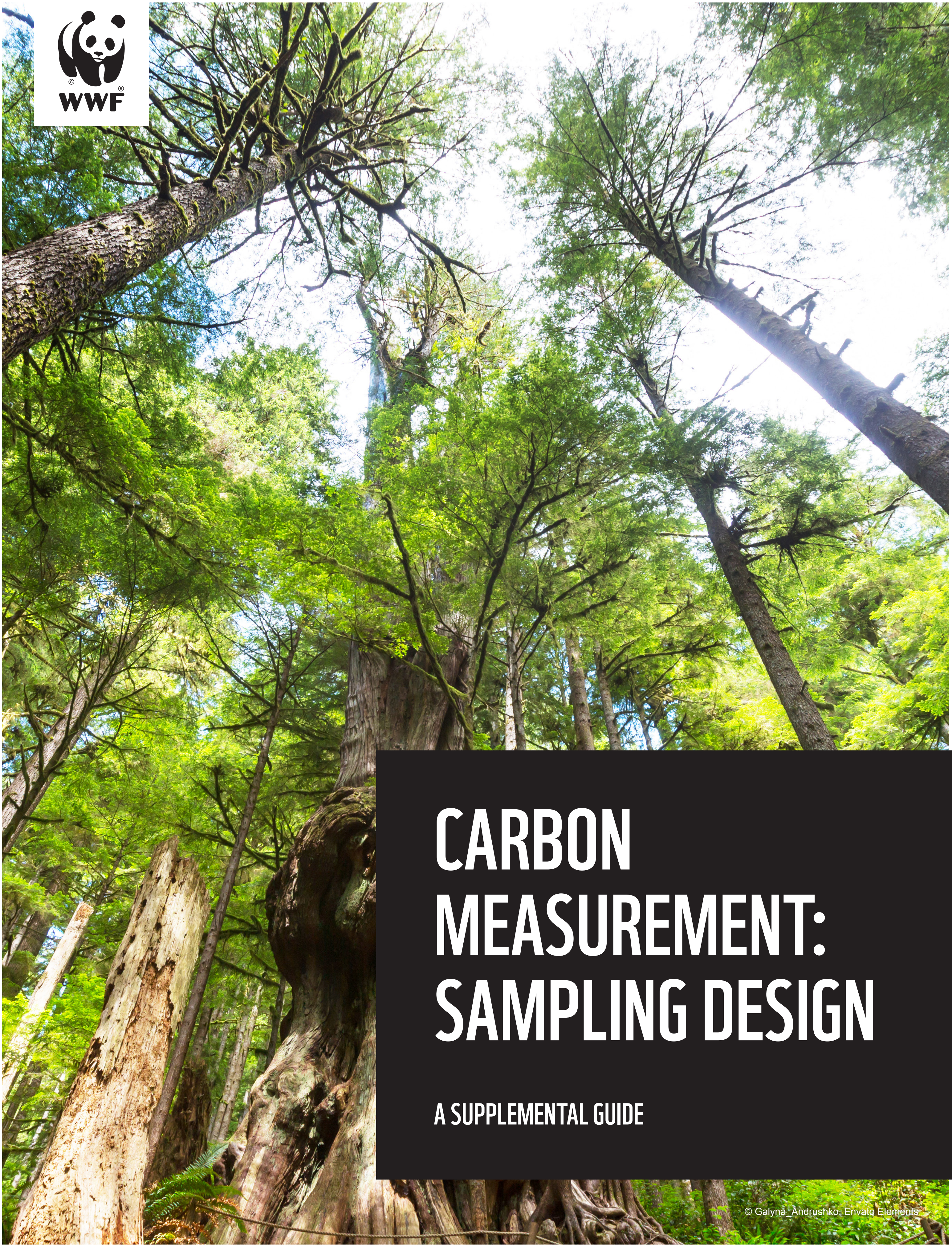
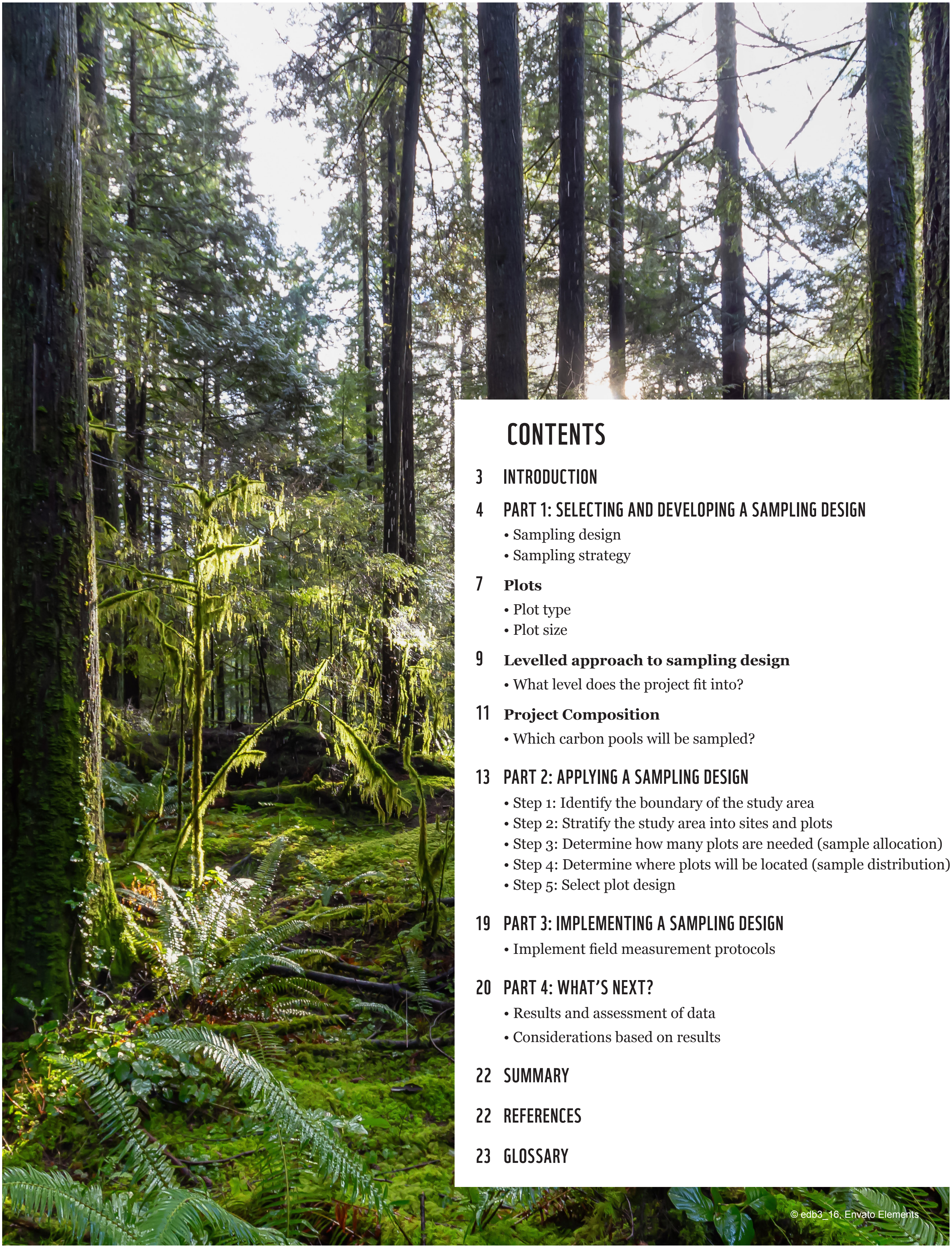


