Methodology for GHG and Co-Benefits in Grazing Systems v1.0

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1. Methodology Overview

1.1. Scope

This *Methodology Protocol* is intended to provide a holistic assessment of multiple ecological state indicators for grasslands under the practice of prescribed grazing. It can be used by *Project Proponents* and other stakeholders to obtain estimates of Soil Organic Carbon (SOC) stocks within a project area, and measure additional ecological co-benefits such as animal welfare, ecosystem health, and soil health.

The general guidance is intended to assist *Project Proponents* in applying a measurement-based soil organic carbon approach focused on maximizing accuracy of SOC stock estimation, while minimizing sampling efforts and costs. Soil sampling coupled with remote sensing data or spatial interpolation methods will be used to calculate SOC stocks. Soil samples will also be used to assess soil health while remote sensing data and peer reviewed literature will provide an assessment for ecosystem health.

The main ecological health indicator assessed in this methodology is:

- CARBON SEQUESTRATION
  - Soil Organic Carbon (SOC) stocks and CO_2 equivalents (CO_2e)

Additional Co-Benefits assessed are:

- SOIL HEALTH
  - pH
  - Macronutrients
    - Nitrogen, Phosphorus, Potassium
  - Cation Exchange Capacity - CEC
  - Minor nutrients:
    - Calcium, Magnesium, Potassium, Sodium, Aluminum
- ANIMAL WELFARE
  - Measured using standards aligned with the project area locale
- ECOSYSTEM HEALTH
  - Ecosystem Vigor
    - Normalized Difference Vegetation Index (NDVI)
  - Ecosystem Organization
    - Woody vegetation landscape metrics
    - Protected perimeter of wetlands and watercourses
  - Ecosystem Resilience
    - Bare Soil Estimation (BSI)

1.2. A Measurement-based Soil Organic Carbon Methodology

Several steps are required to estimate the long term changes in soil organic carbon stocks within a project area:

1. Develop a soil sampling plan for the project area according to [Section 3.1](#).
2. Sample collection and preparation
3. Laboratory analysis of soil samples
4. Estimation of SOC stocks for the project area
5. Converting SOC stocks to CO_2 equivalent stocks
6. Calculating the change in CO_2e stocks between monitoring periods

A general schema for the measurement-based approach to estimate changes in SOC stocks is presented in Figure 1. SOC stocks measured in the first sampling round (i.e. the Baseline), are compared to those calculated in subsequent sampling rounds to quantify changes in carbon stocks after project commencement.

This methodology entails two main alternative approaches for estimating carbon stocks. The first one is an innovative approach based on using sample data coupled with satellite remote sensing data to generate statistical models to estimate the changes in SOC stocks through time. The second approach implements a spatial interpolation based on proxies from GIS data layers.
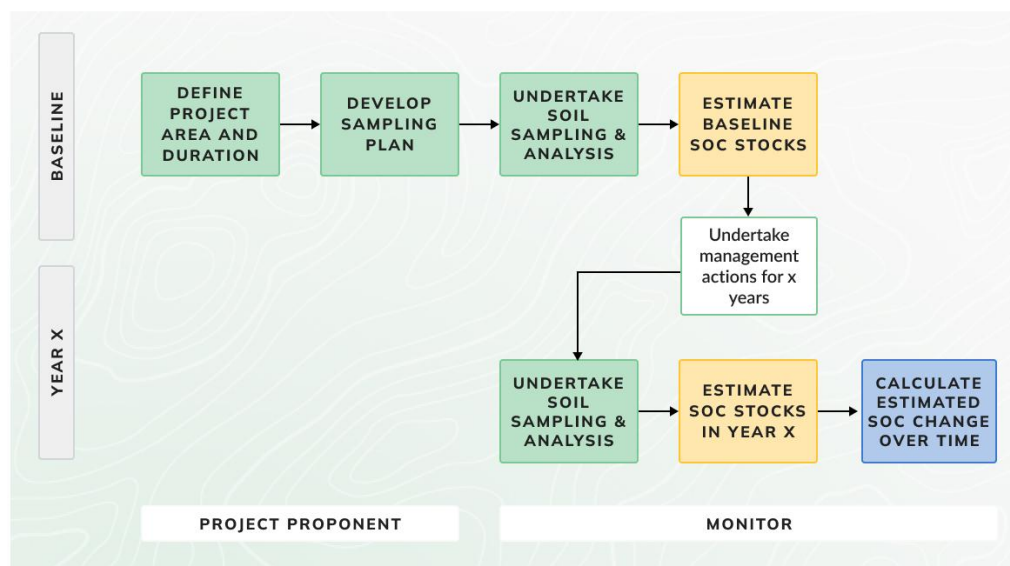
Figure 1: Main Steps for assessing changes in SOC stocks within a project area.

1.3. Co-Benefits

The co-benefits are intended to allow for a holistic assessment of the project area beyond carbon sequestration. The soil health, ecosystem health, and animal welfare metrics are chosen based on their widespread use as known, reliable indicators sensitive to the changes in ecological state.

1.3.1. SOIL HEALTH INDICATORS

Soil health indicators assess soil performance and functionality[1]. Chemical indicators such as pH, macronutrients, minor nutrients and Cation Exchange Capacity values can be used to assess changes in soil function and are sensitive to variations in management. Thus, chemical indicators will be ranked according to local benchmarks for the project region and project soils (see Section 4).

1.3.2. ECOSYSTEMS HEALTH

Ecosystem health is assessed holistically through the use of context-dependent indicators of ecosystem vigor, organization and resilience (see Section 5).

1.3.3. ANIMAL WELFARE

The American Veterinary Medical Association[2] defines Animal Welfare as the means by which "an animal is coping with the conditions in which it lives. An animal is in a good state of welfare if (as indicated by scientific evidence) it is healthy, comfortable, well-nourished, safe, able to express innate behavior, and if it is not suffering from unpleasant states such as pain, fear, and distress. Good animal welfare requires disease prevention and veterinary treatment, appropriate shelter, management, nutrition, humane handling, and humane slaughter." Animal welfare evaluations are often locale specific. Regional guidelines and variations should be taken into account during the evaluation (see Section 6).

2. Project Boundary

2.1. Spatial Boundaries

The spatial boundary encompasses all land on which the *Project Proponent* will undertake the *Proposed Activity*. Spatial boundaries defining the project area should be provided by the *Project Proponent* with any parcels or stratification schemes defined. Acceptable polygon data formats include ESRI shapefile OGC GeoPackage, KML/KMZ and GeoJSON.

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[1] NRCS USDA Soil Health
[2] AVMA: Animal Welfare: What Is It?

2.1.1. MASKING FOR GRASSLANDS AREA

To ensure proper estimation of soil organic carbon stocks, any man-made objects such as roads or buildings, woody vegetation, water bodies, riverine areas and other land types not included within the bounds of the *Proposed Activity* must be excluded. A mask representing grasslands **under the practice of prescribed grazing** must be provided since this will be used to calculate the amount of carbon sequestered. This mask can be created using GIS and remote sensing tools, land cover algorithms, visual inspection or any other method chosen by the *Monitor* or *Project Proponent*.

2.2. Temporal Boundaries

The Crediting Term is the finite length of time for which a Project Plan is valid, and during which a project can generate credits. This methodology adheres to a 10-year Crediting Term. The monitoring scheme within the Crediting Term of a project should adhere to the following guidelines:

- The Project Initial Monitoring Date is the date when the baseline measurement is performed and acts as the starting date of the 10-year Crediting Term.

- The minimum number of monitoring rounds for a 10-year crediting term is four (4).

- Monitoring rounds at the beginning of the first year (baseline) and during the last year of the project are mandatory.

- It is recommended (not mandatory) that two (2) soil sample rounds occur consecutively during the last two years.

- The minimum duration between monitoring rounds is ten (10) months.

- The end date of the Crediting term will correspond to the date of the last monitoring round, and must fall 10 years after the Project Initial Monitoring Date +/- five (5) months.

- The maximum time between monitoring rounds is four (4) years.

The examples below outline acceptable soil sampling timelines during the 10-year crediting period.
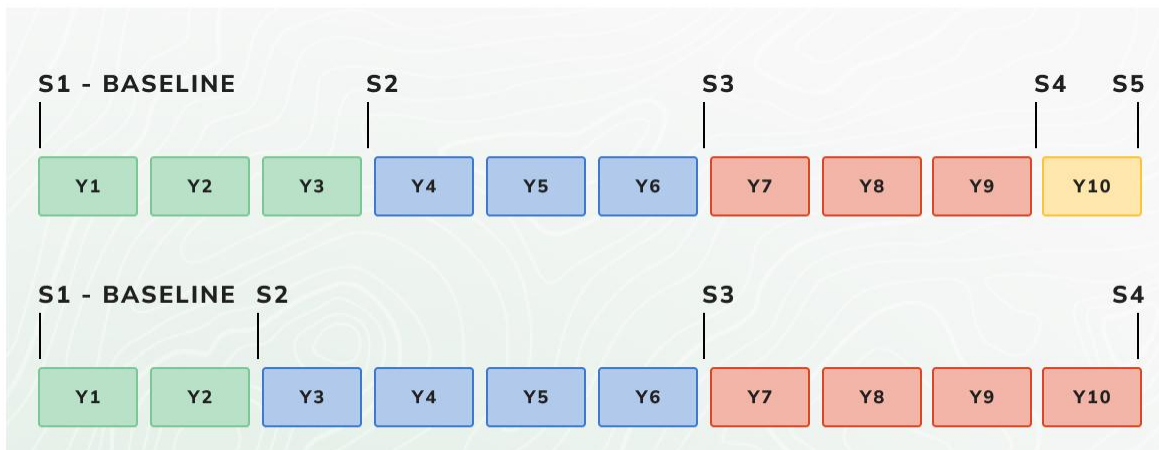
Figure 2: Examples of acceptable sampling timelines. Each crediting period is shown in a different color. The first sampling round is the baseline sampling, which sets "time zero" for the 10-year crediting term of a project. The last sampling round must happen at the end of the 10-year term. Between the baseline sampling date and the last sampling date, at least two (2) other sampling rounds must be carried out (could be more). Number of years between consecutive sampling rounds is flexible, as long as no longer than four (4) years pass between consecutive sampling rounds.

Note: The schema described above can be modified if an extreme climatic event or disaster is declared for the area of the project, in which case please contact the RND Science Team (science@regen.network).

3. Calculating the Carbon Sequestration and Net GHG Reduction

3.1. Collection of Data

3.1.1. SAMPLE SIZE

The sample size is defined here as the number of samples necessary to detect significant levels of change in the soil organic carbon between monitoring rounds. Traditional SOC quantification methods (i.e intensive sampling[3]) often require a much larger sample size than the satellite calibration or spatial interpolation approaches described herein.

The RND Science team developed a specific online calculator for the satellite calibration and interpolation approaches (see Section 3.1.1.1.), to estimate the sample size for the soil sampling plan. The minimum number of samples provided by the calculator for a project must be met to achieve a reliable and statistically valid level of rigor. Monitoring periods where the number of samples falls below the minimum could result in a deviation. In this case please contact the science@regen.network.

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[3] Conant, R. T., Smith, G. R., & Paustian, K. (2003). _Spatial Variability of Soil Carbon in Forested and Cultivated Sites. Journal of Environment Quality, 32(1), 278._ doi:10.2134/jeq2003.2780

3.1.1.1. SAMPLE SIZE ESTIMATION FOR SATELLITE CALIBRATION AND SPATIAL INTERPOLATION

Both for the satellite calibration and the spatial interpolation approaches, **the number of samples needed for the soil sampling plan is the same**, and will be calculated by using the Carbonplus Grasslands Sample Calculator V1.0. The Calculator only requires two inputs: the net grassland area in hectares (ha) of the Project, and the level of landscape variability. It then provides a minimum and an optimal number of sampling points for the project.

More detailed information about the underlying concept and equations of the Calculator can be found in the document The RND inc. CarbonPlus Grasslands Sample Size Calculator- Explanatory Document- V 1.0.

