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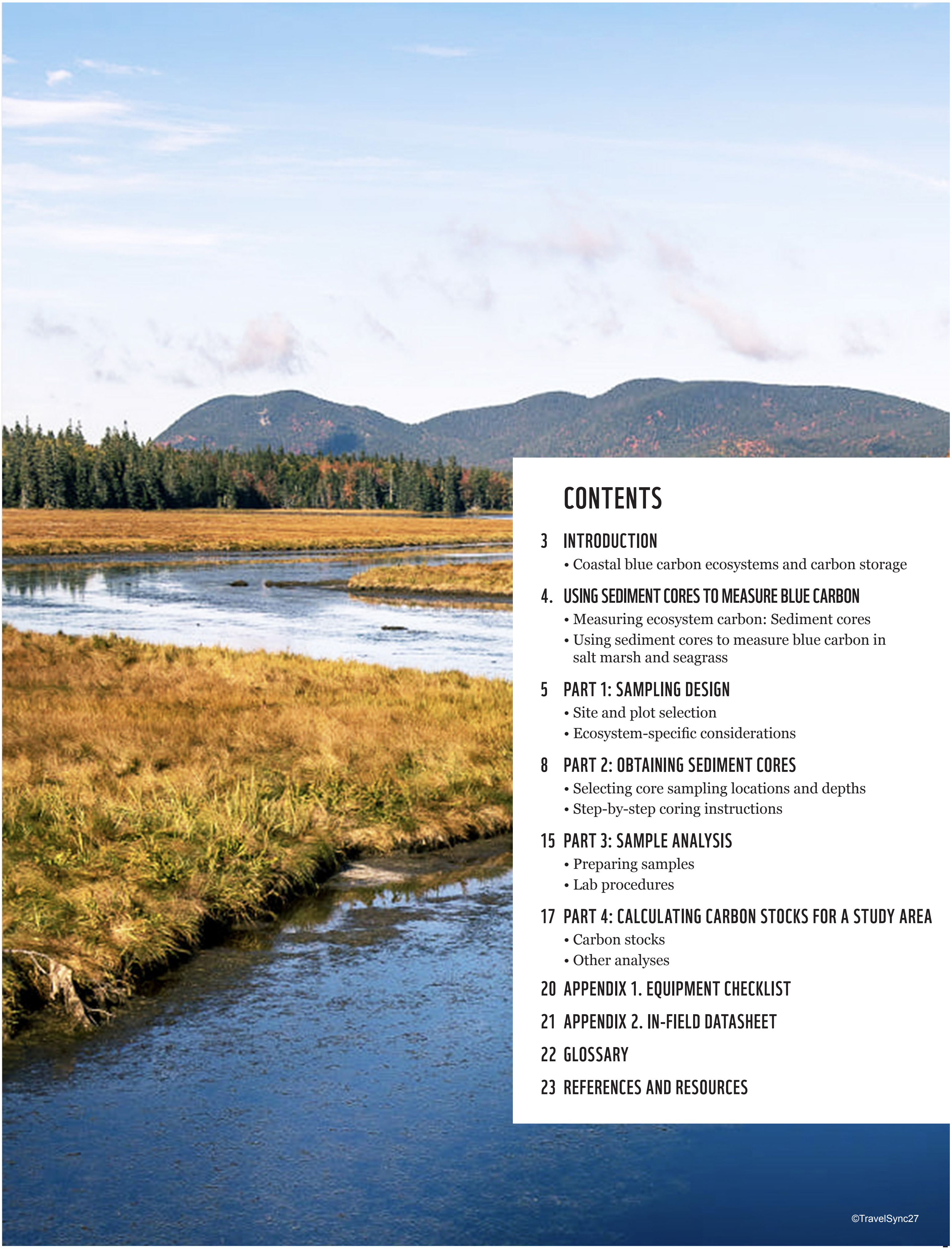
MEASURING CARBON IN COASTAL SEDIMENTS



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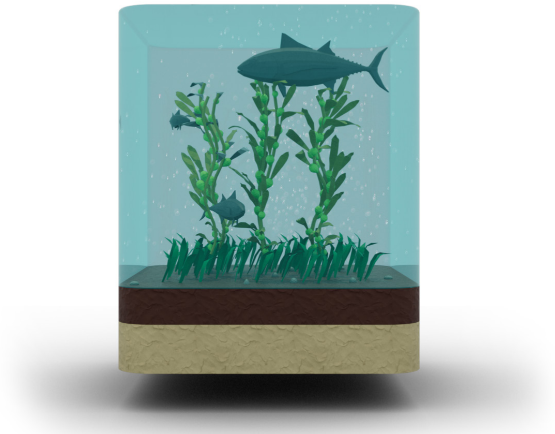


INTRODUCTION

COASTAL BLUE CARBON ECOSYSTEMS AND CARBON STORAGE

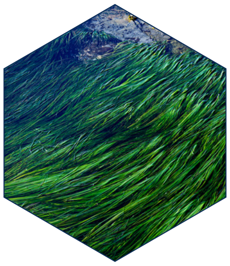
Coastal blue carbon ecosystems are wetland habitats occupying the space between land and sea, and are formed by the deposition of plant materials and sediments over thousands of years. In Canada, these ecosystems, including salt marshes and seagrass meadows, are distributed along all three coasts.

In highly productive salt marshes and seagrass meadows, carbon is stored in both the vegetation and sediments. Carbon dioxide is converted into plant biomass via photosynthesis and is stored temporarily in the plant material — for example in the leaves and roots. Longer-term storage of carbon is found within the sediments. As plants grow and senesce, organic matter accumulates in the sediment, locking the carbon away for long periods of time. This process of capturing and storing atmospheric carbon is referred to as **carbon sequestration**.

The leaves and roots of salt marsh plants and seagrasses can also alter water flow and prevent erosion, contributing additional organic matter to the system. Over time, plant and animal material and sediments are deposited one layer at a time, normally with the older layers at the bottom and newer layers at the top. Each layer records information from a specific point in time.

Because of this ability to capture and store atmospheric carbon, there has been growing interest in the role of coastal ecosystems for nature-based climate solutions. With recent pushes to better understand the carbon storage potential of coastal ecosystems, methods have been developed to measure both the amount of carbon stored in an area (**carbon stocks**) and how carbon is accumulated over time (**carbon accumulation rates**). This guide provides information on how to obtain **sediment cores** to measure blue carbon.