CARBON MEASUREMENT: SAMPLING DESIGN

A SUPPLEMENTAL GUIDE



CONTENTS

INTRODUCTION

Measuring carbon across landscapes can help communities understand how effective different ecosystems are at capturing and storing carbon. This knowledge can advance land-use planning and conservation actions, including nature-based climate solutions.

The most common method for accurately measuring ecosystem carbon involves in-field sampling. But before heading into the field, it is important to have a clear plan about where to sample, how many plots and samples are needed, and how to best set up those plots. This plan is known as a sampling design.

This guide provides an overview of how to create a sampling design for basic and intermediate carbon measurement projects. It will cover a range of expected project outcomes and provide additional resources for specific ecosystem types. This guide has four topics:

- **Part 1** defines sampling design and sampling strategy and describes the rationale for each strategy. It also includes considerations for choosing plots and determining the level of complexity of your project.
- **Part 2** describes the five steps for applying your sampling design once it's chosen.
- **Part 3** briefly describes the field measurement protocols needed to gather the data for your project and offers links to resources on exactly how to sample in different ecosystems.
- **Part 4** offers considerations and questions that will inform the next steps of your project after choosing and implementing your sampling design.

Note: Key terms are in **bold and green**. They are linked to and defined in the glossary at the end of this guide.

1 SELECTING AND DEVELOPING A SAMPLING DESIGN

SAMPLING DESIGN

A **sampling design** is a framework for choosing what and where to sample to estimate the carbon stored in a larger **ecosystem** area. Sampling designs allow for the strategic measurement of smaller sections (i.e., sites and plots) within the larger study area. Combining measurements from multiple plots allows us to estimate the value for the study area.

The **study area** encompasses the entire area to be investigated.

Within the study area, specific, smaller **study sites** (strata) are identified to capture variation of the area. Study sites are used to divide the study area up into smaller, uniform locations, and are selected based on characteristics of the ecosystem, management type or community interests.

Plots are laid out within study sites to obtain a representative sample of the study site. In-field sampling will occur within these plots. Plot locations are selected based on sampling design, which can be random, systematic, stratified-random, or based on convenience.

STUDY AREA

THE ENTIRE AREA THAT YOU WISH TO INVESTIGATE

STUDY SITES

IDENTIFIED TO CAPTURE THE VARIATION OF THE AREA

PLOTS

WHERE SAMPLING TAKES PLACE

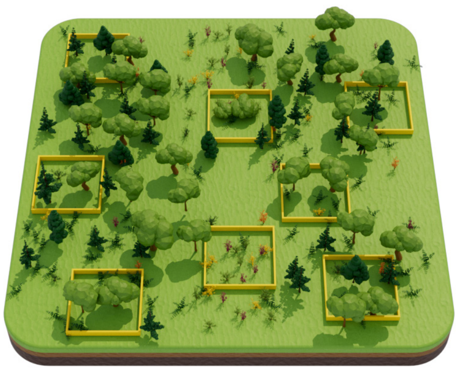
SAMPLING STRATEGY

A **sampling strategy** is a plan for deciding where sites and plots will be located within the study area. A sampling strategy maps out the plots and study sites to most effectively estimate the **carbon stock** for the larger study area. Each sampling strategy has its benefits and limitations (see figures that follow). Choosing a sampling strategy depends on the characteristics of the landscape and the project goals.

> **Note:** If the sampling strategy and plot types are already known, skip to the section "Levelled approach to sampling design" for steps on choosing a project level.

SAMPLING STRATEGY TYPES

RANDOM SAMPLING

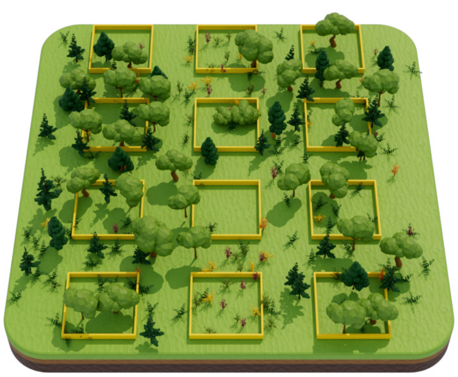


What: Plots are randomly selected across the study area.

