© JOHN MARTIN, CI

Conceptualizing the Project and Developing a Field Measurement Plan

LEAD AUTHORS

James Fourqurean, Beverly Johnson, J. Boone Kauffman, Hilary Kennedy

CO-AUTHORS

Igino Emmer, Jennifer Howard, Emily Pidgeon, Oscar Serrano

MEASURING CARBON STOCKS VS. CARBON POOLS

A *carbon stock* is the amount of organic carbon (C_{org}) stored in a blue carbon ecosystem, typically reported as megagrams of organic carbon per hectare (Mg C_{org}/ha) over a specified soil depth. These stocks are determined by adding all relevant carbon pools within the investigated area. Relatedly, *carbon pools* are reservoirs such as soil, vegetation, the ocean, and atmosphere that store and release carbon. Relevant blue carbon pools include:

- The living aboveground biomass, primarily herbaceous (for seagrass and tidal salt marsh) and woody (for mangroves) plant mass. This biomass also includes epiphytic organisms (e.g., algae and microbes living on the main plants).
- The dead aboveground biomass, primarily leaf detritus (in all three ecosystems) or wood (in mangroves), and other organic debris such as macro-algae.
- The living belowground biomass dominated by roots and rhizomes.
- The belowground carbon comprised of dead plant tissues and soil organic matter ('autochthonous' and 'allochthonous' carbon).

Carbon pools in blue carbon ecosystems are further differentiated into short-term pools (e.g., prevailing less than 50 years, e.g., living biomass) and long-term pools (e.g., prevailing for centuries or millennia, e.g., soil organic carbon). For blue carbon purposes, long-term carbon pools are the most important for determining carbon mitigation potential (IPCC 2007; Kyoto Protocol 1998).

CARBON STOCK ASSESSMENTS

During planning, a project's end goal must be clearly defined as this will influence both the design and execution of the assessment process. A clear end goal dictates geographic areas to include, carbon pools to measure, the level of specificity required, and the need/time scale for future reassessment. Moreover, the available resources must be considered to maximize the project's cost effectiveness.

The planning process has four essential elements:

1) Conception;
2) Carbon pool field sampling;
3) Sample preparation and laboratory analysis; and
4) Calculations for scaling up carbon stocks to the project area.

Conceptualizing the project is discussed in detail in this chapter. Detailed descriptions of the approaches and techniques required for field sampling of carbon pools and the specific laboratory techniques for analyzing each pool are presented in Chapter 3 (General Principles of Field Sampling of Soil Carbon Pools in Coastal Ecosystems) and Chapter 4 (General Principles of Field Sampling of Vegetative Carbon Pools in Coastal Ecosystems). Remote sensing options that may inform field site location and scaling up of results are presented in Chapter 6 (Remote Sensing and Mapping).

The approaches outlined here represent best practices based on the latest peer-reviewed research. However, project managers are encouraged to explore the literature and choose the best method for their project or they may choose to adapt these methods according to their local knowledge, training, resource constraints or other data collection needs, or the evolving nature of IPCC and related sourcebook guidelines.

CONCEPTUALIZING THE PROJECT

The main steps needed to prepare a robust field measurement plan are summarized in **Fig. 2.1**. Each step should be taken in a consistent, well-justified and well-documented manner. While Pearson *et al*. (2007) provides guidance on project design for terrestrial forests, much of the discussion is applicable to blue carbon ecosystems and, consequently, highly influenced the recommendations below.

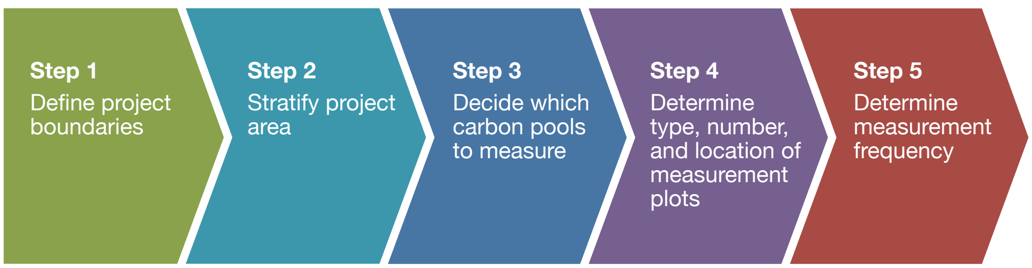

Figure 2.1 Steps to preparing a measurement plan

Define the Project Boundaries

Determining the project's spatial boundaries will depend on its scope and objectives. Project areas may range from a single site (tens of hectares) to national-scale assessments (hundreds of thousands of hectares). They may contain ecosystems that have been degraded or converted. The project area may be one contiguous block of land, or consist of many small patches of land spread over a wide area. Once the boundaries have been determined, every effort should be made not to change them; however, if changes are unavoidable, they must be well-documented, and any estimates of total carbon stock or carbon stock change must be adjusted to reflect the change in area.