Salt marshes are regularly flooded habitats of the intertidal zone dominated by dense stands of salt-tolerant herbs, grasses, and low-lying shrubs.



Seagrass meadows can be distinguished by flowering plants belonging to four plant families, which grow in fully saline, marine environments.

USING SEDIMENT CORES TO MEASURE BLUE CARBON

MEASURING ECOSYSTEM CARBON: SEDIMENT CORES

Sediment cores are cylindrical sections of sediment taken from the ground. By taking cores out of the sediment, we are pulling out layered time capsules. We can then measure the carbon stored in each layer. By adding up the amount of carbon stored in the layers of the core, we can get a picture of how much carbon is stored in these sediments. This is critical information to quantify the role that blue carbon habitats can play in mitigating climate change.

USING SEDIMENT CORES TO MEASURE BLUE CARBON IN SALT MARSH AND SEAGRASS ECOSYSTEMS

In this guide, we will focus on measuring the **carbon stocks** of coastal ecosystems, however sediment cores can also provide information on other physical and biological processes including:

- **Sediment accumulation rates**, which can be used to understand the balance between accretion (i.e., sediment build-up over time) and erosion. Changes in sedimentation rates can reflect local ecosystem disturbances, and the balance between accretion and erosion is important for determining the resilience of an ecosystem to sea level rise.
- **Biodiversity and biological indicators of change** can be examined using a range of genetic, microscopic, and biogeochemical tools. These data can be used to understand community and species alterations in association with a changing environment.
- **Human-made materials and markers of global events** can be found within sediment cores and tell us about changes in the global climate as well as local use of coastlines.

In this guide and the accompanying videos (listed below), we will describe the methods for measuring blue carbon in the sediments of salt marsh and seagrass ecosystems.

CHECK OUT THE VIDEOS

- Introduction to Sediment Cores
- Site Selection and Required Materials
- Core Depths
- Sediment Coring
- Sediment Compaction
- Sediment Core Extraction
- Core Extrusion - Required Materials
- Preparing for Core Extrusions
- Transferring Cores to the Extruding Device Stand
- Slicing and Sub-sectioning Sediment Cores
- Core Sample Analysis

MEASURING BLUE CARBON WITH SEDIMENT CORES

All blue carbon monitoring projects can be broken into four main components:

1. **Sampling design**
2. **Obtaining sediment cores**
3. **Sample analysis**
4. **Calculating carbon stocks for a study area**

1

SAMPLING DESIGN

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**.

Your project goals dictate which ecosystem carbon stocks you will measure and what samples you will collect. If reporting the total ecosystem carbon stock for an area is the main priority, then collecting sediment cores and measuring vegetation biomass are going to be the focus of your sampling design. In some cases, other environmental factors, such as salinity or pH, might also be of interest to provide additional context for your carbon stock data. It is important to know exactly what will be measured to ensure all the necessary equipment is ready for the field.

SITE AND PLOT SELECTION

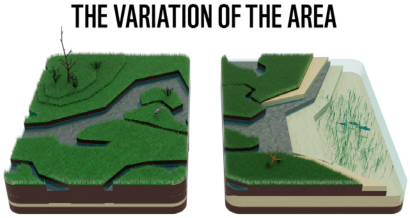
CHECK OUT THE VIDEO

STUDY AREA

THE ENTIRE AREA THAT YOU
WISH TO INVESTIGATE

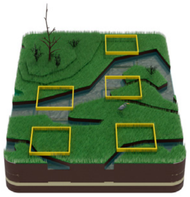
STUDY SITES

IDENTIFIED TO CAPTURE
THE VARIATION OF THE AREA



PLOTS

WHERE SAMPLING TAKES PLACE



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** are identified to capture variation within 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 strategy.

SITE AND PLOT SELECTION

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. Choosing a sampling strategy depends on the characteristics of the landscape and the project goals. For instance, **stratification** (optional) is used to divide the study area into smaller distinct **sites**. This process can reduce the cost of sampling by increasing the statistical power of your field data. Stratification can be achieved by dividing the study area into unique sites based on in-field measurements, such as assemblages of plant communities, tidal inundation, salinity gradients, elevation, or anthropogenic disturbances, or through remote sensing variables (these digital tools may be helpful).

Readily available **tools** can aid with these steps to map project boundaries and apply stratification to the study area of a project.

1. DETERMINE SAMPLE ALLOCATION

- Decide how many samples to collect within the project study area using a combination of planning tools and practical considerations.
- Consider the size for your study area, the estimated variation across your study area, and your project goals (degree of allowable error in your estimates) to determine the number of samples needed.
- Define the upper limit of your sampling capacity, considering project constraints (e.g., budget, staff time, site accessibility).
- Use available tools to help guide statistical methods.

2. MAP OUT SAMPLING PLOTS WITHIN EACH SITE

- Determine the location of sampling sites within your project study area using a sampling strategy such as convenient, linear, stratified-random, equally distributed, probability-based grid, or composite.

There are field-based methods to help select sampling locations, and digital tools that automatically identify sampling sites based on user-defined sampling strategies (these tools may be helpful).

TIMING OF FIELD WORK

Timing is an important consideration when planning fieldwork. The time of year that carbon sampling should occur depends on the location of your study area and research goals. Obtaining a sediment core will be most feasible between spring and fall, when the possibility of snow or ice is reduced. Additionally, if vegetation samples are needed, sampling during peak growth is recommended.

In most cases, you will want to sample during low tide to avoid excess water that could disturb the integrity of the samples.

Information on tides is available here.

ECOSYSTEM-SPECIFIC CONSIDERATIONS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SALT MARSH

Stratification in salt marsh ecosystems is most commonly accomplished by dividing the study area into study sites consisting of high marsh and low marsh. This delineation can be achieved through observations of vegetative differences. A combination of satellite imagery and field observations of the study area can also be used to identify the boundary between these sites.

If of interest, vegetation surveys are recommended prior to collecting carbon data. Vegetation should be sampled along multiple parallel transects, running from the upland edge of the marsh to the seaward edge. In addition to vegetation surveys, we recommend measuring sediment depths along these transects, which can be used to identify suitable sampling plots. Sediment depths should be measured using a soil probe at 10m intervals along the transect. The most effective sampling design in salt marshes captures the variation across each site in terms of elevation, vegetation, and tidal inundation. Based on this and the observations made in the field, a linear plot layout is typically applied for salt marsh ecosystems.