How: An open software program can be used to automatically lay a grid and distribute plot locations (see "Sampling Design – Random Sampling Tool" in WWF-Canada's Carbon Measurement Learning Library). Alternatively, you can manually overlay a grid on the study area and assign a number to each grid intersection. An online tool can then be used to randomly select numbers within the range provided, indicating where to designate plots.

Why: This method assumes that every potential plot has an equal chance of being selected, which works well when the study area is uniform or if there is no prior data about the study area. Typically, random sampling is chosen for its simplicity and statistical rigour and is therefore suggested as a default method.

SYSTEMATIC SAMPLING



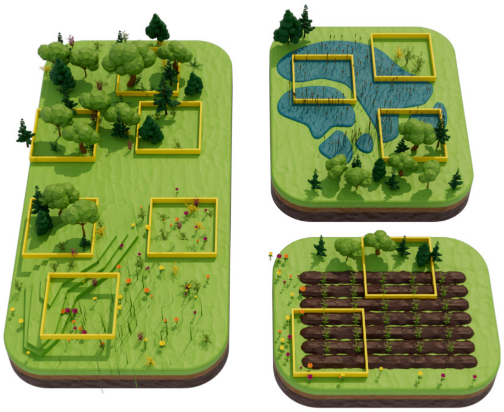
What: Plots are selected at regular intervals across the study area.

How: An open software program can be used to automatically lay a grid and distribute plot locations (see "Sampling Design – Systematic Sampling Tool" in WWF-Canada's Carbon Measurement Learning Library). Alternatively, you can manually overlay a grid on your entire study area and determine the interval by which plots will be selected. The spacing between plots will depend on the size of your study area and how many plots are needed; spacing will remain consistent across the study area. To avoid bias, assign the starting plot randomly using the same method described for "Random sampling." For example, you may assign plots every 750 metres (m) starting from the western edge of the study area and moving east. At the eastern edge of the study area, move 1.5 kilometres (km) south and then move west along the grid, assigning plots every 750m.

Why: This strategy ensures even coverage of the study area and is typically used for smaller study areas with uniform ecosystem types. Systematic sampling may also be used along a continuous ecological gradient of interest, such as a wetland gradient. The benefit of this strategy is that it guarantees wider coverage of the study area; a limitation is that it may miss patterns of variation that occur between the selected intervals.

Note: Use a systematic sampling strategy only when the variation of ecosystem types is already known. Otherwise, consider using a random sampling strategy.

STRATIFIED-RANDOM SAMPLING



What: Plots are randomly selected after the study area is divided into study sites (often called "strata") based on certain characteristics.

How: Strata are selected based on characteristics of the ecosystem, management type or community interests. Once strata are identified, plots are randomly assigned within them using the method previously described under "Random sampling."

Why: A stratified-random sampling strategy is the most accurate and cost-effective strategy for sampling when there is known variability within the study area because it represents each unique part of a study area. This may provide more accurate carbon stock estimates for specific strata. For example, if one stratum is for secondary forests and one is for old-growth forests, you will be able to determine average carbon estimates specific to those forest types, while using random sampling alone would group secondary and old-growth forests together. This sampling strategy is appropriate when subregions make up a very small proportion of the study area (e.g., a very large study area containing small, inconsistent patches of restored forests), as these subregions might be missed when using other sampling methods. Stratified-random sampling is not advised when the study area is largely uniform.

CONVENIENCE/PRACTICAL SAMPLING

What: Plots are selected where sampling is most accessible.

How: Plots are established at least 50m inside the study area **boundary** in locations where they can be easily accessed by road, trail, canoe route or other access point.

Why: While not statistically rigorous, this is a useful method when performing an initial assessment of a study area, as it can be a low-cost and low-commitment way to inform decisions about future sampling.

PLOTS

Plots can vary in type and size, depending on what is being measured and how often. Plots can be used to sample an area once (referred to as single-use plots) or repeatably over time (permanent plots).

PLOT TYPES

SINGLE-USE

Single-use plots are effective for project areas that will be measured once, and/or when **destructive sampling** techniques will be used.

In single-use plots, destructive sampling can occur within the plot but should only be carried out after all non-destructive surveying is completed. Peat sampling, for example, is a destructive sampling technique, so vegetation surveys must be completed before peat samples are collected.

PERMANENT

Permanent plots are intended to be sampled repeatably over time, using **non-destructive** sampling techniques that measure the exact same vegetation during each field **survey**.

The steps for setting up permanent and single-use plots can be found in the guide “Measuring Carbon in Trees” (see page 10).

PLOT SIZE

Plot size depends on the type of vegetation being measured. Generally, there are three sizes of plots:

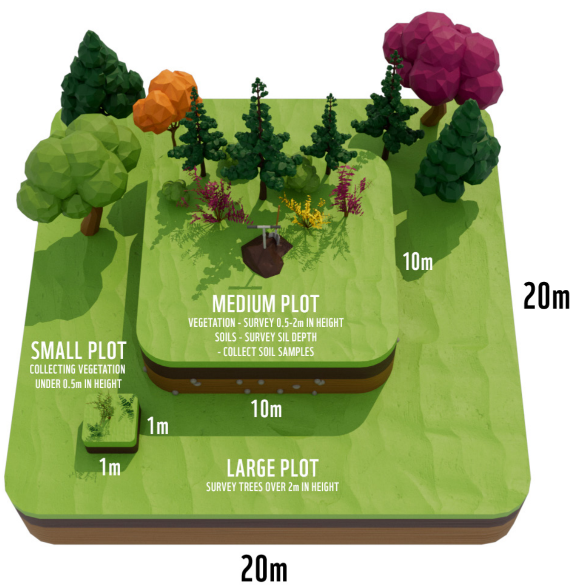
Large plots are typically 400m² in area and are for measuring trees over 2m in height.