Once the project location and scale have been decided, the next step is to map the area. Maps allow field teams to optimize their campaign by selecting locations for sampling that maximize geophysical range as well as environmental and biophysical variables within the area. Maps can also be used to verify accessibility through roads, tidal channels, and rivers. Starting with thorough and accurate mapping is valuable not only for determining where to sample, but also for extrapolating carbon measurements from individual samples to large scale project sites. If future reassessments are anticipated, an accurate initial map of the area will be vital for determining changes to the carbon stock and ecosystem services. Topographic, land use, soil, and vegetation maps, as well as aerial photographs may be acquired from local government agencies and used to discern project boundaries with varying accuracy. Satellite images and remote sensing techniques are very useful in mapping blue carbon ecosystems and for gathering information about the ecosystem more generally. Detailed information on remote sensing can be found in Chapter 6 (Remote Sensing and Mapping).

2

Stratifying the Project Area

Stratification is used to divide large heterogeneous sites (which require many samples to account for variation) into smaller more homogeneous areas (where fewer samples are needed) and is also useful when field conditions, logistical issues, and resource limitations prevent dense sampling regimes (**Fig. 2.2**). Stratification divides the project area into sub-areas or "strata" that are relatively ecologically homogenous (e.g., species diversity and geomorphology). Many tools exist to assist in stratification including local knowledge, satellite imagery, and geographic information systems.

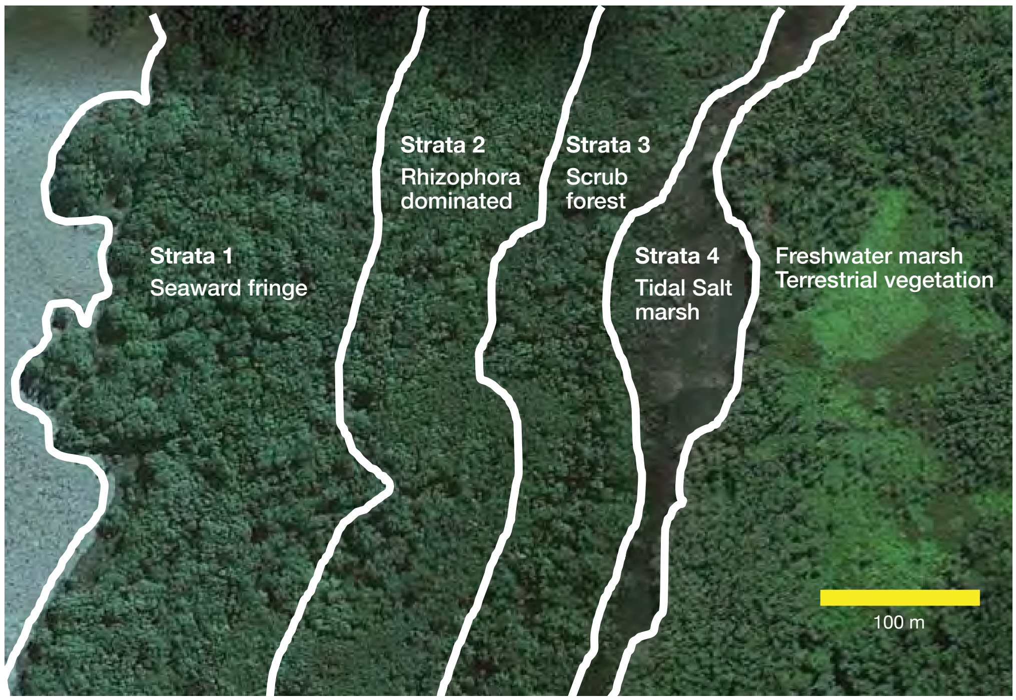

Figure 2.2 Example of mangrove stratification (© Boone Kauffman, OSU)

Stratification should be carried out such that the criteria used to define the strata are related to the variable being measured. For our purposes, the main variable being measured is carbon; thus, the features that influence the blue carbon content are used to determine the strata for a project area. Blue carbon stocks are largely influenced by variation in vegetative species and vegetative density. For example, mangroves contain tall forest, dwarf mangrove, shrub forests, and nypa palm (also sometimes known as Nipa, *Nypa fruticans*); tidal salt marshes consist of grass, shrub, and reed growth forms; and seagrass species vary according to water depths. These variations can guide strata delineation. Other factors that may be used to define strata include:

1) Existing land use (tidal salt marsh areas being used for agricultural purposes);
2) Potential land use (areas vulnerable to conversion for aquaculture or development);
3) Variations in soil characteristics (soil depth or type, or sediment grain-size);
4) Geomorphological features (proximity to geologic features, drainage features); and
5) Proximity to the ocean (areas tidally flooded daily or areas only flooded at the highest high tides).

While stratification is used to reduce the number of samples that are needed and increase carbon stock estimate accuracy, it is important to note that stratifying using strict criteria that create many small strata (that all need to be sampled) or conversely using loose criteria that create only a couple large strata (where some variation will be missed) negates this advantage. The strata size and number should be a balance between accuracy desired, time required, and resources available.

Decide Which Carbon Pools to Measure

Each stratum established in the project area will usually contain more than one carbon pool. The project purpose and objective will determine which carbon pools within each stratum to measure. Not all pools will be significant or require quantification for all projects. Projects may choose not to account for one or more carbon pools if they can prove that they will not significantly change the assessment results, but it is always better to measure all carbon pools in at least a few representative sampling sites.