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SEAGRASS MEADOW

Tidal variation has a prominent influence on the characteristics of seagrass meadow ecosystems. Therefore, seagrass meadows should be sampled along transects that run parallel to the shoreline and align with the depth of the sediment. Within each site, a random or probability-based grid sampling strategy is recommended, with at least two replicates per site, to capture representative samples that reflect similar elevation, slope, and stratum of the plots.

Samples in the intertidal zone should be taken during **low tide** for ease of access to minimize sampling disturbances from excess water.

OTHER CONSIDERATIONS

Accessibility to the site may be restricted for many reasons, including the presence of physical barriers (e.g., the site is blocked off by a river) or legal restrictions (e.g., the site is protected). Before going into the field, ensure that you have all the necessary permits and permissions required to complete the project. Alternative sites may need to be considered during the planning phase.

SECTION SUMMARY: SAMPLING DESIGN

- Define the total study area of the project.
- Stratify (optional) the study area into smaller, homogenous sites and representative plots.
- Select an appropriate layout for your plots (sampling strategy).
- Identify how many samples will be required using statistical and practical considerations.
- Ensure the timing of your sampling aligns with seasonal and tidal fluctuations.
- Tailor the sampling design to more specifically align with salt marsh or seagrass ecosystems.

2 OBTAINING SEDIMENT CORES

EQUIPMENT

CHECK OUT THE VIDEO

There are many types of corers available, each with their own distinct advantages and limitations. Here, and in the accompanying videos, we will be presenting a push coring method using a PVC pipe — a method that is commonly used in coastal ecosystems. Other types of coring equipment can be used depending on budget, availability, and suitability for the ecosystem you are working in.

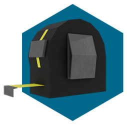
Different geographies and study areas present their own unique challenges, and the methods described may need to be adapted for the conditions you are working in. Note that equipment requirements are similar for both salt marsh and seagrass ecosystems.

EQUIPMENT LISTS

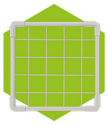
For setting up a plot:


GPS


CLIPBOARD

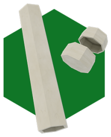

50 M TAPE MEASURE

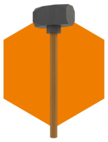

NOTEBOOK AND PENCIL/PEN

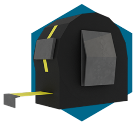

QUADRAT*

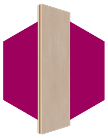
*(optional for measuring vegetation biomass)

For taking a sediment core:

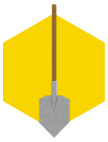

PVC PIPE AND END CAPS


SLEDGEHAMMER


TAPE MEASURE

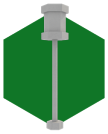

WOOD


WORK GLOVES

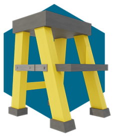

SHOVEL

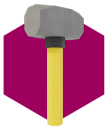
Note: Corer made from PVC tubing. The tube should be as long as the target depth for the core (usually between 30 cm and 1 m), with approximately 20cm of additional headspace. Three- or four-inch diameter PVC tubing is usually used. Endcaps should fit the diameter of the PVC tube. You will need top and bottom caps for each core.

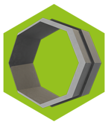
For core extrusion, packaging and processing:

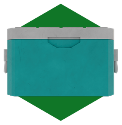

EXTRUSION DEVICE


PAINT SCRAPER

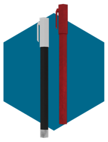

STEP STOOL


SMALL SLEDGEHAMMER


PVC COLLAR


COOLER


RESEALABLE BAG


MARKERS

Note: Custom-made extruding device, consisting of a piston that fits exactly inside the tube, a metal rod, and a platform for stability.

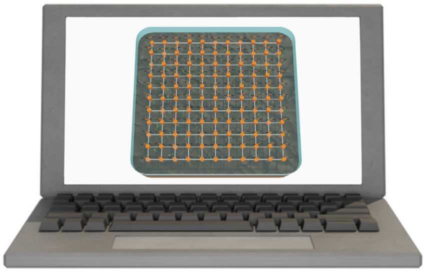
SELECTING CORE SAMPLING LOCATIONS AND CORE DEPTHS

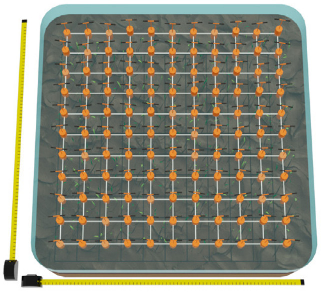
CHECK OUT THE VIDEO

Within each sampling plot, you must select a core sampling location that is representative of the entire plot area. This ensures the carbon data you collect reflects the average conditions of the larger area you will extrapolate the data to.

(Optional) To find a representative core sampling location, use a soil probe or auger to measure the sediment depth within a 10-by-10 m area. You can plan this digitally in advance, or use manual methods in the field:

Method 1: Digital overlay. Use a GIS software to apply a 1-by-1 m grid across your 10-by-10 m plot. At the coordinates of each intersection identified using GIS software, record the **depth of refusal**.





Method 2: Field tape grid. Lay out two perpendicular 10 m tapes. Measure the depth of refusal at every 1m interval. Move the tape 1 m and repeat until you have completed the grid of measurements.

Calculate the average depth of all measurements in your gridded plot. Select a core sampling location where the depths closely match the average. If you find your initial sampling location is significantly deeper or shallower than the average, move the corer to a more representative location.

Sampling sediment depths within a plot also provides us with information on the **depth of refusal**, which is the depth at which the corer can no longer be pushed into the sediment, signifying a transition from organic (carbon rich) to mineral (carbon poor) sediments or bedrock.

It is important to collect samples to the depth of refusal as this is the only way to measure the true carbon stock of the ecosystem. If sampling to the depth of refusal is not achieved, it is likely that the carbon stock will be poorly estimated.

Once you have selected your core sampling location, record the following in a notebook, or fill in the accompanying datasheet (Appendix 2).