Medium plots are generally 25m² (range from 16-100m²) in area and are designated for trees and shrubs between 0.5-2m in height.

Small plots are typically 1m² or smaller (range from 0.25-1m²) in area and are designed to measure plants less than 0.5m in height, as well as **ground vegetation**, such as moss or lichen.

INTEGRATED PLOT DESIGN

All three plot sizes can be overlaid to create what is known as an **integrated plot design**, also referred to as a nested plot design, in which the centre mark for all plots is identical, and all three plot sizes can be mapped relative to this centre mark. Both permanent and non-destructive single-use plot types can incorporate an integrated plot design. Using an integrated plot design is recommended when measuring multiple **carbon pools**.



LEVELLED APPROACH TO SAMPLING DESIGN

Defining the project scope, study area and ecosystems of interest can effectively guide sampling design within the three levels outlined in this section.

What level does the project fit into?

The scope or intent of a project can be divided into "levels" to help determine sampling design. A level indicates the degree of methodological complexity, where Level 1 is the most basic, Level 2 is intermediate and Level 3 is the most complex. Each level builds on a previous one, allowing for a gradual increase in the accuracy of a project as its goals evolve.

LEVEL 1

- Great for community or learning project
- Requires minimal resources
- Data is not detailed enough for formal reporting

LEVEL 1 – BASIC APPROACH

If factors such as capacity, training resources and funding are limited, a Level 1 approach can provide basic carbon estimates at a lower cost. Level 1 methods can support carbon estimates for protection, restoration and improved management, but may not meet the measurement, reporting and verification (MRV) requirements of carbon crediting programs or other projects in which accuracy and precision are critical.

LEVEL 2

- Higher accuracy
- Ideal for reporting purposes
- Requires more planning and support

LEVEL 2 – INTERMEDIATE APPROACH

Level 2 approaches enhance the rigour and accuracy compared to Level 1, resulting in more reliable carbon estimates for public reporting. For future participation in carbon crediting programs and to ensure collected data meets reporting and verification requirements, refer to Level 3.

LEVEL 3

- Highest accuracy
- Necessary for MRV reporting and carbon crediting programs

LEVEL 3 – ADVANCED APPROACH

Level 3 is considered the most rigorous and accurate, making it ideal for MRV processes related to carbon crediting programs and other projects in which accuracy and precision are critical. Given that reporting requirements differ, **subsequent sections of this guide describe steps and considerations only for Levels 1 and 2**. If there is interest in pursuing a Level 3 approach, we recommend consulting the requirements or protocols that apply to your case.

The following table outlines considerations for each sampling design level.

LEVEL 1	LEVEL 2	LEVEL 3
Sampling strategy: Use convenience/practical or random sampling design (no specialized computer software required).	**Sampling strategy:** Use stratified-random sampling (non-uniform study area) or random sampling (uniform or unknown study area) and mapping software to map sites and plots.	**Sampling strategy:** Use a stratified-random sampling (non-uniform study area) or random sampling (uniform or unknown study area) with digital mapping for site and plot locations.
Integrated plot design: Typically, only trees and soils will be measured (as they constitute the largest carbon pools).	**Integrated plot design:** Set up medium and small vegetation plots, as well as soil and tree plots, based on project needs. See “Plots” section for a visual example.	**Integrated plot design:** Depending on project needs, set up medium and small vegetation plots, along with soil and tree plots, as needed (see “Plots” section).
External resources: May require contracted laboratory analysis.	**External resources:** May require contracted laboratory analysis.	**External resources:** Refer to carbon crediting standards and protocols before beginning project work. May require contracted laboratory analysis.
Plots: The number of plots will be determined by the available budget, which may affect accuracy.	**Plots:** Use permanent plots for repeated sampling whenever possible. Ensure there are enough plots to meet accuracy requirements based on acceptable error (see Step 3 “Determine sample allocation” under Level 2).	**Plots:** Use permanent plots for repeated sampling whenever possible. Ensure there are enough sample plots to meet accuracy requirements based on acceptable error (see Step 3 “Determine sample allocation” under Level 2 approach). Are mapping and software tools available? Most projects with complex MRV reporting require specific mapping and carbon modelling software.

Important note about Level 3

Project protocols and sampling design should conform to MRV reporting requirements and/or carbon crediting standards and programs if those are of interest. The following resources may be helpful:

WWF: Beyond Carbon Credits

First Nations Carbon Toolkit

British Columbia Forest Carbon Emissions Offset Project Process

Coastal First Nations Great Bear Initiative: Carbon Credits

VERRA Carbon Standard

Open MRV

Forest Carbon Partnership

PROJECT COMPOSITION

Which carbon pools will be sampled?

The types of carbon pools to be measured will determine the methods needed to estimate carbon stocks and form the basis for how to stratify (i.e., subdivide) the study area. Methods are available in WWF-Canada's carbon measurement guides.

The tables below summarize the different carbon pools and sampling design considerations related to Level 1 and Level 2 projects. Details related to each pool (trees, non-tree vegetation, non-peat soils and peat soils) can be found in the associated guides.