In general, a carbon pool should be measured:

- If it is a significant portion (e.g., > 5%) of the total carbon in the stratum;
- If it is likely to or has changed significantly (either naturally due to climate change and extreme weather or due to human impacts such as land-use change or dredging); or
- If the carbon pool is unknown

Small carbon pools or those unlikely to be affected by change may be excluded or sampled less frequently depending on the project budget and other constraints. In most blue carbon systems, **soil carbon is by far the dominant carbon pool**. However, it is usually necessary to measure additional carbon pools in order to conform to requirements for carbon project certification. For example, both national carbon accounting and carbon market projects require four basic carbon pool measurements: aboveground living biomass (e.g., trees, grass, shrubs), aboveground dead biomass (e.g., leaf litter, downed wood), belowground living biomass (e.g., roots and rhizomes), and soil carbon.

In all three habitats, it is common to have vegetation and sediment that has traveled from surrounding habitats to the project site. For example, seagrass beds will often have a few mangrove propagules and leaves, and seagrass leaves are common in mangroves and tidal salt marsh sediments. Organic matter derived from terrestrial uplands can also be transported to and incorporated within blue carbon ecosystems. In most cases, this allocthonous organic material does not make up a significant proportion of the total ecosystem biomass and can be ignored. However, if the allocthonous material present is significant (> 5%), it can be classified as its own pool and quantified directly. In some cases allocthonous organic carbon present in the soil pool can be quantified using stable isotopes, but this may not be practical in all areas or needed for all projects (Johnson *et al.* 2007).

MANGROVE CARBON POOLS

Similar to most terrestrial forest ecosystems, mangroves can be roughly divided into four carbon pools (**Fig. 2.3**):

- Aboveground living biomass (trees, scrub trees, lianas, palms, pneumatophores);
- Aboveground dead biomass (litter, downed wood, dead trees);
- Belowground living biomass (roots and rhizomes); and
- Soil carbon which includes the dead below-ground biomass.

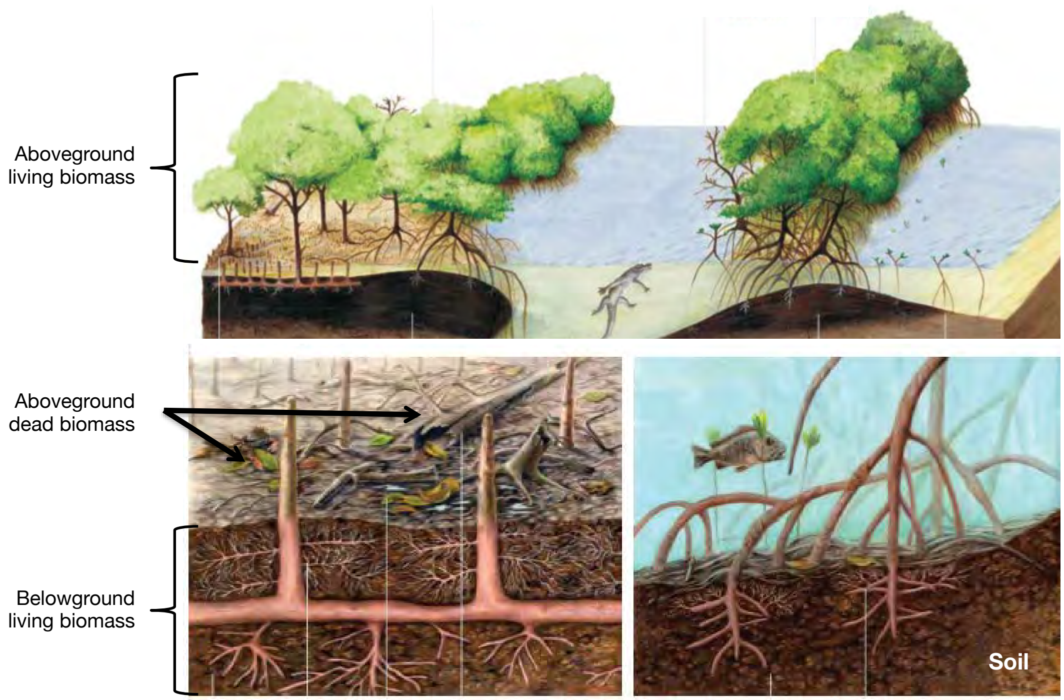

Figure 2.3 Carbon pools in mangrove ecosystems

In mangroves, all trees are included in the assessment because they are a large carbon pool (up to 21% of the carbon stock), are relatively easy to measure (due to well documented allometric equations that convert plant biomass to carbon content), and are heavily affected by land use. Dead wood can be an important pool (2.5–5.0% of the carbon stock), but may be especially important following disturbances such as land-use activities or tropical storms (Kauffman & Cole 2010). The live root component (5–15% of the total belowground carbon stock) is difficult to measure, but some allometric equations do exist (Chapter 4). Non-tree vegetation and leaf litter are usually minor ecosystem components and often can be excluded from measurements without compromising the accuracy.

Blue carbon is mostly stored belowground in organic-rich soils many meters deep where it can remain for very long times (up to millennia). The large size of these belowground pools and their poorly understood vulnerability to land-use change makes their measurement extremely important.

TIDAL SALT MARSH CARBON POOLS

Three major carbon pools can be considered in tidal salt marsh ecosystems. (**Fig. 2.4**):

- Aboveground living biomass (shrubs, grasses, herbs, etc.);
- Belowground living biomass (roots and rhizomes); and
- Soil carbon.