Main steps for estimating the sample size:

1. Load the online Carbonplus Grasslands Sample Calculator V1.0
2. Enter the net grassland area (ha) of the Project, as calculated in Section 2.1.1.
3. Determine the Landscape Variability Class:

All else equal, areas with higher variability are going to require more samples than areas with less variability[4]. The Landscape Variability Class of the project can be determined according to a set of landscape characteristics, qualitatively assessed by a local expert (ideally an agronomist, biologist or similar background professional with access to the land). Observations from the land stewards should also be taken into consideration. Table 1 can be used as a survey to classify the project area. The final Landscape Variability Class of the project area will be defined as follows:

- **Low Variability:** If at least 4 proxies are ranked as Low, and not more than 1 proxy ranked as high.

- **Moderate Variability:** If at least 3 proxies are ranked as Moderate, and not more than 1 proxy ranked as high.

- **High Variability:** At least 2 proxies are ranked as High.

4. Set the final sample size between the minimum and the optimal numbers provided by the calculator:

For a given grasslands area and Landscape Variability Class, the Carbonplus Grasslands Sample Calculator V1.0 provides for a **minimum** and an **optimal** sample size:

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[4] Herrick et al., 2009. Volume II: Design, supplementary methods and interpretation. Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems.

- **The *minimum number* is the lowest sample size allowed**. It should still allow for reaching the minimum accuracy of 50%, if best practices in sampling, geolocating and lab analysis are followed, but still could imply large discounts (up to 50%) in the final credits. It also carries a larger risk of not hitting the 50% uncertainty threshold.
- **The *optimal number* should be preferred, in particular for the first sampling round**, as it lowers the chance of having significant uncertainty discounts (see section 3.6.4.). Having more samples also enables adjusting the sampling size for the following sampling rounds to the desired level of uncertainty and sampling costs.

The *Project Proponent* should analyze trade offs between risks, final revenues, potential uncertainty discounts and sampling costs and define a sampling size that could be somewhere between the minimum and the optimal range.

If prior soil sampling results indicate that lower sampling intensity than the minimum stated by the calculator is sufficient to achieve the minimum accuracy, then exceptions can be considered under the appropriate justification. In this case, please contact the RND Science Team (science@regen.network).

Table 1: survey for determining the Landscape Variability Class of the project area.

VARIATION IN SOIL CARBON	LANDSCAPE CHARACTERISTICS
HIGH	☐ Steep slopes (>20%) are present ☐ More than 3 Soil Types (suborder level) ☐ Diverse vegetation assemblages ☐ Adjacent/ crossed by a waterbody ☐ Large area (> 1,500 ha) ☐ The management history of parcels largely differs. This applies not only for the implementation of regenerative management, but also in the level of intensity of the previous land use. Some areas may have been more degraded than others, and thus the starting point for each parcel differs greatly.
MEDIUM	☐ Moderate slopes (between 5 and 20%) across a majority of the project area ☐ 2-3 soil types (suborder level) ☐ Similar vegetation assemblages, variable herbaceous species in different areas ☐ Not adjacent to a water body ☐ Medium sized area (500 - 1,500 ha) ☐ In some areas regenerative grazing management has been implemented before others. The land use history of the different parcels has been similar despite differences in stock density, frequency of rotation or dates of implementation. The previous land use was similar across paddocks/ parcels.
LOW	☐ Flat area (slopes of less than 5%) across a majority of the project area ☐ 1 soil type (suborder level) ☐ Uniform herbaceous vegetation (e.g. open grassland, same species across study area) ☐ Not adjacent to a water body ☐ Small area (< 500 ha) ☐ The same management history has been implemented across the entire project area.

Design considerations:

- It is a good practice to avoid undersampling at the design stage, not only to compensate for any high variance or outliers, but also to prevent a situation at the analysis stage where the required reliability was not achieved and additional soil sampling efforts would be required. The need for additional soil sampling would be expensive, time-consuming, and inconvenient.
- It is highly recommended that several cores are extracted at each sampling location, in order to improve the total accuracy of the results. These subsamples could be composited or analyzed separately. Compositing reduces the sampling cost, but a separate analysis

would allow detecting any outliers coming from sample handling or lab analysis. Both options are accepted.

> *Note: If the project does not meet the Minimum Sample Size requirements, or in the case of following the Optimal number of samples but still not achieving the 50% accuracy, please contact the RND Science Team (science@regen.network).*

3.1.1.2. ANCILLARY SOIL SAMPLE DATA

Data from other farms can be used as ancillary data to increase the sample size for satellite calibration or spatial interpolation if the number of samples falls below the required minimum. Any ancillary data used must meet the following requirements:
I. The sample dates for the project area and the sample dates for the farm providing the ancillary data must fall within one month of each other.
II. The project area and the farm providing the ancillary data must be within the same climatic region according to the Köppen Climate Classification System[5].
III. The project area and the farm providing the ancillary data must have been under the same management practices for at least 3 years.
IV. The project area and the farm providing the ancillary data must have similar soils, topography and vegetation cover, and must fall within the same landscape variability class.
V. The sample extraction methods and sample analysis methods at the ancillary farm must match the protocols used for the primary farm

3.1.2. STRATIFICATION

In statistics, stratified sampling is a technique used to partition the population into subgroups, or strata, based on similar characteristics. Stratified sampling can help reduce the number of samples needed to measure soil health by segregating the landscape into subregions which share similar biophysical characteristics. Less samples are needed because the samples collected are representative of soil characteristics across the entire strata.

> *Note: The RND Science team highly encourages stratification to achieve better accuracies from the amount of samples estimated by the RND online calculator in section 3.1.1.1.*

When to stratify?
Stratification is always recommended as it tends to increase the accuracy of the results. Stratification should be applied particularly if:
A. The spatial boundaries provided include a large number of parcels and there is a need to aggregate similar parcels.

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[5] Beck et al. 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution

B. The parcels provided by the *Project Proponent* have high variability of soils, moisture, vegetation cover, hydrologic conditions, management history or other variables that might be affecting SOC in the topsoil.

How to stratify?
Variables highly correlated to soil organic carbon can be used as proxies to divide the project area into strata. This approach will help establish a sampling plan which covers the full range of percent SOC values, thus providing more accurate stock estimates. Some variables found to be good proxies to spatial variability of SOC at the field scale[6] include:

- **Topographic:** elevation, slope, aspect, erosion, terrain ruggedness Index (TRI) and the multi-resolution valley, bottom flatness index (MrVBF)
- **Land Use / Land cover (LULC):** Vegetation cover, above ground biomass, land management history
- **Satellite Imagery:** Multispectral satellite bands (e.g. Sentinel-2, Landsat TM), NDVI , BSI, NDWI, Tasseled Cap
- **Hydrologic:** topographic wetness index (TWI), catchment area and stream power index (SPI)
- **Pedologic:** soil types, clay content
- **Other:** pH

The project area can be re-stratified at each soil sampling round as improved quality of information becomes available, however at least the minimum number of sample locations estimated by the online calculator must remain consistent between monitoring rounds. Additional sampling locations must be recorded as specified in Section 3.1.3.

The monitoring report must specify the methods and variables used to define strata. A geospatial file defining stratified zones used for each monitoring round must be provided with each report. Also, any additions or any changes in the sampling points between sampling rounds must be clearly reported.

Useful Resources:
- cLHS - Conditioned Latin Hypercube Sampling[7][8]
- QuickCarbon Stratifi[9]
- Equal-range stratification[10]

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[6] Modeling and Stratification Technology Report for the ESMC. Lawrence et al., 2022
[7] White. 2019. cLHS - Conditioned Latin Hypercube Sampling
[8] Minasny and McBratney. 2006. A conditioned Latin hypercube method for sampling in the presence of ancillary information
[9] QuickCarbon Stratification Tool
[10] Hengl et al. 2003. Soil sampling strategies for spatial prediction by correlation with auxiliary maps
[20] Viscarra Rossel and Brus. 2018. The cost-efficiency and reliability of two methods for soil organic C accounting

- k-means [20][11]
- A thorough review of variations on these methodologies authored by Biswas and Zhang (2018)[12].

3.1.3. ASSIGNING SAMPLE LOCATIONS

☐ Soil sample locations must be determined prior to any soil sampling performed.

☐ Geolocations for soil sampling points must be selected at random. GIS tools, such as the QGIS "random points inside polygons tool", can be useful for creating random sampling points.

☐ If stratification was used, at least three sampling locations must fall within each strata to ensure underlying variations in soil organic carbon are represented.

☐ Sample locations must remain consistent between sampling rounds, though if sample locations differ, it is crucial to record the GNSS coordinates for the newly sampled locations, as well as specify and justify the changes in the sampling locations between rounds in the report.

☐ There are various approaches to establishing sample locations using a traditional sampling framework. Please reference the resources provided in Section 3.1.2. and select a sampling plan that is appropriate for the project location and variability.

It is recommended that a visual inspection is done based on updated satellite imagery or on the field prior to sending the sampling plan, so that any points that look hard to access or falling over or close to trees, shrubs, roads or other features, are manually moved within a 20m radius from the original geolocation.

3.1.4. EXTRACTING SAMPLES

It is important that samples used for soil carbon quantification follow proper sample collection and preparation procedures. Improper collection or preparation of soil samples can result in substantial errors, which can render the results of expensive sampling rounds unusable and compromise the integrity of the results. Please refer to the Soil Sampling Guide for in depth recommendations for soil sampling instructructions.

Regen Network recommends the following instructions to collect soil samples:
1) Prior to core extraction, clear the sample location of living plants, plant litter and surface rocks.
2) The minimum sampling depth is 10cm, but the recommended sampling depth is 30cm. Justification must be provided if sample depth is out of the 10-30cm range.
3) The sampling depth must be the same at all sample locations in all given carbon estimation areas. Where the nominated sampling depth cannot be reached due to bedrock or

[11] Brus et al. 1999. A sampling scheme for estimating the mean extractable phosphorus concentration of fields for environmental regulation

[12] Biswas and Zhang. 2018. Sampling Designs for Validating Digital Soil Maps: A Review

impenetrable layers, the sampling point should be moved to a better spot within a 20m radius.

4) The sampling depth must be consistent between all sampling rounds (i.e if samples are collected at 15cm for the baseline, samples must be collected at 15cm for following monitoring rounds).

5) A GNSS receiver with a minimum accuracy of 4 meters must be used to record the sampling point in the field. The GNSS model must be reported in the monitoring report. If the minimum accuracy of 4 meters requirement is not met by the device, the Monitor should explore options like the point averaging method to improve accuracy.

6) If subsamples are taken, please document the geometry of the sub-samples. Distance and direction from a reference point are recommended.

7) If subsamples are taken more than 4 meters apart, the sample location for each subsample should be recorded using a GNSS receiver.

8) Samples must be taken at least 10 meters away from any tree, shrub, structure, or body of water.

9) Please refer to Section 2.1 in the Soil Sampling Guide for the recommended soil sample collection tools.

10) If the soil profile is altered (incorporating substances external to the profile, or vertically altering the profile – eg. tilling, clay delving, water ponding) the sampling depth must be at least 10 cm below the depth of profile alteration.

11) Report the day, month and year for each sample collected within the given sampling round.

12) It is a requirement that all sampling rounds occur at least 6 months after the application of non-synthetic fertilizer.

Each laboratory has specific soil sample collection instructions. Users may choose a laboratory that is certified in their local area, or a part of a land-grant institution. Please refer to Table 1 in the Soil Sampling Guide for a list of laboratory specific instructions, laboratory accreditation requirements, approved laboratories, soil tests offered, and estimated costs for the US.

Note: please contact the RND Science Team (science@regen.network) if you'd like to add a lab to the list of laboratories we list in the Soil Sampling Guide

Report must include:
- Tools and methods used to estimate number of samples
- Sample stratification method and stratification map
- Tool used to extract soil cores
  - If core sampler used, include tool diameter in mm
- GNSS coordinate for each sample location and sub-samples (if applicable)
- GNSS device used to record sample locations

Additionally, the *Project Proponent* must provide the raw lab reports to the *Monitor*.