CARBON POOL: TREES **(≥2m height)**

SAMPLING DESIGN CONSIDERATIONS	LEVEL 1: BASIC APPROACH	LEVEL 2: INTERMEDIATE APPROACH
Sampling strategy	Systematic, random, stratified-random, convenience	Systematic, random, stratified-random Determine sample allocation to meet desired level of accuracy
Plot layout	Standard 400m² sampling plots	Standard 400m² plots, with one permanent plot per strata (highly recommended)
Measurements	Species, **DBH**, height for each tree in plot	Species, DBH, height for each tree in plot

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CARBON POOL: VEGETATION (NON-TREE) **(≤ 2m height)**

SAMPLING DESIGN CONSIDERATIONS	LEVEL 1: BASIC APPROACH	LEVEL 2: INTERMEDIATE APPROACH
Sampling strategy	Systematic, random, or convenience	Systematic, random, stratified-random
Plot layout	Medium and small vegetation plots An integrated plot design is a useful tool to pair these plots with other sampling in the same study area	Medium and small vegetation plots. Reminder that destructive sampling techniques are not used in permanent plots For single-use plots, an integrated plot design is a useful approach to pair these plots with other sampling
Measurements	**Short-statured trees** between 0.5m–2m in height: species, DBH at 0.3m, height **Shrubs** and other non-tree vegetation between 0.5m–2m in height: cubic volume For other types of vegetation, including those under 0.5m in height, refer to the guide	Short-statured trees between 0.5m–2m in height: species, DBH at 0.3m, height Shrubs and other vegetation between 0.5m–2m in height: cubic volume For other types of vegetation, including those under 0.5m in height, refer to the guide

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CARBON POOL: NON-PEAT SOILS

SAMPLING DESIGN CONSIDERATIONS	LEVEL 1: BASIC APPROACH	LEVEL 2: INTERMEDIATE APPROACH
Sampling strategy	Systematic, random, or convenience	Systematic, random, or stratified-random
Plot layout	Samples taken are in the plot centre	For single-use plots, samples are taken in the plot centre For permanent plots, samples are taken directly outside of the plot area
Measurements	Measurements taken by coring or digging soil pits In field: Soil sample depth, total core length In lab: Bulk density, carbon content Average carbon stock per plot (kg C/m^2)	Measurements taken by coring or digging soil pits In field: Soil sample depth, total core length In lab: Bulk density, carbon content Average carbon stock per plot, site, and study area (kg C/m^2) Total carbon stock (kg C)

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CARBON POOL: PEAT SOILS

SAMPLING DESIGN CONSIDERATIONS	LEVEL 1: BASIC APPROACH	LEVEL 2: INTERMEDIATE APPROACH
Sampling strategy	Systematic, random, or convenience	Systematic, random, or stratified-random
Plot layout	Samples are taken in plot centre	For single-use plots, samples are taken in plot centre For permanent plots, samples are taken directly outside of the plot area
Measurements	Measurements taken by coring In field: Soil sample depth, total core length In lab: Bulk density, carbon content Average carbon stock per plot (kg C/m^2)	Measurements taken by coring In field: Soil sample depth, total core length In lab: Bulk density, carbon content Average carbon stock per plot, site, and study area (kg C/m^2) Total carbon stock (kg C)

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2 APPLYING A SAMPLING DESIGN

5 STEPS TO APPLYING A SAMPLING DESIGN

While Part 1 of this guide offers guidance for developing a sampling design and strategy, Part 2 focuses on the steps needed to apply the chosen design for Levels 1 and 2. This process follows five steps, each of which will be described in this section:

1. IDENTIFY THE BOUNDARY OF THE STUDY AREA
2. STRATIFY THE STUDY AREA
3. DETERMINE THE SAMPLE ALLOCATION
4. DETERMINE THE SAMPLE DISTRIBUTION
5. SELECT A PLOT

STEP 1: IDENTIFY THE BOUNDARY OF THE STUDY AREA

The size of the project area will help determine the number of sites, plots and samples needed to accurately determine the **average carbon stock** (kg C/m²) and **total carbon stock** (kg C) of the study area. This applies to projects of any scale.

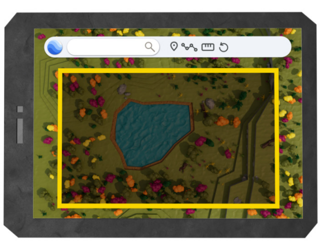
PROJECT AREA: HOW BIG IS THE STUDY AREA?

Is the area of interest a small section of forest or patch of grassland? If it can be explored on foot or with a drone, it's likely considered "small" (i.e., less than 1,000 hectares [ha]). A "large" project typically exceeds 10,000ha and cannot be explored solely on foot.

The size of the study area will dictate if mapping software is needed.

- For small projects (<1,000ha), use drone or ground surveys to identify different ecosystem types and understand variations across the area. Like large-area projects, small-area projects can be mapped using software such as Google Earth, ArcGIS or QGIS to identify the area boundary and designate plots. For small areas, sampling 10 to 50 plots is sufficient for a full-scale carbon measurement project.
- For large projects (>10,000ha) where drone or ground surveys aren't feasible, mapping software is needed to develop a sampling strategy. Use a strategy from the "Sampling design and strategy" section of this guide to determine sites and plots.

Level 1:
While useful for accuracy, identifying a study area boundary is not required for Level 1 projects. In some cases, project objectives might be to explore preliminary results (i.e., carbon stock per unit area) to guide future work, with boundary-mapping efforts to be done later. These preliminary results can be compared to expected carbon stock values to determine if a Level 2 approach is beneficial.



Level 2:
Identifying the boundary of the study area is required for Level 2 projects because it allows one to measure the study area's size, map out the sites and plots based on a sampling strategy, and use statistical tools to assess the accuracy of estimates.

Use mapping software to draw a boundary around the entire study area. Obtain the total area of the study area (km² or m²).

Open-access tools for mapping a boundary:

Google Maps tutorial

Google Earth Pro tutorial

Google Earth Engine tutorial

For a full description for drawing or importing your study area in Google Earth Engine, please see "Sampling Design – Random Sampling Tool" in WWF-Canada's Carbon Measurement Learning Library.