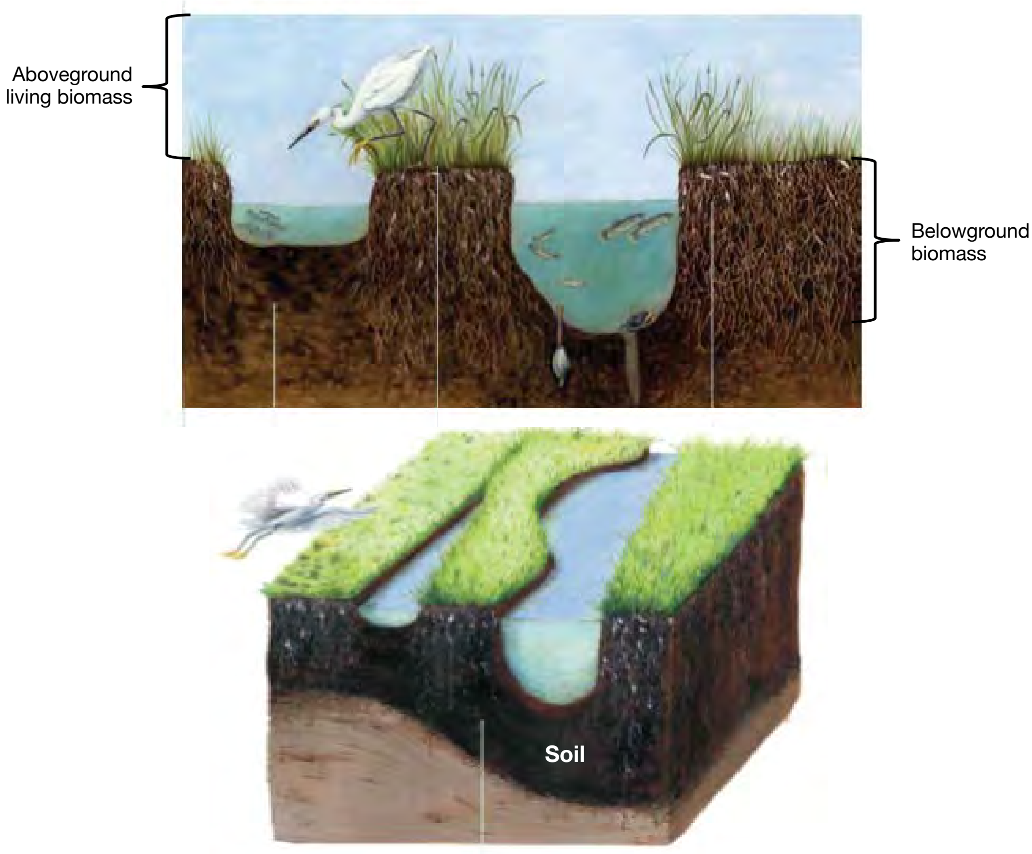

Figure 2.4 Carbon pools in tidal salt marsh ecosystems

In tidal salt marshes, most annual primary production occurs in the belowground biomass (roots and rhizomes) (Valiela *et al*. 1976) with root-to-shoot ratios (e.g., belowground to aboveground biomass ratio) ranging from 1.4 to 50 in salt marsh plants (Smith *et al*. 1979; Darby & Turner 2008a). Thus, most carbon in tidal salt marshes is stored in the living belowground biomass and the non-living soil carbon pool. These two pools are often difficult to separate and therefore treated as a single carbon pool (Chmura *et al*. 2003). Dead aboveground biomass is usually carried away with the regular tides and can usually be excluded from measurements without compromising the accuracy.

SEAGRASS CARBON POOLS

Three major carbon pools can be considered in seagrass meadows. (**Fig. 2.5**):

- Aboveground living biomass (seagrass leaves and epiphytes);
- Belowground living biomass (roots and rhizomes); and
- Soil carbon.