3.2. Sample Analysis

3.2.1. WHAT TO MEASURE?

To quantify SOC stocks, percent soil organic carbon and bulk density must be measured for each soil sample. Additional metrics to assess soil health are required from a smaller subset (30%) of the total number of samples.

- **All soil samples must be analyzed for:**
    1. Percent soil organic carbon
    2. Bulk density
    3. Gravel content (when relevant)

- **30% of the samples randomly chosen, will be also analyzed for:**
    1. pH
    2. Macronutrients
        a. Phosphorus
        b. Potassium
        c. Nitrogen (at least one of the following)
            i. Total Nitrogen
            ii. Nitrate Nitrogen
            iii. Ammonium Nitrogen
    3. CEC (cation exchange capacity)
    4. Minor nutrients: at least three (3) of the following:
        a. Calcium
        b. Magnesium
        c. Potassium
        d. Sodium
        e. Aluminum

Additional local parameters that are relevant to the project location and management activity can be included in the soil health assessment. Benchmarks for these indicators must be clearly indicated. More details on this process can be found in Section 4.

3.2.1.1. BULK DENSITY

Bulk density quantification may require the collection of a separate set of soil samples depending on the laboratory used. If bulk density measurements are not provided by the laboratory, it can be calculated using one of the following methods.

1. If laboratory analysis provides soil dry weight and volume, use the total soil volume dried in the laboratory protocols to calculate bulk density according to Equation 4.

$$Soil\ Bulk\ Density\ (g/cm3)\ =\ \frac{Dry\ Soil\ Weigh}{Total\ Soil\ Volume} \qquad\qquad (Eq.\ 4.)$$

2. If only the sample core dry mass is provided by the laboratory analysis, then the volume of the sample will be calculated based on the number of cores (in the case of a composite sample), the diameter of the coring device used, and the sampled depth (Equation 5). This volume can be used in the Soil Bulk Density equation above (Equation 4) to calculate bulk density. Check that units are appropriately converted to cm to ensure accurate bulk density measurements.

$$Total\ Soil\ Volume(cm^3) = number\ of\ cores * \pi * (Core\ Radius)^2 * Sample\ Depth\ \text{(Eq. 5.)}$$

3. Bulk density can be collected, processed, and analyzed on location/in-field using the Ring Method outlined in Section 3 of the Soil Sampling Guide. This approach uses Equation 5 to calculate volume by using the radius of the ring rather than the radius of the coring device. Samples can be dried in a microwave to assess dry soil weight.

3.2.1.2. GRAVEL CONTENT

If the soil typically has a significant rock or gravel content (i.e. more than 15% weight by coarse fragments that do not pass through a 2-mm sieve), then it is recommended that the coarse particle fraction is determined to allow for a correction in the estimation of carbon stocks using eq. 6 (section 3.3.1.2). In rocky soils, avoiding this step might lead to an increased error in the stocks calculations.

3.3. SOC Stocks Calculations

Once data for the SOC% and bulk density is retrieved from the lab for each sampling point, there are three different procedures that could be used to quantify the SOC stocks for the project area:

A. To calibrate remote sensing data based on correlations between SOC % and the corresponding spectral data from sampling points. In this case, a SOC% map is created based on the resultant model, and so a bulk density map needs to be created separately through interpolation or pedotransfer functions, to be able to calculate the carbon stocks through map algebra (Fig. 3.A.).

B. To calibrate remote sensing data based on correlations between SOC stocks at sampling points and the corresponding spectral data. In this case, SOC stocks are estimated in advance at each sampling point based on the corresponding SOC%, bulk density and sampling depth data (Eq. 6). A map of SOC stocks is created based on the resultant model, which is then used to quantify the total SOC stocks within the managed grasslands in the project area (Fig. 3.B).

C. To estimate SOC stocks at point locations and interpolate those values to calculate the total stocks for the project area (Fig. 4).

Section 3.3.1 outlines the two remote sensing-based approaches (A and B).
Section 3.3.2 outlines the interpolation alternative (C).

Section 3.3.3 provides for the steps to estimate the final total carbon stocks for the project at a given time.

3.3.1. CALCULATING SOIL ORGANIC CARBON STOCKS USING A SATELLITE CALIBRATION APPROACH
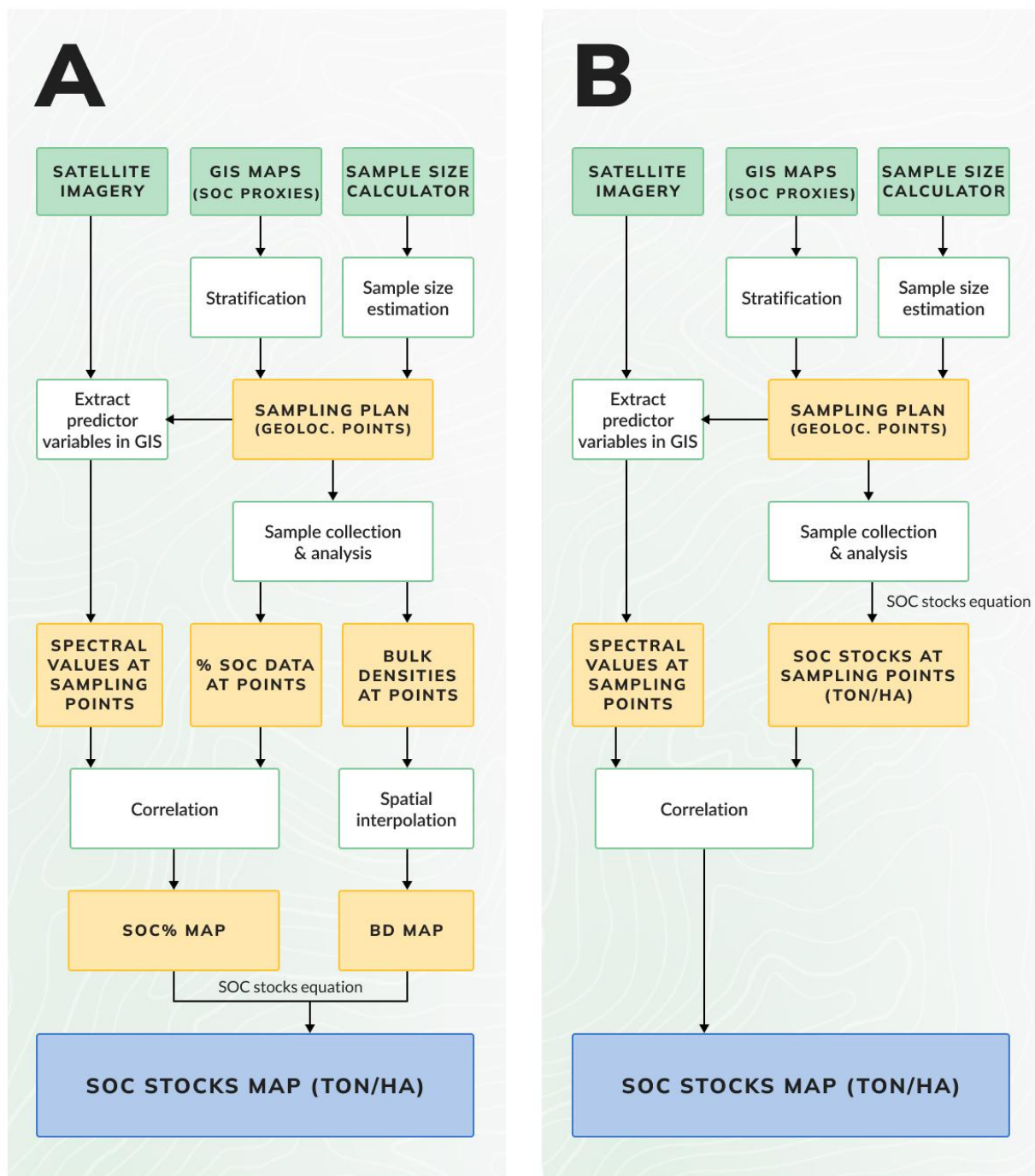
Figure 3. General Methodology for Soil Organic Carbon monitoring using Satellite Remote Sensing coupled with sampling. Soil organic carbon stocks can be quantified based on: (A) correlations between spectral values and SOC% values, or (B) correlations between spectral values and SOC Stock values.

3.3.1.1. EXTRACTING SPECTRAL VALUES AT SAMPLING POINTS

Satellite imagery and other remote sensing data can be paired with percent soil organic carbon values from collected soil samples to train statistical models which can be used to estimate soil organic carbon stocks at unsampled locations. The GNSS coordinates recorded at soil sample locations tie the two datasets together. Imagery used for the remote sensing approach must have a spatial resolution of 20 meters or finer. Ancillary data, such as digital elevation models (DEMs), pedologic maps, and derived indices may also be used for analysis. Tables 2 and 3 provide examples of data which could be used for analysis.

Table 2. Sentinel-2 bands and their corresponding wavelengths.

Band	Resolution	Central Wavelength	Description
B2	10 m	490 nm	Blue
B3	10 m	560 nm	Green
B4	10 m	665 nm	Red
B5	20 m	705 nm	Red Edge 1
B6	20 m	740 nm	Red Edge 2
B7	20 m	783 nm	Red Edge 3
B8	10 m	842 nm	Near Infrared (NIR)
B8A	20 m	865 nm	Red Edge 4
B11	20 m	1375 nm	Short Wave Infrared 1 (SWIR 1)
B12	20 m	1610 nm	Short Wave Infrared 2 (SWIR 2)

Table 3. Remote sensing indices, topographic variables and soil data.

Name	Description	Data Used
Normalized Difference Vegetation Index (NDVI)	NDVI is a measure of vegetation health	Equation: $\frac{NIR-Red}{NIR+Red}$
Normalized Difference Moisture Index (NDMI)	NDMI is a measure of vegetation water content	Equation: $\frac{NIR-SWIR}{NIR+SWIR}$
Bare Soil Index (BSI)	BSI identifies bare ground cover within a landscape	Equation: $\frac{(Red+SWIR) - (NIR+Blue)}{(Red+SWIR) + (NIR+Blue)}$

Normalized burn ratio 2 (NBR2)	NBR2 is used to detect burn scars on the landscape	Equation: $\frac{(SWIR1 - SWIR2)}{(SWIR1 + SWIR2)}$
Soil-adjusted Total Vegetation Index (SATVI)	SATVI is a vegetation index that reduces sensitivity to effects from soil	Equation: $((SWIR1-Red)/(SWIR1+Red+L)*(1+L) - (SWIR2/2)$ where L=1 (or 0.5)
Elevation	Elevation is a measure of the distance above sea level	Elevation
Slope	Slope represents the rate of elevation change from a digital elevation model	Elevation
Aspect	Aspect measures the slope direction	Elevation
Topographic Wetness Index (TWI)	TWI is a measure of topographic control on hydrological processes	TWI = ln(a/tan b) Where: a = upslope contributing area (m2) and b= slope in radians
Percent Silt	A measure of the composition of silt in the soil from 5-15cm and from 15-30cm	NA
Percent Clay	A measure of the composition of clay in the soil from 5-15cm and from 15-30cm	NA

The workflow below outlines the method to calculate SOC stocks using Sentinel-2 imagery and ancillary data, however other high resolution imagery, such as PlanetScope, WorldView, or GeoEye, can be used. All images and ancillary data included in the analysis should be specified, and any preprocessing steps must be well researched, checked, and documented by the *Monitor* to assure the highest quality results.

1. Sentinel-2 surface reflectance (BOA) imagery with a sensing date +/- 4 months around the sampling date should be used. It is highly recommended cloud free images be used as cloudy images often affect results even if clouds don't directly cover the study area. The *Monitor* must document any preprocessing tasks performed on Sentinel-2 tiles used for analysis.
2. Typically multiple Sentinel-2 images are available within a +/- 4 month period. So, it is recommended to analyze several images independently to find the best correlations.
3. Ancillary data such as the variables listed in Table 3 does not have to fall within the +/- 6 month sensing period as long as no significant change in the variable has occurred.