- Date and time
- Site conditions
- Weather
- Tidal conditions

SECTION SUMMARY: LOCATION AND DEPTH OF CORES

- Measure the depth of refusal using a soil probe or auger.
- Select a representative core sampling location.
- In a notebook or datasheet, record:
  - Date and time
  - Site conditions
  - Weather
  - Tidal conditions

STEP-BY-STEP CORING INSTRUCTIONS

CHECK OUT THE VIDEO

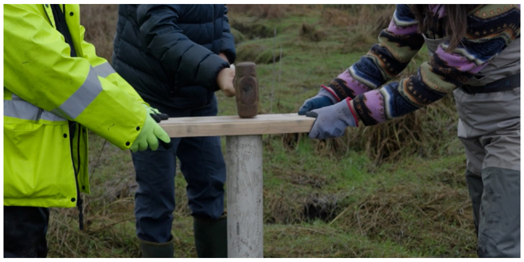
A team of three people is needed to safely collect each sediment core using the PVC tube method: two individuals to hold the piece of lumber that will serve as the platform for the sledgehammer, and one person to hammer in the tube. The two people holding the lumber should be wearing gloves for safety and comfort.

Once you have selected the site where you will be taking your core, find a flat area close to the core sampling location and lay out your equipment and processing tools.

Note: Mark the outside of the PVC core tube with ruler markings so you know how deep the core has been inserted into the sediment.

INSERTING THE CORER

1. Place the PCV pipe at the core sampling location, bevelled end down, and keep it as straight as possible.
2. Gently push the PVC pipe into the ground until the PVC is firmly set into the ground and can stand on its own.
3. With the PVC pipe in the ground, lay a piece of lumber across the top of the pipe. This will be used to absorb the impact of the sledgehammer.
4. The two people holding the lumber should be stationed at either side, with the person hammering positioned in between.
5. With the PVC pipe set straight and lumber in position, begin to hammer the PVC pipe into the ground.
6. Ensure the tube remains straight while hammering (i.e., not going in at an angle). Depending on the type of sediment, it may be very easy to get the tube into the ground, or very challenging. Feel free to take turns hammering.
7. Continue to hammer until the PVC has reached the desired depth (either depth of refusal or a pre-determined depth).



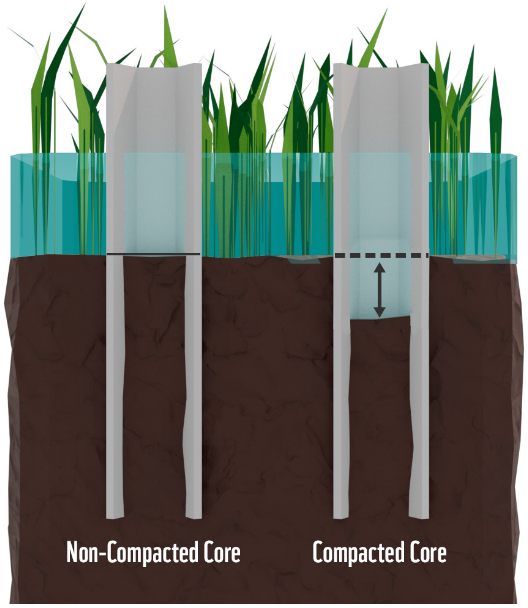
MEASURING SEDIMENT COMPACTION

CHECK OUT THE VIDEO

As the PVC pipe is hammered into the ground, the sediment can become compacted. It is important to measure this compaction.

1. With the PVC tube fully inserted into the ground, measure the distance from the top of the PVC tube to the sediment surface on both the outside and inside of the tube. The difference between these two measurements is the amount of compaction.
   a. Outside of core: top of corer to the ground surface
   b. Inside of core: top of corer to the top of the core
2. Place an endcap on the top of the tube.

At this point, you can also record approximately how deep the core is, based on the markings on the outside of the PVC tube. However, the true length of the core will be based on the subsections obtained during the extruding process, which is described below.



SECTION SUMMARY: INSERTING THE CORER AND MEASURING SEDIMENT COMPACTION

1. Align the corer to the core sampling location and push it into the ground.
2. Place a piece of lumber over the corer and hammer the PVC-tube into the ground to the desired depth.
3. Measure core compaction and record in your notebook:
   - Outside of core: top of corer to the ground surface
   - Inside of core: top of corer to the top of the core

SEDIMENT CORE EXTRACTION

CHECK OUT THE VIDEO

To remove the core from the ground, follow the following steps:

1. Make sure that there is a cap on top of the PVC tube.
2. Using a shovel, dig down alongside the tube, helping to alleviate any suction that has been created between the tube and the surrounding sediment. You can also gently rock the tube back and forth to release it.
3. Once you can see the bottom end of the tube, **place the endcap** over it so that no sediment is lost from the bottom.
4. If you are working in standing water, or if the sediments are very water-logged or rocky, this step can be challenging.

   Note: This is especially relevant when working in *seagrass meadows*.
5. It may be difficult to dig around the tube to cap it at its base, and you may lose some of the sediment from the bottom of the core. In this case, you may end up with a shorter core than intended, and you may want to pick a different spot and try again.
6. It is important to **keep the core upright** once it has been pulled out of the ground so that the sediment does not get mixed within the PVC tube before the core is divided into subsections.

Alternative method: Use a pipe clamp and vehicle jack to pull the core out (see example here).

SECTION SUMMARY: SEDIMENT CORE EXTRACTION

- Release the core from the suction of surrounding sediment by digging around the core or gently rocking the PVC pipe.
- Once the bottom of the core is revealed, place an endcap on the bottom so that no sediment is lost.
- Keep the core in an upright position while transporting the core to the **core processing location**.

CORE EXTRUSION

CHECK OUT THE VIDEO

Before dividing the sediment core into sections for storage and analysis, ensure you have prelabeled bags for each subsection. Each bag should be marked with the Core ID, which is a unique identifier for the **date**, **core location**, and the **section depth**. For example, *UC-02-B: 0–2 cm* can represent a core taken in "Ucluelet" from "Plot 2", "Sampling location B", with a depth interval of "0–2 cm".

There are different methods for sectioning sediment cores. Here we describe the process of pushing the core up vertically from the base using a custom-made extruding device that fits perfectly inside the PVC tube. Each subsection is then sliced off at the top of the tube.