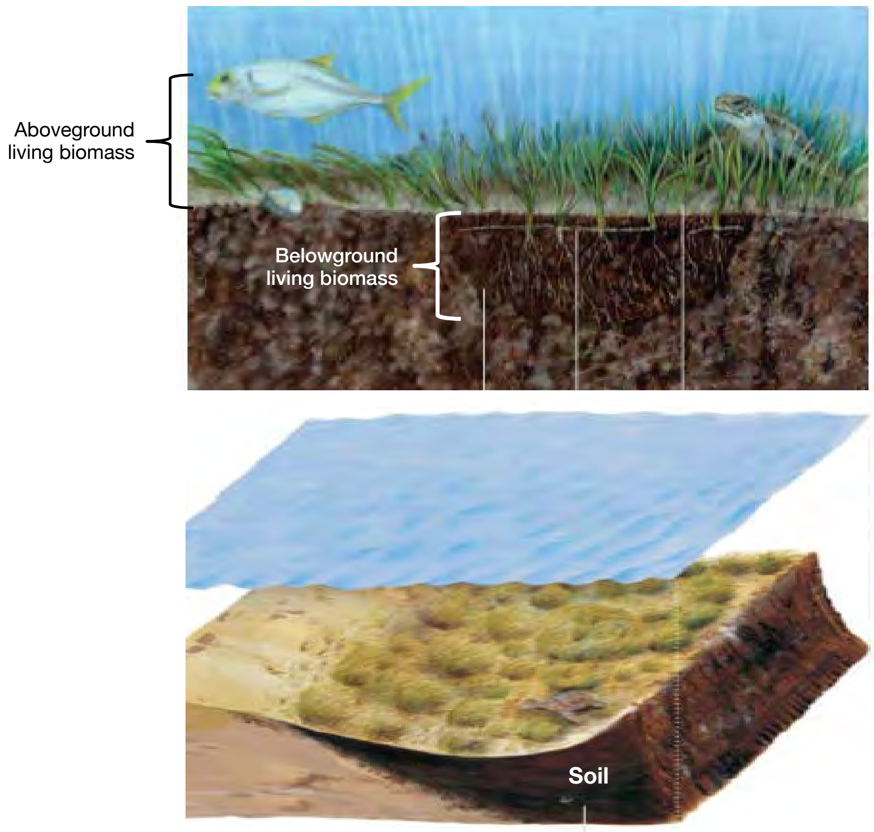

Figure 2.5 Carbon pools in seagrass ecosystems

The largest carbon pool in seagrass ecosystems is the soil carbon. Dead aboveground biomass is usually negligible since seagrass leaves are rapidly decomposed and/or rapidly exported from seagrass meadows through the movement of tidal waters. Epiphytes are noted as a carbon pool; however, their size varies by species and location.

On a global scale, belowground living seagrass biomass only represents 0.3% of the total organic carbon pool found below the surface. Therefore, it can usually be combined with the soil carbon pool estimate without significantly over-estimating the soil organic carbon pool (Fourqurean *et al*. 2012a).

Determine Plot Type, Number, and Location

Determining the minimum number of plots needed to ensure accuracy will aid in keeping initial field measurement and long-term monitoring program costs as low as possible. However, sampling density will ultimately be determined by the project goal and desired accuracy.

A Tier 2 National assessment requires data sufficient for estimating national or regional carbon stocks and may be achieved with a relatively low sampling density that covers a relatively large area. In contrast, a carbon market project requires a higher level of accuracy achieved through increased sampling over a smaller area over time.

Based on the carbon pools present in the ecosystem and the project area stratification, there is a need to determine the optimal shape, size, and sampling intensity necessary to accurately describe the ecosystem properties without needless redundancy. As such, plot design should be done with the project objectives, accuracy, sampling efficiency, and safety in mind.

PLOT TYPE

For assessing blue carbon stocks, two sampling plot types can be used: permanent and temporary. Permanent plots have greater long-term value and credibility in determining carbon stock changes through time, but temporary plots may be more practical.

Permanent plots are persistent, well-demarcated areas that allow for directly comparable measurements to be taken over time.

- **Advantages**: Stratification and plot design are only done once; they are statistically more accurate for determining carbon stock changes over time because the same plot and vegetation is measured at both points in time; they provide low cost verification as an independent verification organization can measure permanent plots and make a direct comparisons (Pearson *et al*. 2007).
- **Disadvantages**: Sites can be manipulated and enhanced (improved management, increased plantings, etc.) to make it appear that more carbon has been sequestered than is true for the rest of the strata; plots can be lost due to natural disasters or anthropogenic intervention thereby requiring enough plots to provide an accurate measure should some be destroyed. (Pearson *et al*. 2007).

Temporary plots are used to generate a single blue carbon measurement. They can be used to determine carbon stock change over time; however, measurements are not directly comparable thereby reducing accuracy.

- **Advantages**: They are cheaper to set up as they do not require permanent demarcations; a new location can be chosen relatively easily if the area where the original samples were taken is lost.
- **Disadvantages**: More plots may be needed to achieve the required precision level.

NUMBER OF PLOTS

The optimum number of plots depends on the accuracy level required, the inherent biomass variability between plots within the same strata, and the cost associated with sampling. Ideally there would be an existing carbon estimate for the study site, and the variance associated with those measurements would be known. Under those circumstances Pearson *et al*. (2007) provides comprehensive methods for determining plot number based on known intra-strata variation (an online tool for calculating the number of plots is also available at: http://www.winrock.org/resources/winrock-sample-plot-calculator). However, the more likely scenario is that no information is available. In this situation, the first time the area is sampled, it is recommended to examine as many plots as the resources (budget and staff time) allow. Subsequent measurements can then use these initial data to determine if more or fewer plots are needed to achieve the desired accuracy level.

It is important to note that some areas may naturally be highly variable; therefore, the minimum number of plots needed may not be known or practical. High variability areas (largely due to soil carbon variations at various depths) will have higher uncertainties (the uncertainty level simply needs to be reported along with any results). The project manager will need to determine how much effort is feasible.

PLOT LOCATION

Plot location should be arranged to minimize disturbance to the ecosystem, while accounting for the variation within strata. There are several methods by which plot placement can be determined. The most common are:

1) **Linear:** This method can be used when either the stratification procedure shows that strata are most logically based on the distances from a location (river, shore, tidal channel) or when traversing the distance between randomly placed plots is prohibitive; however, the actual variability may not be represented (**Fig. 2.6a**).
2) **Random:** Within each strata, plots are picked at random to increase the likelihood of capturing the true variation within and across strata (**Fig. 2.6b**).
3) **Probability-based grid:** This method uses a square or hexagonal cell overlay placed within the defined strata where one random point is sampled from each cell. This method allows for sampling to be evenly spread throughout the strata while still maintaining the assumptions required for a random sample (**Fig. 2.6c**).