4. The QGIS[13] Point Sampling tool (or analogous tool) could be used to extract remote sensing data at each sampling location. This data should be exported and paired with soil organic carbon percentage and bulk density values, or directly to the SOC stocks per unit area (ton/ha), according to the approach followed (see section 3.3.1.2. options A and B below).

3.3.1.2. Option A. CORRELATION BETWEEN SOC PERCENTAGE AND REMOTE SENSING DATA

In this case, the remote sensing model is based on the relationship between spectral data and the SOC% values at sampling points, instead of using the stock values. The output is a SOC% map of the project grasslands area that must be combined with a bulk density map in order to estimate the SOC stocks (Fig. 3.A., in section 3.3.1.).

The following steps 1 to 3 outline how to calculate the total SOC stocks for a given sampling round:

Step 1) Creating the SOC% raster

The first step is to find the most accurate model to predict SOC% values based on the sampled data and the remote sensing data from the project area, for the corresponding sampling round.

Models should be fitted to the dataset created in Section 3.3.1.1(4), to detect correlations between the estimated SOC percentages and the remote sensing data from the sampling points.

The approaches below outline models which can be used to predict the SOC% values for unsampled locations within the project area. The *Monitor* may select any approach, but must provide a detailed report of the method used and any metrics used to evaluate accuracy and uncertainty, as well as the justification for selecting a specific model.

I) **Regression**: Multiple linear regression and non-linear regression models can be fit to the Sentinel-2 image bands and other predictor variables included in analysis. Once models have been generated for all bands, model accuracy should be evaluated using the leave-one-out cross-validation approach to calculate R^2 value, root mean squared error (RMSE) and the normalized-by-average version of the RMSE (nRMSE). Once all models have been scored, the model with the highest predictive accuracy should be selected to predict SOC% throughout the project area. Design considerations:
    - Outliers can be removed, but the methods used and a justification must be included in the report. Outlier removal should be performed using standard statistical techniques such as external studentized residuals, z-scores, or box plots. Removing too many outliers may result in overfitting and can

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[13] Point Sampling Tool Plugin for QGis

compromise the size and reliability of the dataset, so any outlier removal must be justified by the *Monitor* in the report.
- The maximum possible value of SOC% from the output map should be clipped to the maximum SOC% value from the samples from the Project Area. This is a conservative measure that prevents overestimations beyond the range of input values that were used to generate the model.

II) **Machine Learning**: In contrast to simple regression models which rely on prior assumptions about the relationship between predictor and the response variable, machine learning doesn't require prior assumption knowledge. These types of models can be useful in more complex study areas by discovering patterns that more basic regression models might overlook. It is important to note, however, that machine learning models tend to perform best with large training data sets and this constraint will limit the cases when use of machine learning models are justified. Accuracy for machine learning models can be evaluated using a leave-one-out cross-validation approach as noted in the regression section above.

The selected model will be run based on the corresponding Sentinel-2 bands and/or ancillary data rasters from the whole project grasslands area to estimate SOC% at the unsampled pixels. The raster output from this step is a map for the entire project area, where each pixel has a value of SOC% .

Converting percent soil organic carbon to soil organic carbon stocks requires bulk density and soil depth measurements to incorporate soil volume into stock calculations (eq. 6). Soil depth is a constant value which corresponds to the depth of the soil samples taken in [Section 3.1.4.](#)

Step 2) Creating the bulk density raster

Bulk density can be estimated using one of the following approaches:
I. **Spatial interpolation:** Spatial interpolation algorithms such as kriging, Inverse Distance Weighting (IDW), or splining can be used to estimate bulk density values at unsampled locations. The resulting bulk density estimates should be scored and assessed using methods such as cross validation and other prediction error statistics. The spatial interpolation method used should be specified by the *Monitor*.
II. **Pedotransfer functions:** Pedotransfer functions (PTF) relating percent soil organic carbon to bulk density may be used as a method to generate a bulk density raster for the project area. The pedotransfer function used should be supported by peer reviewed literature and assessed by comparing PTF estimates with bulk density values collected during sampling..

Step 3) Creating the SOC Stocks raster

Soil organic carbon stocks are calculated through map algebra by applying Equation 6 to the percent soil organic carbon and bulk density rasters, using soil depth as a constant:

$$\text{SOC stock(ton/ha) = SOC\% × BD (g/cm3)× Soil Depth (cm)} \qquad \text{(Eq.6)}$$

The raster output from this step is a SOC stock map for the entire project area, where each pixel has a value of SOC stock in ton/ha.

For example, if sampling depth was 30cm, a pixel with a SOC% value of 4% and a bulk density of 1.3 g/cm3 then SOC stockwill be 156 ton/ha.

See Supplement 2 for information and resources on automation tools which can be used to help carry out steps 1-3.

3.3.1.2. Option B. CORRELATION BETWEEN SOC STOCKS AND REMOTE SENSING DATA

In this case, the remote sensing model is based on the relationship between spectral data and the SOC Stock values at sampling points. The output is a SOC stock map that is used to estimate the total stocks of the project grasslands area (Fig. 3.A., in section 3.3.1.).

The first step is to estimate SOC stocks per sampling point.
The general equation for calculating SOC stocks is:

$$\text{SOC stock (ton/ha) = SOC\% × BD (g/cm3)× Soil Depth (cm)} \qquad \text{(Eq.6)}$$

For rocky soils (i.e coarse fragments weight > 15%), it is recommended that the equation includes a coarse particle (CP) correction factor as follows:

SOC stock (ton/ha) = SOC% × BD (g/cm3)× Soil Depth (cm) x (1- CP/100)   (Eq.6bis)

Where CP is the coarse particle fraction, unitless.

So, based on the sampling depth and the SOC% and bulk density data provided by the laboratory, a SOC stock value can be calculated for each point.

For example, for a sampling point with a SOC% value of 4%, a bulk density of 1.3 g/cm3 and a sampling depth of 30cm, the estimated SOC stock would be = 4* 1.3*30= 156 ton/ha.

Models should be fitted to the dataset created in Section 3.3.1.1(4), to detect correlations between the estimated SOC stocks at the sampling points and the corresponding remote sensing data.

The approaches below outline models which can be used to predict the SOC stock values at unsampled locations within the project area. The *Monitor* may select any approach, but must provide a detailed report of the method used and any metrics used to evaluate accuracy and uncertainty, as well as the justification for selecting a specific model.

I) <u>Regression</u>: Multiple linear regression and non-linear regression models can be fit to the Sentinel-2 image bands and other predictor variables included in analysis. Once models have been generated for all bands, model accuracy should be evaluated using the leave-one-out cross-validation approach to calculate R^2 value, root mean squared error (RMSE) and the normalized-by-average version of the RMSE (nRMSE). Once all models have been scored, the model with the highest predictive accuracy should be selected to predict SOC stocks throughout the project area. Design considerations:
  - Outliers can be removed, but the methods used and a justification must be included in the report. Outlier removal should be performed using standard statistical techniques such as external studentized residuals, z-scores, or box plots. Removing too many outliers may result in overfitting and can compromise the size and reliability of the dataset, so any outlier removal must be justified by the *Monitor* in the report.
  - The maximum possible value of SOC stock (ton/ha) from the output map should be clipped to the maximum SOC stock value from the samples from the Project Area. This is a conservative measure that prevents overestimations beyond the range of input values that were used to generate the model.

II) <u>Machine Learning</u>: In contrast to simple regression models which rely on prior assumptions about the relationship between predictor and the response variable, machine learning doesn't require prior assumption knowledge. These types of models can be useful in more complex study areas by discovering patterns that more basic regression models might overlook. It is important to note, however, that machine learning models tend to perform best with large training data sets and this constraint will limit the cases when use of machine learning models are justified. Accuracy for machine learning models can be evaluated using a leave-one-out cross-validation approach as noted in the regression section above.

The model will be run based on the corresponding Sentinel-2 bands and/or ancillary data rasters from the whole project grasslands area to estimate SOC stock at the unsampled pixels. The raster output from this step is a SOC stock map for the entire project area, where each pixel has a value of stock, in ton/ha .

See [Supplement 2](#) for information and resources on automation tools which can be used to help carry out steps 1-6.

3.3.2. CALCULATING SOIL ORGANIC CARBON STOCKS USING A SPATIAL INTERPOLATION APPROACH

Spatial interpolation methods such as kriging, Inverse Distance Weighting (IDW), or splining can be used to estimate carbon stocks at unsampled locations. The spatial interpolation method used should be specified by the *Monitor*. Fig. 4. below outlines the general workflow.

The maximum possible value of SOC stock (ton/ha) from the output map must be clipped to the maximum SOC stock value from the samples from the Project Area. This is a conservative measure that prevents overestimations beyond the range of input values that were used to generate the model.

Uncertainty from the resultant SOC stock raster must be assessed using leave-one-out cross-validation or another approach supported by peer reviewed literature (Note that, for instance using a train-test split approach would require considering an additional % of samples collected during the sampling rounds for testing).

General methodology for Soil Organic Carbon monitoring using spatial interpolation of sampling data
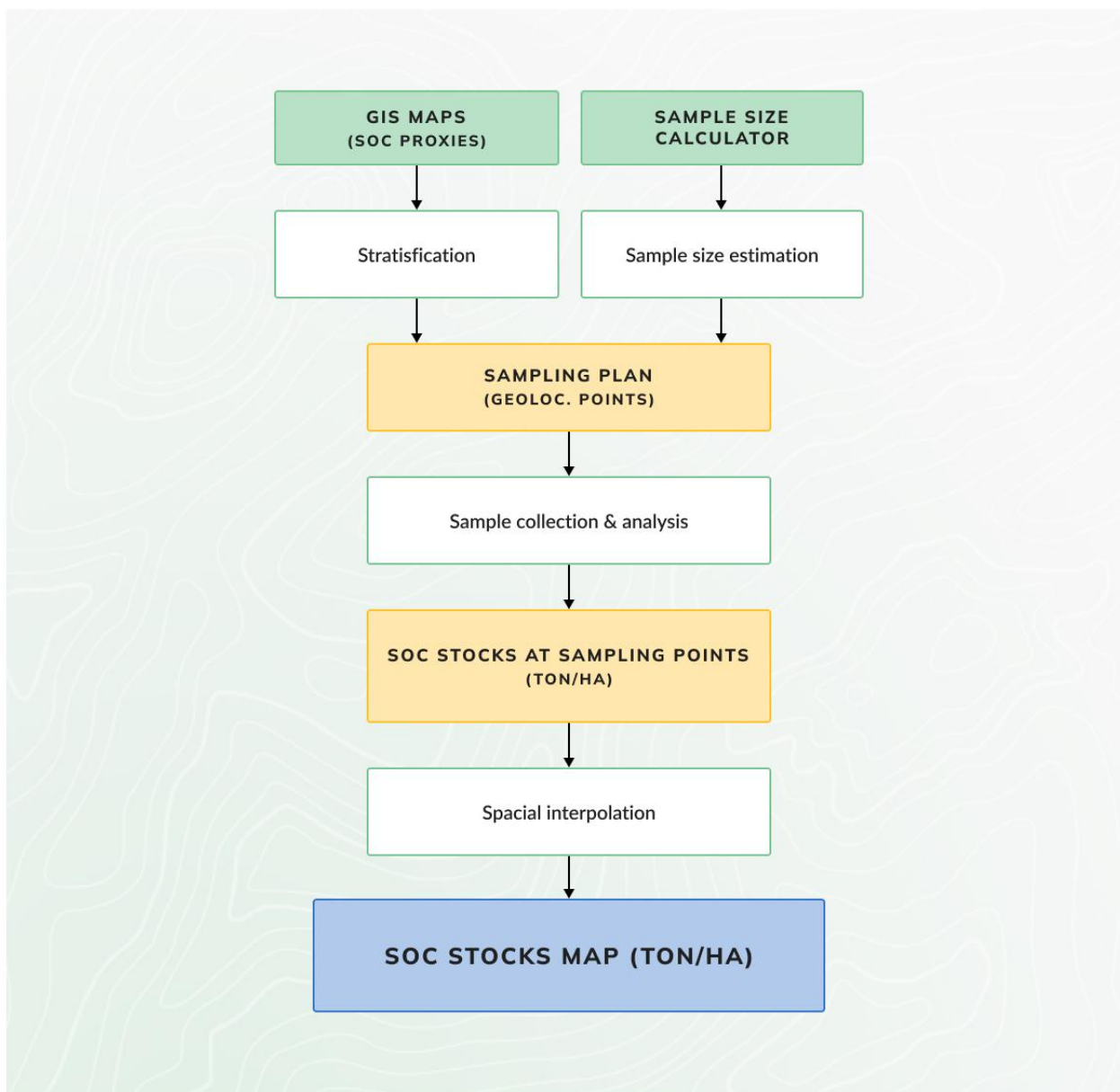

Figure 4. General Methodology for Soil Organic Carbon monitoring using spatial interpolation of sampling data.