STEP 2: STRATIFY THE STUDY AREA

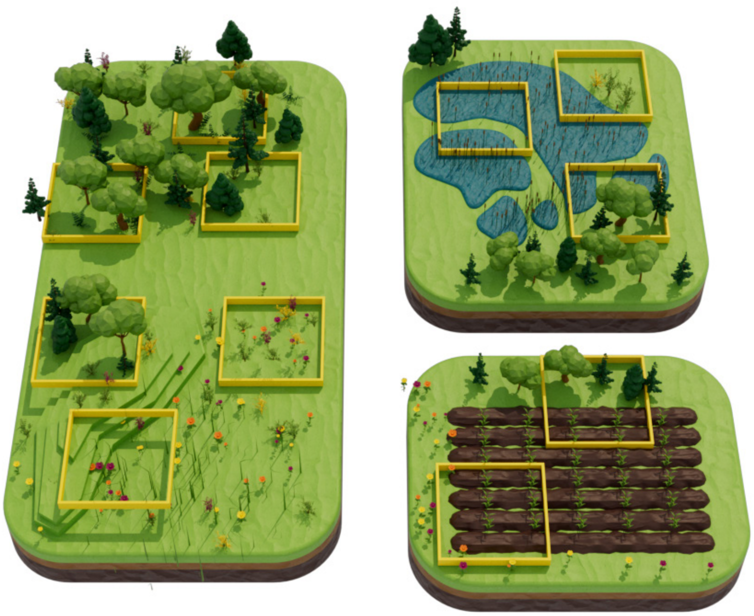


Image: Example of study area stratified into sites and plots.

Stratification is applicable to both small and large projects, but not necessarily required to achieve project goals. If using stratification, the most appropriate sampling strategy is the "stratified-random sampling" method.

Stratifying the area can yield more accurate carbon stock estimates and provide a cost-effective sampling strategy. It can also be done after sampling, when more information about the study area is available.

Stratification can be informed by:

- Knowledge from the community; i.e., map each stratum using software and community expertise.
- Land use and land cover maps that are already stratified.

Examples of open-access tools to stratify your study area:

Google Earth Engine tutorial

QGIS tutorial

May require: Land use and land cover classes processed in Google Earth Engine (tutorial)

For a full description of stratification using Google Earth Engine, please see the guide "Sampling Design Workflow" in WWF-Canada's Carbon Measurement Learning Library.

STEP 3: DETERMINE THE SAMPLE ALLOCATION

HOW MANY PLOTS ARE NEEDED?

Level 1:
Determining the minimum number of plots is not required for Level 1 projects, as they are not intended to meet the monitoring, reporting and verification requirements of carbon crediting programs. Instead, the number of plots can be determined by staff availability and budget. If there is interest in increasing the accuracy of your results and determining the minimum number of plots for your study area, refer to the guidance for a Level 2 approach.

Level 2:
Determining the number of plots to sample within the study area is required to determine the minimum number of samples to be taken based on the desired accuracy of the estimates. See below for how to calculate the number of plots needed using the “Sample Design Sample Allocation Calculator” or refer to the “Sampling Design – Random Sampling Tool,” which are both found in WWF-Canada’s Carbon Measurement Learning Library.

The “Sampling Design – Random and Systematic Sampling Tools” and “Sample Design Sample Allocation Calculator”* can be found in WWF-Canada’s Carbon Measurement Learning Library.

To use it, you will need:
Total size of study area
Allowable error (default is 10%)

Optional values:
Allocation of plots per study sites in stratified areas

For example, if the study area is 10,000km^2 and the allowable error is 10%, 43 plots will need to be set up.

*The method provided here for determining sample allocation is from the United Nations Framework Convention on Climate Change methodologies toolkit (Version 1). This framework uses the central limit theorem to estimate the minimum number of plots needed to meet a desired level of accuracy and precision for estimating the carbon stock of a large area.

STEP 4: DETERMINE THE SAMPLE DISTRIBUTION

WHERE WILL PLOTS BE LOCATED?

Convenience sampling

Systematic sampling

Stratified-random sampling

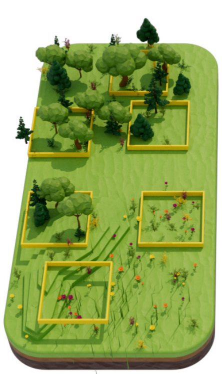
Random sampling

For both Levels 1 and 2, determining sample distribution is required. Refer to the “Sampling strategy” section of this document to choose a strategy that aligns with the project goals.

Sample distribution depends on the chosen sampling strategy:

Convenience/practical sampling: No mapping products needed. Plots are in accessible locations, determined by budget and area accessibility.

Systematic or random sampling: Include the entire study area. Each plot location is equally likely. Use online mapping tools (see the toolbox that follows) or manually divide the study area with a grid and choose squares randomly, or use the random walk method (examples are outlined here).



Stratified-random sampling: Allocate (Step 3 “Sample allocation”) plots proportionally based on the size of each study site (e.g., a 50ha area will have twice as many plots as a 25ha area).

- Plots per strata = [Size of strata in km^2 / Total size of study area in km^2] *Minimum # of plots for entire study area.
- The size of the strata will vary based on community expertise (e.g., traditional harvesting areas, existing or historical wetlands, etc.) or based on land use and landcover maps.
- In the case of multiple sizes of strata, complete the above equation for each size to determine the number of plots per strata of that size.