The method chosen will depend on study site accessibility, but when possible random or probability-based grid plot design is recommended. If the strata were defined properly, no significant differences will exist between plots. If significant differences ($p > 0.05$) do exist, sampling additional plots for robust estimates may be needed, or simply report the variability found within the stratum. The latter, however, reduces accuracy.

PLOT SHAPE AND SIZE

There are many acceptable plot sizes and shapes that can adequately describe ecosystem composition, biomass, and carbon content. Sample plot shape and size is a trade-off between accuracy, time, and cost for measurement. For example, large square plots (e.g., 100 m^2) are relatively simple to define, require only basic equipment to mark boundaries (measuring tapes and stakes), and sampling in these areas is relatively time- and resource-efficient. However, sampling a small number of larger plots limits the total area that can be surveyed. As a result, the entire project area may not be represented and, as a consequence, carbon assessments extrapolated from these plots will not be as accurate. In contrast, sampling many small, circular plots (e.g., 10 plots, 14 meters diameter) will be more time- and resource-intensive, but will encompass more variation in the project area and support more accurate carbon accounting. Many smaller plots are, therefore, more suitable where variation within the project area is high and resources are available.

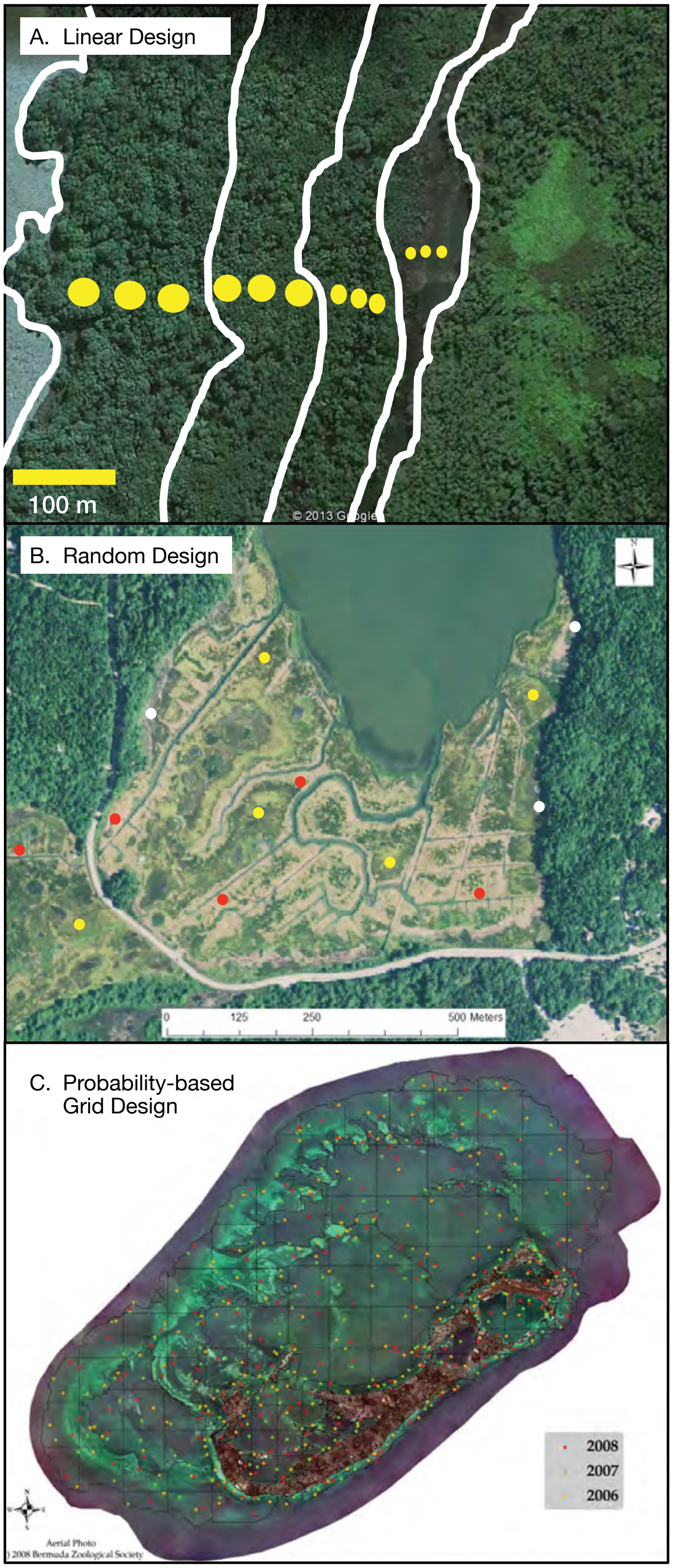

Figure 2.6 Plot location strategies. A) Linear plot design is common in densely vegetated areas where traversing between sites is prohibitive and when there is an inherent gradient (© Boone Kauffman, OSU). B) Random plot design places plots at random location within each strata, this assures that all strata are equally represented (red, yellow, and white dots represent potential sites for plot locations in the low, high and higher marsh, respectively) (© Beverly Johnson, Bates College). C) Probability-based grid design utilizes software (e.g., ArcView) to create grids that fit over, and are proportional to each stratum. Software is used to generate random points in each grid to be surveyed (© Sarah Manuel, Department of Conservation Services, Bermuda).