3.3.3. CALCULATING FINAL SOC STOCKS

To ensure only grasslands are included in the final soil organic carbon stock estimate, the grasslands mask created in Section 2.1.1 should be used to estimate final stocks. The QGIS zonal statistics tool (or equivalent tool) can be used to sum all pixels contained within the grasslands. The resulting number is the **final soil organic carbon stock estimate** for the monitoring round.

Note: A special attention must be paid to the units here, given that having ton/ha values at the pixel level can be confusing. Converting pixel values to ton/ pixel area can be a good step to avoid errors when calculating the total tons of SOC for the project area. Alternatively, please be sure to correct the spatial resolution of pixels to match units of tonnes per hectare before calculating the sum. Then just summing the pixels within the grasslands area provides the total SOC stocks, in tons.

3.4. Converting SOC Stocks to CO_2 Equivalents

Converting soil organic carbon stocks to CO_2 equivalent stocks can be done by multiplying the SOC stocks (in metric tons) by a conversion factor of 3.67:

$$\textbf{CO}_2\textbf{eq. (metric ton)= SOC (metric ton) * 3.67} \qquad \text{(Eq. 7)}$$

3.5. Calculating the Greenhouse Gas Emissions

This methodology requires accounting for cattle GHG emissions, and any other emission sources that result in significant (>5%) GHG due to the project activity. For electricity and fuel usage, only the additional emissions from the baseline will be accounted for, whereas cattle and agrochemicals emissions will be considered as totals.

3.5.1. EMISSIONS FROM LIVESTOCK

Livestock emissions must be calculated for each year of the project lifetime in accordance with IPCC or relevant national/state/regional scale factors. Equation 8[14] shows how livestock emissions should be calculated using the number of animals present, the number of days the animals were located in the project area, and a default emission factor for the corresponding group of livestock. The livestock type, region, and the source of the emission factors must be cited in the report.

$$\textbf{E}_{liv}\textbf{= Q x D x EF}_{liv}\textbf{/1,000} \qquad \text{(Eq. 8)}$$

where:

$\textbf{E}_{liv}$ is the total emissions from livestock for a particular year for the project area, in metric tons of CO_2e.

Q is the number of animals within the project area in that year, in livestock head.

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[14] Carbon Credits (Carbon Farming Initiative—Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018

D is the number of days in the reporting period that the livestock was within the project area. EF_{liv} is the default emission factor for the livestock, according to its type, as set out for the particular region; in kilograms of CO_2e per livestock head per day.[15]

There are many ways livestock heads can be reported as per the *Project Proponent*. For example:
1. If total livestock head is reported for a monitoring year, use total livestock head for **Q** and the number of days in the project area for **D.**
2. If livestock head is provided in terms of opening and closing head for a given monitoring year, take the average between the two for **Q** and set the number of days in project area **D,** to 365.
3. If livestock head is recorded for each quarter of a monitoring year, take the average of the four quarters for **Q**, and set the number of days in project area **D**, to 365.

3.5.2. EMISSIONS FROM FERTILIZER

If fertilizers are used within the Project Area, the total Greenhouse Gas (GHG) emissions from fertilizers for the calculation year must be quantified, and used to calculate the creditable carbon change. No distinction is made between synthetic and organic N fertilizers. Calculations of fertilizer emissions must be performed in accordance with IPCC, relevant national/state/regional scale factors, or the following equation:

$$FE_{t-0} = \sum_{x=1}^{t} (EF_{FE} * FE_x) \qquad \text{(Eq. 9)}$$

Where:

FE_{t-0} = emissions *(tCO$_2$e)* from fertilizer use during the whole calculation period

t = number of years in the calculation period (yr)

FE_x = N fertilizer input in year *x* (kgN)

EF_{FE} = Conversion factor for emissions from N fertilizer [tCO$_2$e kg N^{-1}].

The *Project Proponent* should provide fertilizer specific information as it relates to the project area including a) the type of fertilizer used and b) the mean annual fertilizer input during the monitoring period (often reported in kg). Conversion factors (often with units of tCO$_2$e/kg fertilizer), aligned with specific fertilizer types, are used to convert kg of fertilizer to annual emissions in tCO$_2$e. The fertilizer type, mean annual fertilizer input, conversion factor, and final emission quantification should be cited in the report. FE_x will be documented by the project owner.

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[15] Emission factors for Australia can be found in the Supplement to the Carbon Credits (Carbon Farming Initiative)

3.5.3. FUEL & ELECTRICITY USE EMISSIONS

Direct and indirect emissions from increased fuel and electricity usage from the baseline to the calculation year must be accounted for by using equation 10. This includes all fuel sources from stationary combustion, mobile combustion, and electricity.

$$\Delta FU_{t-0} = \sum_{x=1}^{t} (FU_{PR,x} - FU_{BL}) + (EU_{PR,x} - EU_{BL}) \qquad \text{(Eq. 10)}$$

Where:

ΔFU_{t-0} = emissions from increased fuel and electricity use in the calculation period [tCO$_2$e]

$FU_{PR,x}$ = emissions from use of fuels under the project scenario in year a of the calculation period [tCO$_2$e]

FU_{BL} = mean annual emissions from use of fuels under the baseline scenario [tCO$_2$e]

$EU_{PR,x}$ = emissions from use of electricity under the project scenario in year x of the calculation period [tCO$_2$e]

EU_{BL} = mean annual emissions from use of electricity under the baseline scenario [tCO$_2$e]

t= number of years in the calculation period [yr]

The *Project Proponent* should provide fuel specific information as it relates to the project area including a) stationary, mobile combustion, or electricity, b) fuel type, c) amount of fuel used, or d) emission factors used. Appropriate sources for emission factors must be used, such as the EPA Emission Factors for Greenhouse Gas Inventories[16].

3.5.3.1. Fuel Emissions

Emissions from the use of fossil fuels for a given year x (FU_x) shall be documented by the project owner and generally calculated with the equation below, based on fuel consumption by machine type and fuel emission factor:

$$FU_x = \sum_{MT} (FUL_{MT,x} * FEF_{MT}) \qquad \text{(Eq. 11)}$$

Where:

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[16] https://www.epa.gov/sites/production/files/2020-04/documents/ghg-emission-factors-hub.pdf

FU_x = *emissions from use of fossil fuels in year x (tCO₂e ha-1)*

$FUL_{MT,x}$ = *fuel consumption by the machinery type (MT) used in year x (litres)*

FEF_{MT} = *emissions factor for the fuel used in machinery MT (tCO₂e litres-1)*

MT = *machinery type (gasoline two-stroke, gasoline four-stroke, diesel)*

3.5.3.2. Electricity Use Emissions

Emissions from electricity use shall be calculated from the equation below (Eq. 12), both for the baseline and for a given project year, based on electricity consumption by equipment type using the respective emission factor. If electricity is generated using fuel, emissions should be calculated from fuel combustion using the equation above, rather than electricity consumption.

$$EU_x = \sum_{SE=1}^{n} (EUW_{SE,x} * EEF_{SE}) \qquad \text{(Eq. 12)}$$

Where:

EU_x =   emissions from use of electricity in year x [tCO₂e ha⁻¹]

$EUW_{SE,x}$ = electricity consumption from source SE in year x [kWh]

EEF_{SE} = emissions factor for the electricity used in source SE [tCO₂e kWh⁻¹]

SE   = electricity source type (grid, fossil fuel generator, etc)

For EU_{BL}, input is calculated based on the mean of data for the prior 5 years to project start.

3.5.4. ADDITIONAL AGROCHEMICAL EMISSIONS

Agrochemical emissions in the project activity in the calculation period will be documented by the project owner and for each emitter type (specific pesticide, fertilizer, or other agrochemical) and calculated using the equation below:

$$AE_{t-0} = \sum_{x=1}^{t} ((AQ_{ET} * AEF_{ET})_x \qquad \text{(Eq. 13)}$$

Where:

AE_{t-0} = Agrochemical emissions in the project activity in the calculation period (tCO₂e)

$AQ_{ET,x}$ =quantity of agrochemicals for emitter type ET applied (kg)

AEF_{ET} = emissions factor of the agrochemical used (for emitter type ET) (tCO₂e kg⁻¹)

ET = emitter type
x = year of the calculation period (tCO_2e)
t = number of years in the calculation period (yr)

The *Project Proponent* should provide agrochemical specific information as it relates to the project area including a) quantity of agrochemical use, b) emitter type, or c) emission factors used.

3.5.5. Other Emissions

Any other emission sources (OE_{t-0}, *equation X)* that result in significant GHG due to the project activity that constitutes greater than 5% of the total CO_2 benefits generated by the project should be accounted for.

3.6. Calculating the Creditable Carbon Change

3.6.1. BASELINE DEFINITION

The baseline SOC stocks or CO_2e are defined here as the total carbon stocks calculated for the project's *Initial Monitoring Date*, or date of the first sampling round. The methodology adopts a project-based, static baseline[17] which is calculated as the total SOC stocks, in metric tons, from the *Initial Monitoring Date.* All sampling rounds after the *Initial Monitoring Date* will be compared to the baseline to calculate creditable carbon change.

3.6.2. CHANGES IN CO_2e BETWEEN REPORTING PERIODS

The change in SOC stocks between reporting periods is estimated as the difference between the total SOC stocks from the current monitoring period, minus total SOC stocks from the previous period (Equation 14).

$$\text{SOC stock change} = \text{tSOC}_{(t+1)} - \text{tSOC}_t \qquad \text{(Eq. 14)}$$

The same applies for estimating the change in the total SOC converted into CO2 equivalents between two sampling periods (Equation 15).

$$\text{CO}_2\text{e change} = \text{CO}_2\text{e}_{(t+1)} - \text{CO2e}_t \qquad \text{(Eq. 15)}$$

3.6.3. NET CO_2e REDUCTION

The net CO_2e reduction in the project area for a given reporting period is calculated as the difference between the changes in SOC stocks, expressed as metric tons of CO_2e, minus the total GHG emissions, also in CO_2e units:

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[17] *'Coverage, Additionality and Baselines—Lessons from the Carbon Farming Initiative and Other, Schemes'-Chapter 5: Baseline settings- (CCA, Study,, April, 2014).*

NET CO_2e REDUCTION= CO_2e change - E_{liv} - $E_{Fertilizer}$ - $E_{Energy/Fuel}$ - $E_{Agrochemicals}$ (Eq. 16)

3.6.4. UNCERTAINTY AND DEDUCTIONS

Under this methodology framework, the total uncertainty for the project is a sum of the uncertainties calculated throughout the methodology during a given monitoring period. Sources of uncertainties for creditable carbon stock calculations include percent soil organic carbon estimates, bulk density estimates, and any deviations from the original methodology which might have introduced additional errors.

The partial uncertainty for each of the sources is calculated through the normalized root mean square error (nRMSE) from the leave-one-out cross validations.

When estimating the final uncertainty for the estimated change in carbon stocks between two periods, the total absolute uncertainties (not normalized) from both periods would be summed before normalizing.

An alternative approach, when using permanent plots, is to estimate the final uncertainty based on the map of changes in stocks estimated at the point level, using leave-one out cross validation between the map of changes in stocks and the changes in stocks estimated from the samples, at the sampling points.