Tools to determine the sample allocation and distribution for random, systematic or stratified sampling methods:

Random, Systematic, and Stratified Sampling Tools

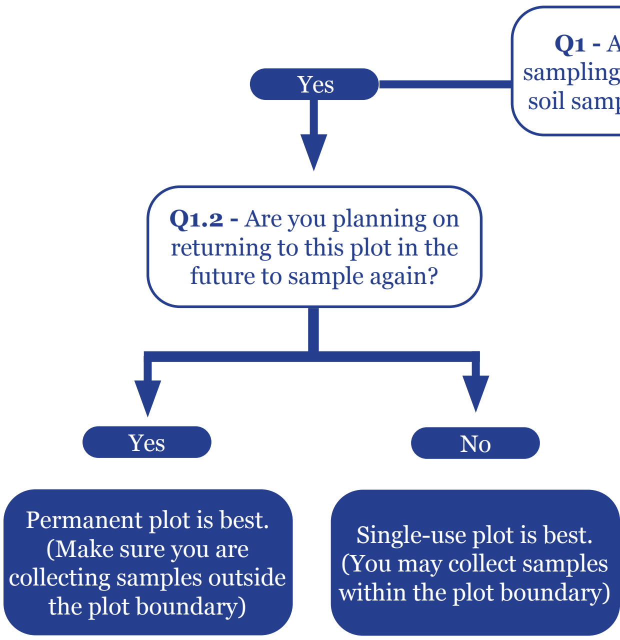
Google Earth Engine tutorial

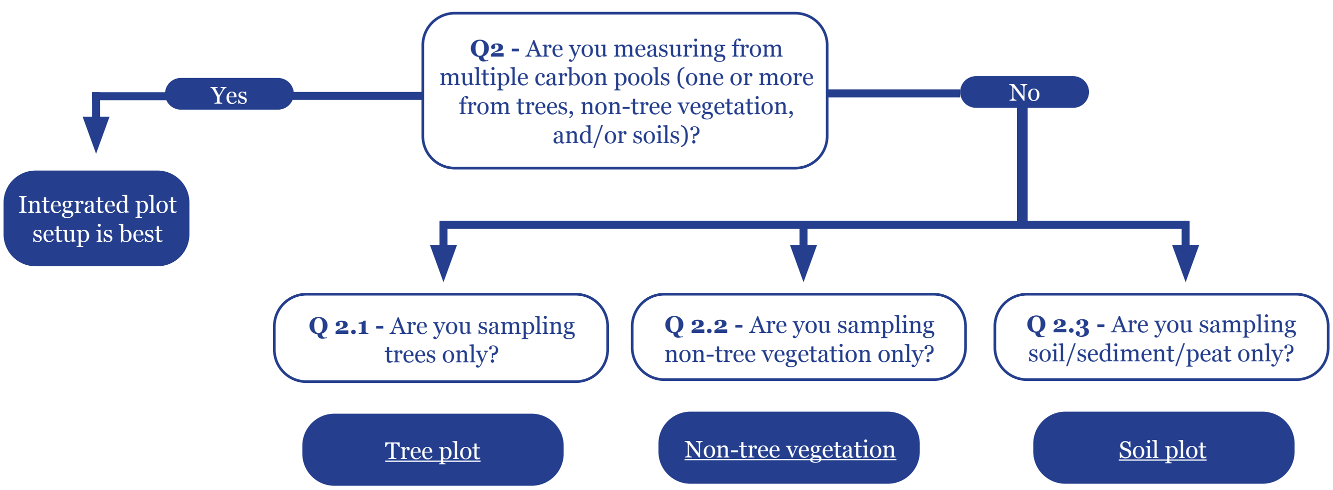
QGIS tutorial

A tool to support these calculations can be found in WWF-Canada’s Carbon Measurement Learning Library.

STEP 5: SELECT A PLOT DESIGN

For both Levels 1 and 2, selecting a plot design is required to obtain a carbon estimate of the study area. The choice of plot type and size depends on the project goals and the carbon pools and ecosystems being evaluated. Use the decision tree below to help guide you based on your project goals.





IMPLEMENT FIELD MEASUREMENT PROTOCOLS

For both **Levels 1 and 2**, implementing a field measurement protocol is required for obtaining high quality measurements to estimate the carbon stock of the study area. Several methods already exist for carbon measurement, including for forests, small trees, shrubs, ground vegetation and different soil types (see section "Project composition" for details).

The protocol selected depends on the ecosystem type and the carbon pool(s) to be measured. Since the study area may contain multiple ecosystem types, methods can be combined to cover all ecosystems in the study sites and study area.

TYPES OF ECOSYSTEMS

Canada's ecosystems are exceptionally diverse and vary in vegetation and soil. From a carbon sampling perspective, they can be grouped as referenced in the "Project composition" section:

- Trees: contain a dominant tree canopy
- Vegetation (non-tree): dominated by shrubs or low growing vegetation
- Non-peat soils
- Peat soils: found in bogs, fens and certain swamps

For details on the other tools needed for field measurement, please visit WWF-Canada's Carbon Measurement Learning Library.

4 WHAT'S NEXT?

RESULTS AND ASSESSMENT OF DATA

Results from field measurements can be converted into an estimate of the average carbon stock (kg/m^2) and the total carbon stock (kg) of the study area. Both metrics are valuable when reporting on the results from carbon stock assessments.

For both Levels 1 and 2, converting the data collected from the field method to an estimate of carbon stock is required for evaluating the outcome of the project. Methods for doing this are included in WWF-Canada's Carbon Measurement Learning Library, along with resources and tools for carbon stock estimation.

CONSIDERATIONS BASED ON RESULTS

Once you've developed a sampling design tailored to your project's goals and budget, you may feel ready to begin field measurements. Before heading out, we encourage you to review this section–it may help you identify additional priorities or considerations that could strengthen your approach.

The questions and prompts are designed to spark meaningful conversations with your project team, department colleagues, community members and decision-makers such as Chief and Council or other governing bodies.

Think of these questions as jumping-off points to help connect your carbon measurement work to other stewardship and management efforts.