CHECK OUT THE VIDEO

Note: Depending on the type of sediment and how long the core is, you may need a step stool, as well as a small sledgehammer to move the core down over the extrusion device if the sediment is dense. Please refer to the accompanying video for a visual of this process.

CHECK OUT THE VIDEO

Before slicing the sediment core into subsections, you will need to carefully transfer it onto the extruding device. Please refer to the accompanying video for a visual of this process.

1. Have one person hold the core as upright as possible and move it next to the piston of the extruding device, while another person removes the endcap before quickly and carefully moving the core onto the piston.

   Note: If the sediments are quite loose, rocky, or watery, you may lose a bit of sediment from the bottom of the core; this is okay. Make a note of this loss on the data sheet.

2. If you are able, push the core slightly onto the piston to stabilize it. However, it is important to have someone holding the PVC tube during this process so the core does not fall off the extruding device.

CHECK OUT THE VIDEO

SECTIONING SEDIMENT CORES

1. Once you are ready to start slicing the core, place the PVC collar of desired thickness on the top of the tube and gently move the PVC tube downwards over the piston so that the sediment appears at the top. Do this until the sediment is level with the top of the PVC collar.

2. Use a paint scraper, small piece of plexiglass, or a serrated knife to carefully cut or slice between the PVC collar and the rest of the core.

   Note: A serrated knife is particularly helpful in salt marsh sediment where roots may be present.

3. Remove the PVC collar and slide the subsection into the appropriately labeled Ziploc bag.

4. Have someone keep track in a notebook to ensure appropriate documentation of subsections and to take any relevant notes.

   Note: If there are rocks or other material that span multiple subsections, place the material in the subsection where most of the material was found, and make a note. Similarly, if the core surface is not flat, which often happens for the top section, an average height estimate can be made from measurements taken around the PVC collar.

5. Continue to take 2 cm subsections using the PVC collar all the way down the length of the core.

   Note: The bottom section may not be exactly 2 cm, but this should be measured and recorded.

6. Once all subsections have been obtained, you will know the total length of the core. **Record this value on the datasheet**.

7. Place all sample bags in a cooler until they can be transported to a freezer for longer term storage.

SECTION SUMMARY: EXTRUSION, SECTIONING AND PACKAGING

- Place the core into position over the core extruding device.
- Place the PVC-collar into position at the top of corer and push the PVC tube downward, so that the sediment appears at the top.
- Keep pushing until the sediment is in-line with the top of the PVC collar.
- Cut between the PVC collar and the top of the corer to slice off the subsection.
- Place the cut subsection in the appropriate Ziploc bag, record the sample name and depth.
- Repeat these steps for the entire core.
- Place samples in cooler for transport to a freezer.

3 SAMPLE ANALYSIS

PREPARING SAMPLES FOR ANALYSIS

CHECK OUT THE VIDEO

Samples should immediately be placed in a cooler and transferred to a freezer at -20°C as soon as possible for long-term storage. Samples should be thawed in a fridge at 5–6°C for 2–5 days before they are further processed in a laboratory. If a drying oven is available, the subsections can be further prepared for laboratory analysis.

The total soil carbon stock of the study area is determined by the amount of carbon within a defined area and sediment depth. For each core sampling location, the following information is needed:

- Sediment depth (cm)
- Dry bulk density (g/cm^3)
- Organic carbon (%)

Here, we outline the laboratory steps for obtaining the dry bulk density and organic carbon content of your samples.

To prepare the samples for analysis, each sample needs to be weighed, dried, and ground-up. This can be accomplished with the following equipment:

- Scale
- Drying oven
- Metal trays
- Gloves
- Measuring tape/ruler
- Notebook
- Glass vials, paper bags, or Ziploc bags
- Lab coat
- Closed-toe shoes
- Permanent marker

LABORATORY PROCEDURES

DRY BULK DENSITY

1. Make sure to wear gloves, a lab coat, and closed-toe shoes.

2. All sections should be thawed at 5–6°C for 48–96 hours before processing in the lab.

3. Prepare metal trays to weigh and dry the sections. Label the bottom of each tray with a unique number in permanent marker.

4. Record the tray number and tray weight in a notebook.

5. Place the sample in a drying oven set to 65°C for approximately 48–96 hours.
   After the allotted time, weigh the sample, record its weight, and place it back into the oven at 65°C for 1 hour, then weigh again. Subtract the second weight from the first. If the resulting difference is ≥ –0.1 g, then the sample is considered to have reached a stable weight. If not, dry for 2–24 more hours and try again.

6. Once the sample has reached a stable weight, record the final dry weight.

Carbon analysis requires more equipment, and often at this stage, the samples will be sent to a laboratory specializing in carbon analysis. However, if you have the required equipment for carbon analysis, follow the steps on the following page.

SAMPLE ANALYSIS

CARBON

Equipment for inorganic and organic carbon content analysis:

- Crucibles
- Muffle furnace

Sample preparation is as follows:

1. Using tape and permanent marker, prepare and label storage containers for the samples, noting:
    a. Site
    b. Core ID
    c. Sample
    d. Depth
    e. Date
2. Grind the samples until sediment is homogenous and contains no indistinguishable bits.
3. This can be done using a coffee grinder, a mortar and pestle, or a sediment-homogenizing device.
4. Once homogenized, place the sample in a labelled storage container.
5. The samples are now ready for analysis or, as a reminder, they can be shipped to a laboratory (but note any requirements from the laboratory for preparation and packaging).

ORGANIC CARBON

The steps below describe how to measure organic carbon using the loss-on-ignition (LOI550) combustion method:

1. Prepare crucibles with a unique ID in pencil.
2. Record the ID and weight of crucibles.
3. Place 1 g of the sediment sample into a crucible.
4. Place in muffle furnace at 550°C for 4 hours.
    a. It will take time for the furnace to preheat; make sure the samples are already in the furnace while it is preheating.
    b. It is very important not to open the furnace when the temperature exceeds 100°C.
5. After 4 hours, turn off the furnace.
6. Wait until furnace has cooled; this may take a long time (i.e., minimum 6 hours).
7. Remove the crucibles and let them rest until they reach room temperature (typically about 20 minutes).
8. Weigh the samples and record the weights in a notebook.