Plot size is predominantly determined by map resolution or dominant vegetation size. Plot size based on map resolution is useful when trying to validate remote sensing techniques for creating carbon maps. Plot size based on vegetation size may vary within a single assessment to accommodate different pools or strata within a system. For example, in a mangrove system, the largest trees and plants are sampled in the largest plots (e.g., 100 m^2). The high density of smaller trees, lianas, and palms make it practical to sample them in smaller plots or a series of plots (e.g., 10 m^2). Litter, seedlings, and grasses can be adequately sampled in even smaller plots (e.g., 1 m^2). Similarly, plots for a large seagrass species such as *Posidonia* spp could be bigger (e.g., 1 m^2) than the plots for grass-dominated salt marshes (e.g., 0.50 m^2), or smaller seagrass species, such as *Halophila* spp or *Zostera* spp (e.g., 0.25 m^2).

SUBPLOTS AND CLUSTERING

If several plot sizes are required for sampling, it is often most efficient to determine the largest size needed and nest the smaller plots into the larger one. Nested plots are designed such that the largest vegetation components (e.g., trees) are measured over the entire plot, but smaller components (e.g., shrubs, grasses) are measured over a smaller area within the larger plot (**Fig. 2.7a**). Clustering is when the largest plot area is divided into sub-plots such that the total area being sampled remains the same but the cluster design is able to capture more variation found within a plot location increasing overall precision.

For example, it might be determined that a mangrove area requires a circular plot about 1520 m^2 (22 m radius) in area for the larger components but nested plots about 250 m^2 (9 m radius) in area is fine for the smaller components. The total area to be measured can be divided into five

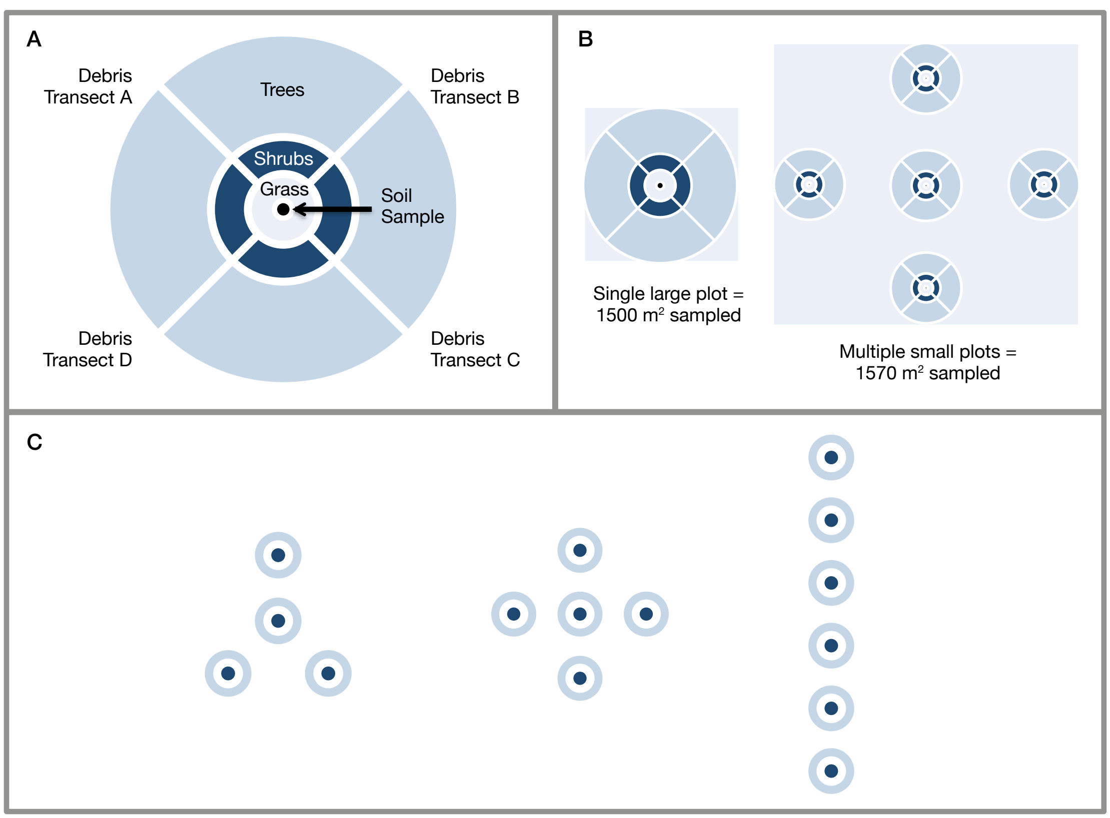

Figure 2.7 Plot nesting and clustering designs. A) Nested plot design where smaller plots are centered. B) Example showing the spatial coverage using single large plots vs. multiple small plots, the area sampled is similar but the total area represented is larger with multiple plots. C) Examples of radial and linear clustered plot designs. (USDA 2008; Kauffman & Cole 2010; Donato *et al*. 2011; Kauffman & Donato 2011)

subplots consisting of a larger sub-plot that has a 10 m radius (~ 314 m^2 * 5 subplots = 1570 m^2) and nested 4 m radius sub-plot (~ 50 m^2 * 5 subplots = 250 m^2). The resulting total area sampled is roughly the same, but the clustered sub-plots reduce between-plot variance and, therefore, the total number of plots necessary to achieve a desired accuracy (USDA 2008; Kauffman & Donato 2011) (**Fig. 2.7b**)

It is important to make some practical considerations when planning sample subplot design and layout. There are many benefits to linear subplot layouts (**Fig. 2.7c**). Linear subplots ease maneuvering in dense mangroves or muddy intertidal marshes, minimize trampling damage, and encompass the variation along an inherent gradient. A radial plot design may be more appropriate for smaller sites and produce more representative data.