FUTURE-FOCUSED:

1. Is there interest in expanding sampling (e.g., adding more forest survey plots) in the same ecosystem type for deeper knowledge?
2. Is there interest in sampling from different ecosystems (e.g., switching from forest surveys to wetland soils) for a broader understanding of a territory, community or region?
3. When planning future carbon measurement, consider comparing your current results to those from similar areas.
   a. Example: If your study area consists of a conifer-dominated forest, you could compare its carbon storage values to other conifer-dominated forests in the area. You may also want to include study areas where other variables are present.
      Study area A: Conifer-dominated forest
      Study area B: Conifer-dominated forest with history of wildfire
      Study area C: Conifer-dominated forest at higher elevation than study areas A and B
4. Is there capacity and interest in setting up permanent plots for carbon measurement?
5. If you started with a Level 1 approach, is there capacity and interest to progress to a Level 2 or Level 3 approach?
   a. For a Level 3 approach, consider seeking external consultation to ensure all MRV requirements are met.
6. Is additional training needed to reach your goals associated with carbon measurement and the interpretation of results?
7. How could you incorporate your results into future funding applications?

COMMUNICATIONS AND ENGAGEMENT:

8. Do you want to communicate results with community members, rightsholders, government (elected, Crown, Hereditary) or non-governmental organizations?

a. Is there interest in sharing the data itself, or just an overview?

- If sharing the data, consider the most efficient and secure method.
- If sharing an overview, focus on your target audience and key messages. Use visuals, translations or other methods to enhance communication.

WEAVING KNOWLEDGE TOGETHER:

9. Could these results support ongoing initiatives in your community?

a. Example A: Carbon estimates could be provided during land-use planning exercises to determine which areas should be considered for stewardship or protection.

b. Example B: Carbon estimates could help to estimate potential carbon stock in areas undergoing reforestation.

10. Are there studies on terrestrial carbon in the same area that you can use for comparison? This is helpful if the results are unexpectedly high or low, or if they vary widely.

11. Is there interest in partnering with academic researchers or NGOs to expand your carbon measurement activities?

a. How would such partnerships benefit your community or organization?

b. Which benefits align with your professional goals as a practitioner or a department, and which support the broader community?

12. How could future carbon measurement activities align with other environmental monitoring initiatives in your community?

SUMMARY

This guide has outlined how to develop a sampling design and select a sampling strategy for your carbon measurement project, introducing how to apply a levelled approach to maximize accuracy and efficiency of in-field sampling. Basic (Level 1) and intermediate approaches (Level 2) were discussed step by step, with the first offering additional flexibility for teams with limited capacity and the second providing greater accuracy for those with additional budget. An advanced approach (Level 3) was introduced, with resources provided for those interested in learning more about the standards and protocols available.

The methods described in this guide complement guides and videos in WWF-Canada's Carbon Measurement Learning Library.

Contact WWF-Canada for advice on carbon measurement projects, GIS services or data translation and interpretation at science@wwfcanada.org.

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Open-source resources for measurement, reporting and verification

Forest Carbon Partnership

Open MRV

Google Maps

Google Earth Pro

Google Earth Engine

GLOSSARY

Average carbon stock: A measure of the density of carbon in a carbon pool, expressed as carbon mass per unit area, typically reported in kg/m^2 or t/ha.

Boundary: The perimeter of the study area, site or plot. A boundary may be approximate (based on landscape features or other characteristics) or exact (based on specific coordinates).

Carbon pool: A system that has the capacity to store or release carbon.

Carbon stock: A measure of the amount of carbon in a carbon pool, typically presented in kilograms or tonnes.

Convenience/practical sampling: A sampling strategy in which plots are selected based on their ease of access. This strategy is not statistically rigorous.

Diameter at breast height (DBH): Diameter of a plant, usually a tree, measured at 1.3m from the ground.

Diameter at stem height (DSH): Diameter of a plant stem, usually a short-statured tree, measured at 0.3m from the ground.

Destructive sampling: A sampling method in which the objects of interest are fully removed from their environment.

Ecosystem: The complex of living organisms, their physical environment and all their interrelationships in a particular unit of space.

Ground vegetation: All plants in a site that are under 0.5m in height.

Integrated plot design (or nested plot design): A plot design in which multiple plots share a centre mark. Both permanent and non-destructive single-use plot types can have an integrated plot design.

Large plot: A plot (typically $400m^2$) for measuring trees over 2m in height. Large plots can be rectangular, square or circular.

Medium plot: A plot for sampling vegetation between 0.5–2m in height. Plots are typically between 16 – $10m^2$ depending on the study area size, plant communities and variation across the site.

Non-destructive sampling: A sampling method in which the objects of interest (e.g., plants) are not disturbed from their environment.

Plots: The specific areas within a site where sampling takes place.

Random sampling: A sampling strategy where plot locations are randomly selected across the study area.

Sampling design: A framework used for choosing what and where to measure by taking samples, which can then be used to get a carbon estimate for a larger study area.

Sampling strategy: A way of mapping out study sites and plots that most effectively estimates the value for the larger study area.

Short-statured trees: Single-stem trees below 2m in height.

Shrubs: Plants with multiple woody branches emerging together from the earth instead of a single woody stem.

Small plot: A plot used to sample plants under 0.5m in height. Small plots are typically $0.25\text{-}1m^2$ in area.

Study area: Distinct areas within a larger region that differ in the types of ecosystems they include.

Study sites: The specific locations found within the study area that contain plots.

Stratified-random sampling: A sampling strategy that divides a study area into study sites based on certain characteristics. Plots are then randomly selected within each study site.

Stratification (also strata (n., pl.) and stratum (n., sing.): The act of subdividing a larger study area or region into smaller, distinct areas to more effectively measure differences across them.

Survey: (In forestry) the collection of measurements and other data (e.g., photos, notes) from a subset of trees or vegetation in the field. Surveys are always non-destructive.

Systematic sampling: A sampling strategy where plots are selected at regular intervals across the study area. This ensures even coverage of the entire area and is commonly used in uniform ecosystems.

Total carbon stock: A measure of the total amount of carbon in a carbon pool, typically presented in kilograms or tonnes.


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