If the uncertainty (U) of the change in stocks for the reporting period is less than or equal to 20%, the *Monitor* may use the net CO_2 reduction value generated in Section 3.6.3 without making any deductions to account for uncertainty (ex. Uncertainty Deduction (UD) = 0). If uncertainty is greater than 20%, the *Project Proponent* must use the Uncertainty Deduction (UD) values in Table 4 to calculate the amount of uncertainty to deduct from the creditable carbon stocks. Uncertainty deduction values are based on the Gold Standard LUF activity requirements Version 1.2.1[18]. Examples for uncertainty deduction are shown below.

Table 4. Ranges of uncertainties and the corresponding discounts.

UNCERTAINTY (U)	Uncertainty Deduction (UD) (% of U)
U≤20%	-No Deduction-
20%<U≤30%	50% of U
30%<U≤40%	75% of U
40%<U≤50%	100% of U

Examples:

- U=10%--> UD=0%
- U=25%--> UD=25% * 0.5= 12.5 %

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[18] Gold Standard LUF activity requirements Version 1.2.1

- U=35%--> UD=35% * 0.75= 26.25 %
- U=45%--> UD=45% *1= 45%

The maximum uncertainty allowed for any measurement in the project is 50%. The *Creditable Carbon Change* after Uncertainty Deduction is then estimated as:

CREDITABLE CARBON CHANGE =(NET CO$_2$e REDUCTION)×(1−UD)   (Eq. 17)

4. Calculating the Soil Health Indicators

The main soil health indicators for Grasslands projects are pH, macronutrients (Nitrogen, Phosphorus, and Potassium), cation exchange capacity (CEC), and other minor nutrients such as Calcium and Magnesium.

In order to assess the soil health of a pasture, the desired levels (i.e. benchmarks) of the most relevant soil health indicators for the Project Area must be established during the baseline period. These levels will vary depending on soil types and ecoregion.
The soil indicators to be assessed in at least 30% of the samples will be chosen according to their relevance for assessing soil health in the Project Area, and must include at least the following:
- Soil pH
- Macronutrients: Phosphorous, Potassium and at least one Nitrogen parameter (i.e. Ammonia, Nitrate or Total Nitrogen).
- CEC (Cation Exchange capacity)
- Minor nutrients: at least three minor nutrients from the following list:
  - Calcium
  - Magnesium
  - Potassium
  - Sodium
  - Aluminum

The *Monitor* could use the scoring approach proposed by the Cornell University Framework[19] to evaluate each of the soil-health variables. Under this approach, and depending on the indicator, there are different cumulative normal distribution scoring curves that can apply. For example, the chemical indicator potassium is scored using a sigmoid function that relates better scores to higher levels of potassium. Phosphorus and pH, on the other hand, are both scored using an optimum, Gaussian-type curve.

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[19] Manual -Comprehensive Assessment of Soil Health - Cornell Framework

| Sigmoid curve | Reverse Sigmoid curve | Gaussian-type curve |
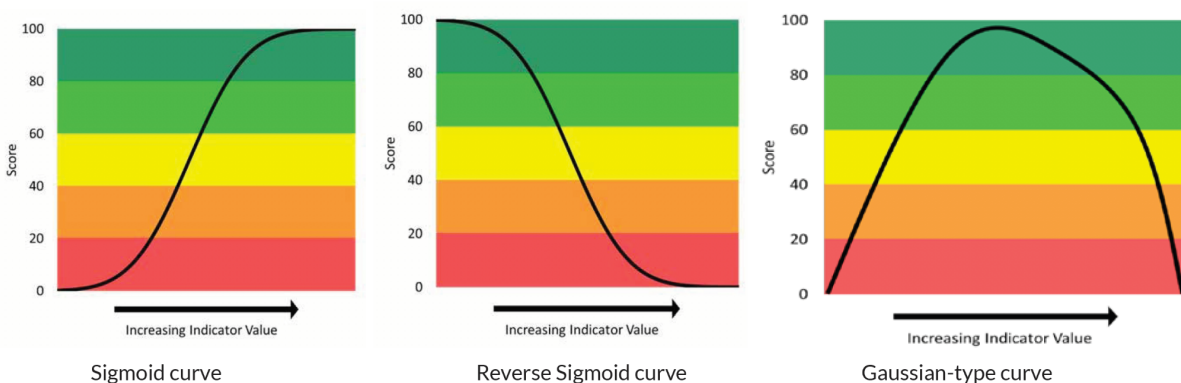
Scoring functions should be regionally adapted by the *Monitor* according to thresholds based on literature or local standards. For each monitoring period, each indicator will be ranked per sample according to the local benchmarks. There are two options for assessment on a per sample basis. The first being the establishment of a distinction between samples falling into optimal vs non-optimal ranges (aligned with the binary scoring section below). Samples categorized as "optimal" are those which fall within the desired levels based on the project's ecoregion and soil type. The second option is a non-binary assessment, where samples can fall into a "poor", "moderate", or "optimal" range (see non-binary scoring section below).

To incorporate the distribution of rankings across the samples for each indicator, the following decision tree is used to determine the final ranking.

Binary Scoring

If the local benchmarks for the assessed indicator only provide for optimal and non-optimal values, the classification score for the final ranking should be calculated using Equation 18.

$$Classification\ Score = \frac{\Sigma\ Soil\ Health\ Ranking}{Total\ Number\ of\ Samples} * 100 \qquad \text{(Eq. 18)}$$

Where *soil health ranking* is:
- Non-optimal = 0.25
- Optimal = 1

Please use the *Classification Score* to determine the final ranking according to Table 5.

Table 5. Soil Health Ranking for a Binary Classification:

Classification score	Final Ranking
0-25%	NEEDS IMPROVEMENT
>25-50%	FAIR

>50-75%	GOOD
>75-100%	EXCELLENT

Non-Binary Scoring

If the local benchmarks for the assessed indicator provide clear indications of poor, moderate and optimal ranges, the final rankings should be calculated using Equation 18, where *Soil Health Ranking is:*

- Poor: 0.33
- Moderate: 0.67
- Optimal: 1

Please use the *Classification Score* to determine the final ranking according to Table 5.
See Supplement Section 1.1 for a soil health assessment example.

4.1. pH

The optimal range of values for pH must be determined by the *Project Monitor* using local metrics for the region and specific soil type(s) found within the project area. Healthy pH levels for soil health follow an optimum, Gaussian-type curve. To estimate the optimum range for pH, build the normal distribution curve according to the average pH values of soil samples collected in the ecoregion. The optimal pH levels and standard deviations must be backed by a trustworthy scientific source and included in the report.

4.2. Macronutrients (NPK)

4.2.1. NITROGEN

Nitrogen metrics measure the productivity of nutrient cycling functions in the soil. The most common indicators used to quantify soil Nitrogen are *Nitrate-Nitrogen, Ammonia- Nitrogen* and *Total Nitrogen*. An increase in the indicators of Nitrate-Nitrogen and Total Nitrogen lead to increased soil health, therefore both of these indicators follow a cumulative distribution function. Nitrate-Nitrogen and Total Nitrogen follow a cumulative distribution function, meaning an increase in either variable indicates better soil health. Ammonia-Nitrogen is different and follows an optimum curve.

In order to estimate curves for each parameter, the average values and standard deviations from pastures in the region must be reported. Alternatively, local scientific studies showing threshold values for optimum, moderate and poor categorization can be used as a reference to build the scoring ranges.

4.2.2. PHOSPHORUS

The availability of soil phosphorus varies with the acidity of the soil. The more acidic the soil, the more phosphate 'fixed' by the soil and made unavailable to plants. As a result, critical values for soil phosphorus change with the soil type. A cumulative distribution function best fits the relationship between soil health and phosphorus and should be used as the scoring curve for this indicator.

4.2.3. POTASSIUM

Plants amass potassium from two soil sources: exchangeable potassium that is immediately available, and non-exchangeable potassium which becomes available at much slower rate. Clay soils have a higher nutrient holding capacity than sandy soils and thus can have higher levels of immediately available potassium. In light of this fact, soil test interpretation and benchmark categorization must be based on soil texture, as the critical value increases with increasing clay content.[20]

A cumulative distribution function best fits the relationship between soil health and potassium and should be used as the scoring curve for this indicator.

4.3. CEC (Cation Exchange Capacity)

'Exchangeable cations' give a measure of overall soil fertility. The cations—**calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) and aluminium (Al)**—are added together to produce the cation exchange capacity (CEC). The higher the CEC, the more fertile the soil[10]. As a result, the cumulative distribution function best describes the relationship between CEC and soil health. The curve and benchmark values for CEC are calibrated according to the mean and standard deviation of regional data. In the absence of local threshold values, missing information for setting benchmark values can be reconstructed using Cornell's approach[21].

4.4 Minor Nutrients

The following nutrients can be quantified and reported individually according to the scoring system.

- Calcium
- Magnesium
- Potassium
- Sodium
- Aluminum

Thresholds for these categories will be defined and justified according to the best knowledge for the project area (scientific papers, local reports).

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[20] Brown Book. What are the optimum nutrient targets for pastures?
[21] Comprehensive Assessment of Soil Health - The Cornell Framework Manual

5. Calculating the Ecosystem Health Indicators

The general framework used to evaluate ecosystems health[22] was originally proposed by Costanza (1992)[31] and later refined in 1999 by Costanza and Mageau[23]. According to Costanza, a healthy ecosystem has the ability to maintain its structure (organization) and function (vigor) over time in the face of external stress (resilience)[24]. This framework provides the foundational basis for methodologies which can assess ecosystem health dynamics and changes in grassland ecosystems.

5.1. Ecosystem Vigor

Ecosystem vigor is widely used as a primary factor for quantifying ecosystem health[25]. The vigor of a living system is a measure of its activity, metabolism and/or primary productivity[35].

5.1.1. VEGETATION INDEX

The Normalized Difference Vegetation Index (NDVI) is a good indicator of plant vigor, and has been used in previous research for the assessment of grassland ecosystem health using remote sensing[26]. NDVI is calculated using red and near-infrared light reflected by vegetation (Eq. 19). Healthy vegetation absorbs most of the visible light while reflecting a large portion of the near-infrared light resulting in a high NDVI value. In contrast, with unhealthy vegetation the, reflected red light increases and the reflected near-infrared light decreases,[27] resulting in lower NDVI values.

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad\qquad (Eq.\ 19)$$

Alternatively, the Enhanced Vegetation Index (EVI) might be preferred to avoid the saturation of the NDVI (Eq. 20).

[22] Xu and Guo. 2015. Some Insights on Grassland Health Assessment Based on Remote Sensing [31] Costanza R. 1992. Towards an operational definition of health. In: Ecosystem health: new goals for environmental management

[23] Costanza R. 1999. What is a Healthy Ecosystem?

[24] Costanza R. 2012. Ecosystem health and ecological engineering

[25] Xu and Guo. 2015. Some Insights on Grassland Health Assessment Based on Remote Sensing

[35] Costanza R. 1999. What is a Healthy Ecosystem?

[26] Xu and Guo. 2015. Some Insights on Grassland Health Assessment Based on Remote Sensing

[27] Normalized Difference Vegetation Index (NDVI). NASA Earth Observatory

$$EVI = 2.5 * \frac{NIR - RED}{NIR + C1 * RED - C2 * BLUE + L)} \qquad \text{(Eq. 20)}$$

where:

C 1 = atmospheric resistance red correction coefficient

C 2 = atmospheric resistance blue correction coefficient

L = canopy background brightness correction factor [1. 0]

To measure ecosystem vigor for grasslands in the project area, NDVI/EVI values for a project must be compared to the values in a *control area*. The *control area* could be one of the following options:

A) **Business as usual belt:** All the grassland areas within a surrounding area or belt of 10km width. This requires good ability to classify the grasslands or pastures and leave out other herbaceous land covers (i.e cropland).

B) **Business as usual target properties:** A group of known properties within the same ecoregion, soil types and general conditions, where business as usual management of grasslands is taking place and is likely to persist during the lifetime of the project (min. 200ha) .

C) **Best case scenario:** An identified area of significant size (min. 200ha) within the same ecoregion, soils, etc, where best case scenario of grasslands health happens due to historical proper management or due to conservation practices.

