegetation Index (NDVI), 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

3. Normalised Difference Water Index (NDWI), an indicator of surface water coverage.

These indices will 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.