INORGANIC CARBON (CARBONATE FRACTION ONLY)

1. Place the samples used for organic matter content analysis in a muffle furnace set to 950°C for 2 hours
    a. It will take time for the furnace to preheat; make sure the samples are already in the furnace while it is preheating.
    b. It is very important not to open the furnace when the temperature exceeds 100°C.
2. After 2 hours, turn off the furnace.
3. Wait until furnace has cooled; this may take a long time (minimum 6 hours).
4. Remove the crucibles and let them rest until they reach room temperature (typically about 20 minutes).
5. Weigh the samples and record the weights in a notebook.

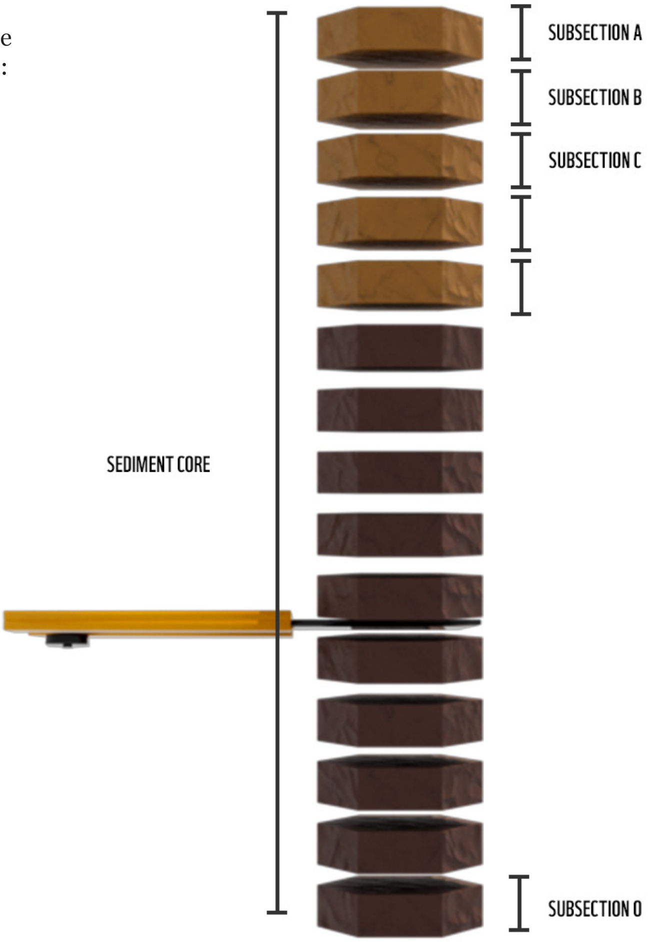
Note: The method above measures carbonate compounds in sediment, which often represent a major portion of inorganic carbon. However, it does not capture mineral-bound carbon or other non-carbonate inorganic carbon forms present in stable minerals. Its main advantage is that it is a low-cost approach that uses the same equipment required for organic carbon analysis. As a result, total carbon of a sample can be approximated by adding organic carbon to the measured inorganic (carbonate) fraction. However, for the most accurate results, samples should be sent to a laboratory for total carbon measurement using an elemental analyser.

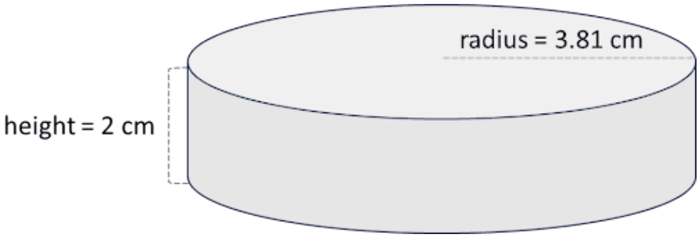
4

CALCULATING CARBON STOCKS FOR A STUDY AREA

The total sediment carbon stock within a project area is determined by the amount of carbon within a defined area and sediment depth. Calculating the total sediment carbon for the study area requires the following information:

- Sediment depth (cm)
- Subsample depth interval (cm) = bottom depth (cm) - top depth (cm)
- Dry bulk density (g/cm^3)
- Total organic carbon (%)





DRY BULK DENSITY

Dry bulk density can be calculated from the mass (g) of the dried sample and its original volume.

Eq 1:
Dry bulk density (g/cm^3) = **mass of dry soil (g) / original volume sampled (cm^3)**

Where the volume of the sample can be calculated using the following:

Eq 2:
Original pre-dried volume of sample = **[π * (radius of the PVC tube)^2] * (depth of the sample)**

For the example above, using a 3” (7.62 cm) diameter PVC tube and a subsection depth of 2 cm, the sample volume would be
volume of sample = [π * (3.81)^2] * 2 = 91.2 cm^3

CARBON STOCKS

The average carbon stock of sediment cores can be determined as follows:

1. For each core subsection, calculate the sediment organic carbon density:
   Eq 3:
   Sediment carbon density (g/cm^3) = dry bulk density (g/cm^3) * (%C$_{org}$/100)

   Note: Total carbon content (%) can be substituted with organic carbon content (%C$_{org}$) to determine the soil organic carbon density (g C$_{org}$/cm^3).

2. To calculate the amount of carbon in a subsection, multiply each sediment carbon density value obtained in Eq 1 by the subsection depth interval (cm):
   Eq 4:
   Average carbon stock of subsection (g/cm^2) = sediment carbon density (g/cm^3) * depth interval (cm)

3. To obtain the average carbon stock (g/cm^2) of the core, add up the values for each subsection calculated above:
   Eq 5:
   Average carbon stock of core (g/cm^2) = sum of average carbon stocks of subsections

   Note: Subsections must add up to 100% of the core to obtain the average carbon stock.

4. Convert the average carbon stock of the core (g/cm^2) from Eq 5 into units of kg/m^2 by multiplying by 10, or more formally:
   Eq 6:
   Average carbon stock of core (kg/m^2) =
   average carbon stock of core (g/cm^2) * (1kg/1000 g) * (10000 cm^2/1 m^2)

Repeat steps one to four for each core.