The following steps are followed for scoring the vigor of the grasslands within a project area:
1. Map out the control area boundaries using one of the the options described above:
A) For the Business-as-usual belt, create a 10kma 10km buffer around the property boundary using the extent of the spatial boundaries defined in Section 2.1.
B) For the Business-as-usual target properties, map the boundary polygons of the selected properties.
C) For the Best case scenario grassland, map the identified property/reserve boundaries.
2. Calculate the highest NDVI/EVI per pixel for a time series from the previous calendar year.
3. Create a grasslands mask using methods from Section 2.1.1. to remove any man-made objects, trees, bodies of water or other such land types from the NDVI/EVI image. Visually inspect the mask to ensure its accuracy.
4. Calculate the average NDVI/EVI value within the whole project area grasslands mask from section 2.1.1.1, by using the QGIS zonal statistics (or equivalent) tool. Next, calculate the average NDVI/EVI values within the control zone/s masked in (4).
5. Compare the NDVI/EVI averages between the project area and the buffer zone and generate a score based on the scoring charts below.

Scoring for options A and B (business as usual control):

EXCELLENT: Project average NDVI/EVI is >25% higher than the NDVI/EVI of the *control area*.

GOOD: Project average NDVI/EVI is 10-25% higher than the NDVI/EVI of the *control area*.

FAIR: Project average NDVI/EVI is within an interval of +/- 10% the average NDVI/EVI of the *control area*.

NEEDS IMPROVEMENT: Project average NDVI/EVI is below 10% lower than the average NDVI/EVI of the *control area*.

Scoring for option C (best case scenario control):

EXCELLENT: Project average NDVI/EVI is equal or higher than the average NDVI/EVI of the *control area*.

GOOD: Project average NDVI/EVI is 0-10% lower than the average NDVI/EVI of the *control area*.

FAIR: Project average NDVI/EVI is 10-25% lower than the NDVI/EVI of the *control area*.

NEEDS IMPROVEMENT: Project average NDVI/EVI is more than 25% lower than the average NDVI/EVI of the *control area*.

The report must include the NDVI/EVI results from control and project areas, and a link to the buffer vector file and the NDVI/EVI raster used.

5.2. Ecosystem Organization

Ecosystem organization represents the structure of an ecosystem and describes the interactions among various components of the ecosystem[28]. This depends on the landscape heterogeneity (LH) and landscape connectivity (LC).[29] The LH can be represented by landscape diversity, which can be determined using the Shannon's diversity index[30]. The LC depends on the overall connectivity of the landscape and that of important ecological patches[31], which can be assessed using landscape metrics.

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[28] Costanza R. 2012. Ecosystem health and ecological engineering.
[29] Ge et al. 2022. Assessment of Ecosystem Health and Its Key Determinants in the Middle Reaches of the Yangtze River Urban Agglomeration, China.
[30] Turner, M.G. Landscape Ecology: The effect of pattern on process. Annu. Rev. Ecol. Syst. 1989, 20, 171–197.
[31] Peng, J.; Liu, Y.; Li, T.;Wu, J. Regional ecosystem health response to rural land use change: A case study in Lijiang City, China. Ecol. Indic. 2017, 72, 399–410.

5.2.1 VEGETATION STRUCTURE LANDSCAPE METRICS

The LH and LC can be assessed at the ecosystem vegetation structural level (grasses, forbes, tussocks, shrubs, trees) using remote sensing and GIS. The metrics and grain size that should be chosen for a particular project will heavily depend on the ecoregion of the project area and the minimum needs for key species or endangered species that inhabit that ecosystem.

For instance, woody vegetation is a key component of most natural grassland ecosystems. Some landscape metrics like the proportion of woody vegetation cover, patch sizes, distances between patches, and/or the shape of patches of woody vegetation can be used as indicators of organization in grasslands, and compared to reference benchmarks from the natural local ecosystems.

The chosen landscape metrics must be estimated at the same time interval, or season, for each year from a land cover classification. For the land cover classification, imagery with a spatial resolution of 20 meters or finer, such as Sentinel-2 (ESA), must be used. The satellite source, GIS software and classification procedure (e.g. supervised nearest neighbor, random forest machine learning algorithm) used for the estimation of woody vegetation cover must be specified in the report, and images must be pre-processed following the workflow described in Section 3.3.1.1. There are several tools that can be used in GIS to estimate landscape metrics. We recommend the use of the LecoS (Landscape Ecology Statistics) plugin in QGIS, which is based on Fragstats.

For each reporting period, a single measurement of each landscape metric is required. The benchmarks for the excellent-good-fair-needs improvement ranking of the vegetation structural landscape metrics must be set locally according to the natural ecosystems characteristics and the habitat needs from key or endangered species in the ecoregion. The choice of landscape metrics and thresholds for scoring must be based on pertinent information from scientific literature. The corresponding cites to the scientific literature must be provided in the report.

5.2.2. PROTECTION OF WETLANDS AND WATERCOURSES

In case there are waterbodies of any kind (ephemeral, permanent or intermittent) within the project area, the percent of the total waterbody perimeter protected from animal entry will be quantified. The potential presence of ephemeral waterbodies must be considered by looking onto historical imagery.

Scoring:

EXCELLENT: 100% of the perimeter of waterbodies are protected from animal entry.

GOOD: The percentage of the perimeter of waterbodies in the project area that is protected from animal entry is higher than 70%.

FAIR: The percentage of the perimeter of waterbodies in the project area that is protected from animals varies between 50-70%.

NEEDS IMPROVEMENT: Less than 50% of the perimeter of waterbodies in the project area is protected from animal entry.

5.3. Ecosystem Resilience

Resilience represents the ability for an ecosystem to maintain its structure and function in the presence of stress, and can be measured by the system's capacity to return its original state following perturbation[17].

5.3.1. BARE SOIL ESTIMATION

Bare soil (i.e. [1 - vegetation cover]) has been identified as a good indicator of ecosystems resilience[32] and grasslands health[33]. The Bare Soil Index (BSI) is a numerical indicator estimated from satellite imagery that combines blue, red, near infrared and short wave infrared spectral bands to capture soil variations. These spectral bands are used in a normalized manner. The short wave infrared and the red spectral bands are used to quantify the soil mineral composition, while the blue and the near infrared spectral bands are used to enhance the presence of vegetation. The formula to calculate the BSI using Sentinel-2 imagery is specified in Equation 21[34]:

$$BSI_{S2} = \frac{(Band11 + Band4) - (Band8 + Band2)}{(Band11 + Band4) + (Band8 + Band2)} \qquad \text{(Eq. 21)}$$

In order to have a relative estimation of the bare soil within the project area versus the *control area*, the following steps are carried out for scoring the ecosystem resilience:

1. Using the project area and the control areas mapped in Section 5.1.1., download and preprocess satellite imagery that falls within +/- 1 month from the reported sampling period. Sentinel-2 (10 square meters) or higher resolution is required and must meet the requirements and pre-processing steps specified in Section 3.3.1.1. Averaging several dates without clouds around the sampling period increases the accuracy of the results.
2. Calculate the BSI for the project area and the control in (2). The resulting BSI raster must be validated through visual inspection of imagery performed by the *Monitor* or ground truth data provided by the *Project Proponent*, to find the range of BSI values that accurately reflect only bare soil areas on the ground.
3. Calculate the area covered by bare soil within the Project Area only, using zonal statistics and the grasslands mask created in section 2.1.1.
4. Calculate the area covered by bare soil within the control area only, using zonal statistics and the grasslands mask created in Section 5.1.1..
5. Estimate the areas covered by bare soil in both the project area and the buffer area.
6. Compare the percent bare soil cover between the project area and the buffer area and use the scoring chart below to generate a score for ecosystem resilience.

Scoring for options A and B (business as usual control):

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[32] Li et al. 2013. Three-Dimensional Framework of Vigor, Organization, and Resilience (VOR) for Assessing Rangeland Health
[33] Ludwig et al. 2000. Monitoring Australian Rangeland Sites Using Landscape Function Indicators and Ground- and Remote-Based Techniques
[34] Spectral Indices with Multispectral Satellite Data

EXCELLENT: Project Area has a percentage cover of bare soil that is notably lower than the percent bare soil cover in the *control area*. The difference is higher than 50%.

GOOD: Project Area has a percentage cover of bare soil that is lower to the percent cover in the *control area*. The difference is smaller than 50% and higher than 20%.

FAIR: Project Area has a percentage cover of bare soil that is +/- 20% of the percent bare soil cover in the *control area*.

NEEDS IMPROVEMENT: Project Area has a percentage cover of bare soil that is higher than 20% with respect to the *control area*.

Scoring for option C (best case scenario control):

EXCELLENT: Project Area has a percentage cover of bare soil that is similar (+/-10%) the percent bare soil cover in the *control area*.

GOOD: Project Area has a percentage cover of bare soil that is between 10 and 20% higher than the percent cover in the *control area*.

FAIR: Project Area has a percentage cover of bare soil that is between 20 and 50% higher than the percent bare soil cover in the *control area*.

NEEDS IMPROVEMENT: Project Area has a percentage cover of bare soil that is higher than 50% with respect to the *control area*.

The BSI results from the control and project areas must be included in the report.

6. Calculating the Animal Welfare Ranking

The Animal Welfare ranks within 4 possible categories (Needs Improvement- Fair- GoodExcellent) depending on the percentage of accomplished items from local recommendations. Refer to [Supplement Section 1.2.](#) for an example of Australian requirements. The report should include statements regarding compliance with the requirements chosen for the project.

Scoring:

NEEDS IMPROVEMENT: <40% requirements are met.

FAIR: Between 40% and 70% requirements are met.

GOOD: >70% requirements are met.

EXCELLENT: 100% requirements met

7. Overall Scoring

1. SOC: Total tCO2$_e$ from section <u>3.6.3.</u>
2. CO-BENEFITS:

The following scoring system shall be followed, using Table 6 below as a template for the calculation of the final scores for the main Co-Benefits.

7.1. Partial and Final Scores

Each indicator within the Ecosystem Health and Soil health co-benefits, as well as the Animal Welfare ranking, will be assigned with points in <u>Table 6</u>, as follows:

- Needs Improvement point = 0.25
- Fair point = 0.50
- Good point = 0.75
- Excellent Point = 1

FINAL SCORE = Sum of the indicators points / Total number of indicators

<div style="border:1px solid #000;padding:1em;">

<u>Calculation Example of the final score for Ecosystem Health</u>

If the partial resulting scores for each indicator of Ecosystem health were:

- Organization = GOOD = 0.75
- Vigor = FAIR = 0.50
- Resilience = EXCELLENT = 1.00

Then the final average score for Ecosystem Health is estimated as :

Ecosystem Health = (0.75+0.5+1)/ 3 = *0.75 (GOOD)*

</div>

7.2. Ranking of Final Scores

According to the final Score, the Soil Health metrics and the Ecosystem Health metrics are ranked as follows:

- Final Score ≤ 0.40 = *NEEDS IMPROVEMENT*

- 0.40 < Final Score ≤ 0.60 = *FAIR*

- 0.60 < Final Score $\leq$ 0.80 = *GOOD*

- Final Score > 0.80 = *EXCELLENT*

Table 6. Template for the calculation of the partial and total scores of the Co-Benefits.

MAIN INDICATOR	PARTIAL INDICATOR	Rating (cross-check the corresponding rating)				FINAL SCORE
		Needs Improvement	Fair	Good	Excellent	
Soil Health Indicator	pH					**Qualitative NI-F-G-E according to sum of weighted points**
	N					
	P					
	K					
	CEC					
Sum of points from the Soil Health Indicators						*Write here Final Score and Qualitative Result*
MAIN INDICATOR	PARTIAL INDICATOR	Needs Improvement	Fair	Good	Excellent	
Ecosystem Health Indicator	Vigor					**Qualitative NI-F-G-E according to sum of weighted points**
	Organization					
	Resilience					
points from the Ecosystem ndicators						*Write here Final Score and Qualitative Result*
Score for Animal Welfare						*Write here the Qualitative Result*

* NI=Needs Improvement; F=Fair; G=Good; E=Excellent

8. Data Reporting

8.1. Report

After each monitoring round, a report must be submitted to the Regen Registry including a description of the methods used for soil sampling, analysis of samples, as well as the equations and references used. The reported results for each section of this Methodology must be accompanied by all the information that supports them. In the case of GIS or remote sensing data, it is required that the maps are included as images within the report for illustrative purposes. The original

vector and raster files must be kept by the *Monitor*. Any documentation containing calculations and statistical analysis should also be saved.