Determine Measurement Frequency

The frequency required to conduct (and repeat) carbon stock assessments depends on the assessment objectives and the rate of expected change in the ecosystem being studied. Carbon stocks change in mangroves, tidal salt marshes and seagrass meadows for numerous reasons and vary in impact and time-response. Such changes can include natural disturbances (e.g., typhoons), variations in plant productivity and natural carbon sequestration rates, changes in land cover due to land-use activities (e.g., aquaculture or upland agriculture), and alterations due to climate change (e.g., sea level rise). Sampling frequency also involves establishing requirements for regulation, management or financing, and resource availability. It also depends on the pool being measured. For example, the aboveground biomass pool in seagrass beds will change more rapidly than the carbon stock in underlying soils. Also, seasonal growth/die off patterns in aboveground living biomass oscillates throughout the year and will most likely cancel each other out. For standing stock measurements, we recommend sampling be conducted at peak aboveground biomass (typically late summer). repeated sampling should occur at the same time of year (Fourqurean *et al*. 2001).

Given blue carbon ecosystem dynamics, approximately five-year intervals are sufficient to monitor aboveground pools (Pearson *et al*. 2005; Pearson *et al*. 2007). For carbon pools that respond more slowly (e.g., soils associated with mangroves, tidal salt marshes, and seagrass meadows), longer periods can be used—perhaps 10 or even 20 years between sampling events, if no sudden perturbations affecting soil integrity occurred. However, long intervals risk that natural or anthropogenic disturbances will be missed (Pearson *et al*. 2007). Therefore, irregular or unexpected events, such as strong tropical storms, rapid sea level rise, or land-use change, may justify sampling at more frequent intervals than originally planned.

CONCLUSION

A project designed with the end goal in mind is mandatory to obtain reliable and robust carbon stock estimates. Project designs will vary depending on local requirements and the ecosystem type. Once the project details have been decided, measurements can commence. Field techniques for measuring the aboveground and belowground living biomass in the different ecosystems vary between mangroves, tidal salt marshes, and seagrass meadows and are described in the ecosystem specific sections of Chapter 4. However, the techniques for sampling carbon contained in the sediments and soils are generally applicable to all three ecosystems and discussed in Chapter 3.

2

QUICK GUIDE

Step 1: Define the project boundaries

- Depends on the scope and objective of the project (single area up to national scale assessments)
- Ensure that the area to be assessed adequately represents the range of species and growth forms found in that ecosystem

Step 2: Stratify the project area

- If the project area is composed of various distinct biological structures (e.g., tall mangrove tree areas, dwarf mangrove areas, palm areas), it may be desirable to stratify the project area into sub sections of relatively homogeneous units/strata
- Remote sensing and satellite images are useful for this purpose, but local expertise is also needed
- Care should be taken to not include adjacent marine, upland, or freshwater ecosystems

Step 3: Decide which carbon pools to measure

- Common carbon pools to measure are:
  - Aboveground living biomass (trees, shrubs, grass, etc.)
  - Aboveground dead biomass (downed wood, leaf litter, etc.)
    - May not be relevant to all ecosystems. Tidal marshes and seagrass meadowstend to not have large enough pools of downed wood and leaf litter due to the composition of the local vegetation and removal of debris by tidal waters and currents.
  - Belowground biomass of live vegetation (roots and rhizomes)
    - Sampling will depend on feasibility
  - Soil
    - The most carbon-rich pool in these ecosystems
- A pool should be measured if
  - It is large
  - It is likely to be affected by land use
  - Future land use is uncertain
  - The pool size is uncertain
- Determine type, shape and size, number, and location of measurement plots
  - Type
    - Decide if plots are going to be temporary (single measurement) or permanent (continued monitoring)
  - Shape and size
    - Reliable data can be obtained from circular or rectangular plots
    - Plot shape and size is determined by the level of accuracy needed, time, risk, and cost
    - A nested plot design is recommended with sizes corresponding to the spatial scale of the component of interest
  - Number
    - Should have enough plots to reach a high level of statistical certainty ($p < 0.05$)
    - An online tool for calculating the number of plots needed is available at www.winrock.org/Ecosystems/tools.asp
    - If the project area has been stratified plot number must be determined for each strata
  - Location
- To avoid bias, plot selection should be random (e.g., along a transect) and selected without any prior knowledge of composition or structure within strata

Step 4: Determine measurement frequency

- Depends on the rate of expected change (natural disasters, land use change, climate change, etc.), requirements for participation in carbon markets, and the cost involved in sampling and laboratory analysis linked to resource availability
- Annually may yield best estimates but is costly and often more than is needed to monitor changes
- 5-year intervals are common and coincide with recommendations for participating in carbon markets
- 10–20-year intervals are also common but run the risk of missing natural or anthropogenic disturbances