TOTAL ECOSYSTEM CARBON

The carbon stock of a study area can be determined as follows:

6. To obtain the average carbon stock of each study site (kg/m^2), add up the average carbon values from Eq 6 (kg/m^2) for each core obtained and divide it by the number of cores taken in each site.
   Eq 7:
   Average carbon stock of site (kg/m^2) = sum of average carbon stocks of cores (g/cm^2)/ number of cores

7. Multiply the average carbon stock of the site by the size of the site (in metres square) to obtain the total carbon stock of each site (kg C).
   Eq 8:
   Total carbon stock of study site (kg C) = average carbon stock of study site (kg C/m^2) * study site size (m^2)

8. Add up the total carbon stocks for the sites and divide by the sum of the site sizes. This gives the average carbon stock of the study area (kg C/m^2).
   Eq 9:
   Average carbon stock of study area (kg C/ m^2) = sum of total carbon stocks of sites (kg C) /
   sum of site sizes (m^2)

9. Finally, to calculate the total carbon stock of the study area (kg C), multiply the average carbon stock of the study area by the size of the study area (in metres square).
   Eq 10:
   Total carbon stock of study area (kg C) = average carbon stock of study area (kg C/m^2) * study area size (m^2)

Note: *The carbon values calculated here are in units of "C."
If interested in units of "CO^2 equivalents," multiply by 3.67.

OTHER ANALYSES

While organic carbon is the primary focus of blue carbon monitoring, additional laboratory analyses can provide critical context regarding the history, origin, and stability of your carbon stocks.

GRAIN SIZE

- Grain size (or particle size) refers to the measurement of the diameter of the individual grains of sediment in your sample. The sediment grains are classified into several categories based on their respective sizes, ranging from very small colloidal particles, through clay, silt, sand, gravel, and cobbles, to the largest, boulders (a size chart is available here).
- Grain size is a primary indicator of the depositional environment. For example, fine-grained sediments (clays/silts) often correlate with higher carbon preservation because they have more surface area for organic matter to bind to and indicate low-energy environments where carbon is less likely to be washed away. Consistent grain size suggests a stable environment, while abrupt changes can indicate historical storms, tsunamis, or changes in tidal flow.

INORGANIC CARBON CONTENT

- Inorganic carbon refers to a subcategory of carbon compounds found in sediments that do not originate from photosynthesis, but instead, from geological processes (e.g., weathering) and biological activity (e.g., animal shells).
- These compounds contain carbon in a chemically inorganic state and are termed carbonates (e.g., calcium carbonate from shells or limestones). Silicates are also related to inorganic carbon. Inorganic carbon can contribute significantly to the carbon cycling processes of some ecosystems.
- Measuring the inorganic content of your samples, can help bolster your understanding of the carbon sequestration capacity of your area of interest. There are many methods to determine inorganic carbon (more information is available here), and they can be combined with organic carbon analysis to determine the total carbon content of your samples.

CARBON AND NITROGEN ISOTOPE ANALYSIS

- Soils and sediments are either derived from plant materials directly within the ecosystem (autochthonous), or organic/inorganic materials transported from adjacent environments (allochthonous).
- Isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$), and their respective ratios in the parent soil are often conserved during sedimentation processes, meaning that you can determine where the sediment from your cores originated from. For example, measured $\delta^{15}N$ of agricultural soils under active cultivation can be 5‰ greater than neighboring conservation soils and forest soils because manure application and harvest can increase ^{15}N abundance.
- More information is available here.

GEOCHRONOLOGY: SEDIMENT DATING TECHNIQUES

- To understand the rate of carbon accumulation over time, you first must determine the rate at which the sediment has accumulated, referred to as the “sediment accretion rate (SAR)”. Two important methods for identifying SAR include radio-carbon and lead-cesium dating.

RADIO-CARBON DATING (14C)

- Radio-carbon dating is used for “deep-time” reconstructions to measure sediment accumulation from approximately 200–50000 years
- Radiocarbon dating measures the amount of the isotope carbon-14 (14-C) contained within the organic materials of a sample. This value is compared to internationally standardized estimates of the atmospheric composition of C-14 from the year 1950 (before nuclear testing) to 60,000 years ago (the oldest measured values).
- Given the age estimates and the sample depths of your core, the long-term accumulation of sediment can be reconstructed using open-sourced tools (DOI: 10.1214/11-BA618). More information is available here.

LEAD AND CESIUM DATING (Pb-210 + Cs-137)

- Lead-210 (Pb-210) and Cesium-137 (Cs-137) can be used to determine the rate of sediment accumulation for more recent dating, 0–200 years. Typically, 10–20 sections of a sediment core are analyzed, covering an accumulation period of about 160 years.
- Pb-210 occurs naturally and has a relatively fast decay rate, allowing for a continuous sediment accumulations.
- Cs-137 is a “marker” isotope from mid-twentieth century nuclear-testing, where peak levels in sediment align with the year 1963.

By knowing the age of the sediment at different depths, you can calculate the carbon burial rate.

APPENDIX 1. EQUIPMENT CHECKLIST

A downloadable version of the equipment checklist is available here.

For setting up a plot:

- GPS
- Clipboards
- 50 m tape measure
- Quadrats

For taking a sediment core:

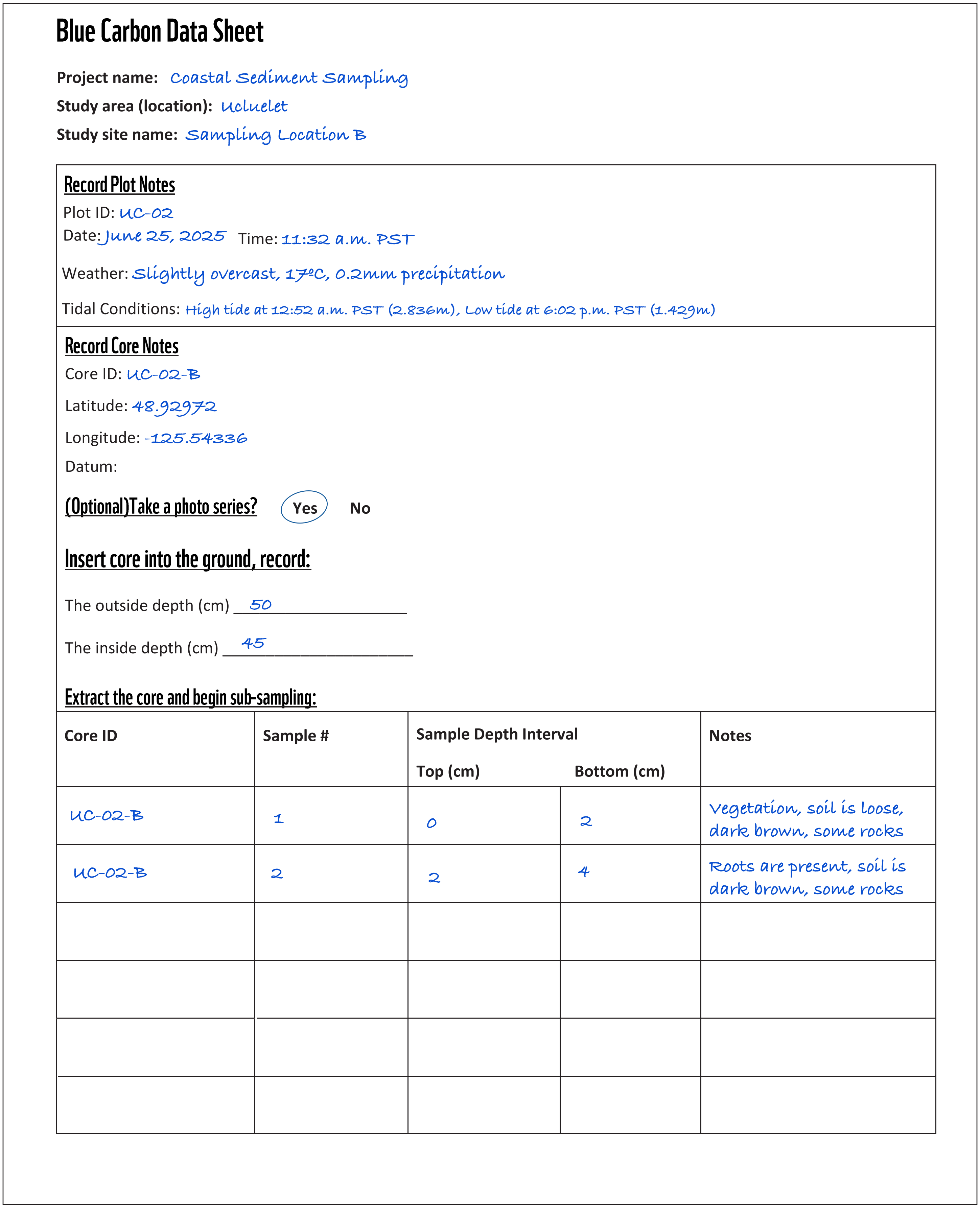
- Corer made from PVC or acrylic tubing. The tube should be as long as the target depth for the core (usually between 30 cm and 1 m), with approximately 20 cm of additional headspace. Four-inch diameter tubes are usually used, but three-inch diameter can work as well.
- Endcaps to fit the diameter of the PVC tube. You'll need top and bottom caps for each core.
- Sledgehammer
- At least one piece of plywood for a hammering surface
- Work gloves
- Measuring tape (1 m)
- Shovel
- Extruding device

For core extrusion:

- Custom-made extruding device, consisting of a piston that fits exactly inside the tube, a metal rod, and a platform for stability
- Step stool
- Smaller sledgehammer
- Paint scraper, small piece of plexiglass, or a serrated knife
- PVC or acrylic collar of the desired subsection depth, usually 1, 2 or 5 cm
- Ziploc bags or polypropylene jars (check with laboratory for preference)
- Permanent marker for labeling sample bags
- Cooler for temporary storage of samples

APPENDIX 2. BLUE CARBON DATA SHEET

Below is an example of a data sheet. A download version is available here.



Blue Carbon Data Sheet

Project name: Coastal Sediment Sampling

Study area (location): Ucluelet

Study site name: Sampling Location B

Record Plot Notes

Plot ID: UC-02

Date: June 25, 2025 Time: 11:32 a.m. PST

Weather: Slightly overcast, 17ºC, 0.2mm precipitation

Tidal Conditions: High tide at 12:52 a.m. PST (2.836m), Low tide at 6:02 p.m. PST (1.429m)

Record Core Notes

Core ID: UC-02-B

Latitude: 48.92972

Longitude: -125.54336

Datum:

(Optional)Take a photo series? [✓ **Yes**] **No**

Insert core into the ground, record:

The outside depth (cm) 50

The inside depth (cm) 45

Extract the core and begin sub-sampling:

Core ID	**Sample #**	**Sample Depth Interval**		**Notes**
		Top (cm)	**Bottom (cm)**	
UC-02-B	1	0	2	Vegetation, soil is loose, dark brown, some rocks
UC-02-B	2	2	4	Roots are present, soil is dark brown, some rocks

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.

Biodiversity: The variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Biological indicators of change: Biological materials (e.g., pollen grains or microorganisms) that are preserved in sediments, whose presence informs us of past climatic or ecological conditions.

Bulk density: The mass divided by the weight of a sample.

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

Carbon accumulation rate: The amount of carbon entering a carbon pool over a defined period of time.

Carbon sequestration: The process of capturing and storing atmospheric carbon in a carbon pool.

Carbon stock: A measure of the amount of carbon in a carbon pool.

Core length: The length of a core sample that has been collected.

Depth of refusal: The stage at which a corer can no longer be pushed into the medium it is trying to sample.

High tide: The state of the tide when its at it’s highest level.

Inorganic carbon: The amount of carbon in the inorganic component of a sample.

Isotope: Atoms with the same number of protons but different numbers of neutrons; can be used to infer the date of an object through the isotope’s distinct half-life (i.e., rate of decay).

Loss-on-ignition: Scientific method for determining the fraction of organic matter in a sample of soil by burning the sample between 450–950° C.

Low tide: The state of the tide when its at it’s lowest level.

Organic carbon: The amount of carbon in the organic matter of a sample.

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

Radiocarbon dating: Uses the decay of a radioactive isotope of carbon (14C) to measure time and date objects containing carbon-bearing material.

Salt marsh: Regularly flooded habitats of the intertidal zone dominated by dense stands of salt tolerant herbs, grasses and low-lying shrubs.

Seagrass meadow: Distinguished by the flowering plants belonging to four plant families, which grow in marine, fully saline environments.

Section depth: The top and bottom of a core sample or section relative to the ground layer.

Sediment core: A vertical sample of a sediment or soil deposit that captures the stratigraphic layers and maintains the depositional sequence of the layers (younger on the top and older near the bottom).

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.

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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