A full checklist of the data is provided in [Supplement 3](#).

8.2. Data Storage

All data used during the analysis should be held during the whole *permanence* period by the *Monitor* and/or *Project Proponent* for monitoring verification. This data includes:
- All raster and vector data used in geospatial analysis to generate results for any section of the methodology.
- A copy of all laboratory reports.
- All the relevant field data from the soil sample collection process (dates, tools, procedures, sample locations).
- Documentation outlining calculations and results of statistical analysis.

A full checklist of the data is provided in [supplement 3](#).

9. Data Verification

The *Verifier* should verify the following items within the following subsections 9.1-5:

9.1. Soil Organic Carbon Data

- Data reported in the soil lab reports must match the data used for the soil carbon stocks quantification. These data include:
  - Percent soil organic carbon
  - Bulk density
- Spectral values extracted from the satellite imagery and ancillary data must match the data used during analysis.
  1. The *Verifier* should download the original imagery and ancillary data used and follow the pre-processing steps used by the *Monitor*
  2. Following the steps outlined in [Section 3.3.1.1](#), spectral values should be extracted and compared to the data used to generate statistical models.
- Models used to estimate percent soil organic carbon should be re-created and compared to reported values.
- Final soil organic carbon stock estimates should be recreated and compared to reported values.

9.2. GHG Emissions

- Using the data provided by the *Project Proponent* animal emissions should be recreated and compared to the reported values
- Using the data provided by the *Project Proponent* fertilizer Emissions should be recreated and compared to the reported values

9.3. Soil Health Indicators

Data from the original soil lab reports must match the data used to assess soil health. These data include:
- pH
- Macronutrients
  - Phosphorus
  - Potassium
  - Nitrogen (at least one of the following)
    - Total Nitrogen
    - Nitrate Nitrogen
    - Ammonium Nitrogen
- CEC (cation exchange capacity)
- Minor nutrients: at least three of the following:
  - Calcium
  - Magnesium
  - Potassium
  - Sodium
  - Aluminum
- Reported soil health ranking should be assessed to ensure that they match reported rankings

9.4. Animal Welfare

- Review animal welfare rankings to ensure the proper number of requirements were met.

9.5. Ecosystem Health

- NDVI:
  - Assessment of the NDVI analysis used over the project area
  - Visual inspections on the ground or by remote sensing for the project area and surrounding area
- Vegetation Structure Landscape Metrics:

- ○ Assessment of the remote sensing protocols used to analyze vegetation landscape metrics within the project area
  - ○ Visual inspections on the ground or by remote sensing
- ● Bare Soil:
  - ○ Assessment of the remote sensing protocols used to analyze bare soil within the project area
  - ○ Visual inspections on the ground or by remote sensing in both the project area and surrounding fields

Supplements

S.1. Co-Benefit Examples

S.1.1. SOIL HEALTH EXAMPLE ASSESSMENT

pH Example:

Methodology Description:

The standard method of measuring soil pH in [project area] is to use a 1:5 (soil:water) suspension method.

Benchmarks:

- According to [source], within [project area] "plant growth, and most soil processes, are favored by a pH range between 5.5 and 8" . Within this range, an optimal range of pH is 6-7 .

Given these ranges, the soil pH ranking for pastures in X is:

-POOR: < 5.5 or > 8.0

-MODERATE: > 5.5 and <6.0 or >7.0 and 8.0<

-OPTIMAL: 6.0 - 7.0

Results:

- Average pH values from [monitoring year] [project name] soil samples: [average of all samples]

- According to the ranking system the classification for [monitoring year] samples falls into the [Poor/Moderate/Optimal] range

The distribution of the pH rankings for the [project name] [monitoring year] data falls within the ranges illustrated below:

[Project Name] pH [Year]: Sample Distribution

Moderate 16.7%
Poor 6.7%
Optimal 76.7%
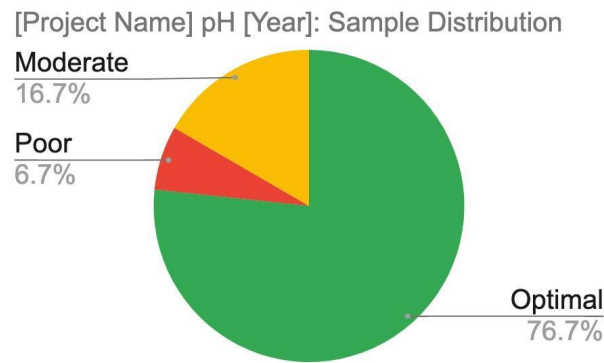
S.1.2. ANIMAL WELFARE EXAMPLE

An example of animal welfare metrics are outlined below according to Cattle Standards and Guidelines for Australia. The Animal Welfare metric ranks within 4 possible categories depending on the percent of accomplished items from the following list (more detailed information Australian Animal Welfare Standards). The calculation is only considered in relation to the total number of items that are applicable to the project.

1. Responsibilities: Are responsibilities fully addressed, clear responsibilities outlined in individual role descriptions and supported by appropriate company policies and training?

2. Access to feed and water: Do the animals on this land have reasonable access to adequate and appropriate feed and water?

3. Risk management: Are records of risk management kept via company policies and monthly manager reports? Are animals managed to minimize the impact of threats to their welfare including, extremes of weather, natural disasters, disease, injury and predation? Are there inspections of the animals at intervals, and at a level appropriate to the production system? Are there systems in place to ensure appropriate treatment for sick, injured or diseased animals at the first reasonable opportunity?

4. Facilities: Are facilities constructed and maintained to allow humane treatment of animals to ensure their welfare?

5. Animal handling: Are staff trained in handling and management practices that are appropriate (such as low stress stock handling) to minimize the risk to the welfare of the animals? See details in Section 5 of Australian Standards linked above.

6. Castration / dehorning: Are the practices of castration, dehorning and spaying only done when necessary and in a manner that minimizes the risk to the welfare of the animal, particularly pain and distress? See details in Section 6 of Australian Standards linked above.

7. Breeding: Are breeding and management practices appropriate to minimize the risk to the welfare of the animals? See details in Section 7 of Australian Standards linked above.

8. Calf raising systems: Are calf-rearing systems appropriate to minimize the risk to their welfare? See details in Section 8 of Australian Standards linked above.

9. Dairy: Are dairy animals managed to minimize the risk to their welfare? Is a daily inspection taking place of lactating dairy cows? Are there systems in place to minimize the heat stress of animals? Is tail docking only carried out under veterinary advice to treat injury or disease? Do the animals kept on feed pads for extended periods have access to a well drained area for resting?

10. Feedlots: Are animals in feedlots managed in a way that minimizes the risk to animal welfare? See details in Section 10 of Australian Standards linked above.

11. Slaughtering: Where it is necessary to kill animals, is it done promptly, safely and humanely? See details in Section 11 of Australian Standards linked above.

S.2. Option for Automation

Regen Network Development Inc. has built a series of work packages automating many of the workflows found within the methodology, greatly reducing the amount of time and work needed to complete a monitoring round. The two main workflows automated within this project are image processing (described in Section 3.3.1.1), and the calculation of CO_2 equivalent stocks and livestock emissions using the satellite-based calibration workflow (Section 3.3).

S.2.1 **CARBON STOCK ESTIMATION**

An automated workflow that uses Google Earth Engine to predict SOC percent and SOC stock for a study area using soil sample data and Sentinel-2 imagery can be found here: https://github.com/regen-network/open-science/tree/master/socMapping. In that GitHub repository you will find a user guide and two Jupyter Notebook scripts.

The workflow consists of two steps. The first step extracts pixel data from time series Sentinel-2 imagery and other layers that correspond with soil sample point locations. The second step uses the extracted data from the first step to find the variables that provide the best fitting linear regression model. Variables from the model with the best fit are then used to calculate metrics using leave-one-out cross-validation (R square, Adjusted R square, RMSE, and normalized RMSE) to calculate accuracy of the predictions. This is done for each date of the time-series

Sentinel-2 imagery. Output is a CSV file that can be viewed to find the image date and specific variables that produce the best SOC predictions.

S.3. Data reporting

Field data

- Sampling dates corresponding to each sampling round, indicating the baseline.
- Sample size:
    - Data entry parameters for the sample size calculator:
        - Landscape variability class
        - grasslands area of the project (ha)
    - Outputs:
        - Minimum sample size
        - Optimal sample size
        - Indicate the final sample size after sample collection
- Sampling depth through all the project lifetime.
- Tool used to extract soil cores
    - If core sampler used, include tool diameter in mm

GIS data- Carbon accounting

- Project boundary (polygon)
- Sampling points (points)- GNSS coordinate for each sample location and sub-samples (if applicable)
- The GNSS receiver model used for geolocating the sampling points must be reported in the monitoring report.
- GNSS device used to record sample location

- If subsamples are taken, please document the geometry of the sub-samples. Distance and direction from a reference point are recommended.
- Grasslands mask (polygon)
- If stratification is performed:
    - The monitoring report must specify the methods and variables used to define strata.
    - A geospatial file defining stratified zones used for each monitoring round must be provided with each report.

- - Also, any additions or any changes in the sampling points between sampling rounds must be clearly reported.
- The remote sensing images and any ancillary data used for the regression/ machine learning or interpolation models (full reference to sensors or satellite, bands, dates).
- The *Monitor* must provide a detailed report of the method used for calculating the SOC stocks, and any metrics used to evaluate accuracy and uncertainty, as well as the justification for selecting a specific model.
- Outliers can be removed, but the methods used and a justification must be included in the report.
- The *Monitor* must report the spatial interpolation method or PTF used for the calculation of Bulk density if choosing option A in section 3.3.1.2.
- Any deviations from the methodology must be reported.

Acceptable polygon data formats include ESRI shapefile OGC GeoPackage, KML/KMZ and GeoJSON.

Lab data- Soil Organic carbon stocks (100% samples)

The original lab reports should be provided, containing the raw data for:

- SOC concentration (%) per sample.
- Bulk density, or the input data for calculations and the final estimates, per sample.

Some reference to the lab (name, link) must be provided.

Farm data- GHG emissions accounting

- The number of animals present, the number of days the animals were located in the project area, and the default emission factor (and its citation) for the corresponding group of livestock, must be cited in the report.
- Any other relevant data for the estimation of GHG from other sources, if it applies.

Lab data- Soil health (min. 30% of total samples)

The original lab reports should be provided, containing the raw data for:
- pH
- Macronutrients
  - Phosphorus
  - Potassium
  - Nitrogen (at least one of the following)
    - Total Nitrogen
    - Nitrate Nitrogen

■ Ammonium Nitrogen
    ● CEC (cation exchange capacity)
    ● Minor nutrients: at least three (3) of the following:
        ○ Calcium
        ○ Magnesium
        ○ Potassium
        ○ Sodium
        ○ Aluminum

Local benchmarks for each of the included indicators should be also provided.

GIS data- Ecosystem health

Ecosystem Vigor and Resilience:

    ● Project boundary (polygon)
    ● Control area (polygon)
    ● Grasslands mask (polygon)
    ● Images used for analysis
    ● The report must include the NDVI results from control and project areas
    ● The report must include the bare soil results from control and project areas.

Ecosystem Organization:

    ● Vegetation Structure Landscape Metrics: The choice of landscape metrics and thresholds for
      scoring and the corresponding cites to the scientific literature must be provided in the report.
    ● Information on the water bodies or watercourses when corresponding (area, perimeter,
      geolocation)

Final Results and scores

The table with partial and final scores

The creditable carbon change (tCO2e) and its corresponding partial components: UD and Net CO2e
REDUCTION values for the reporting period.