Pacific Northwest Coastal Blue Carbon Working Group

Biophysical Research Framework

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Background

Blue carbon is the carbon stored and sequestered in coastal ecosystems such as mangrove forests, seagrass meadows or intertidal saltmarshes (http://bluecarbonportal.org/). Tidal wetlands, including emergent marshes, forested and scrub-shrub swamps, and seagrass beds, play an important role in the global carbon cycle by sequestering carbon from the atmosphere (CO_2) continuously over many growing seasons, building stores of carbon in wetland soils high in organic content (Crooks *et al.* 2014). Thus, wetlands that store blue carbon mitigate for carbon dioxide emissions and moderate climate change.

Carbon sequestration has been shown to be very high in tidal wetlands. On a per-acre basis, tidal wetlands store 3-5 times more carbon than tropical forests (Murray *et al*. 2011). Recent studies have highlighted the potential for carbon sequestration in Pacific Northwest tidal wetlands (Crooks *et al.* 2014). Pacific Northwest (PNW) tidal wetlands have high potential for carbon sequestration for several reasons:

> <u>Sediment delivery:</u> Due to coastal geomorphology and climate, PNW rivers deliver large quantities of sediment to tidal wetlands and bays. High sediment delivery means higher resilience to climate change, since sediment accretion is an important component of tidal wetland equilibration with sea level rise. (The other major component is belowground organic matter produced and stored by plants, such as roots and buried woody debris.)
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> <u>High organic content in soils:</u> Evidence is strong that large quantities of carbon accumulate in PNW tidal wetlands. Several studies have shown very high soil carbon content in Oregon's tidal marsh and tidal swamps (e.g. MacClellan 2011, Brophy 2009) and other PNW tidal wetlands. In many of Oregon's drowned river mouth estuaries, organic soils are very deep, indicating long-term carbon accumulation and storage.
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> <u>Sheltered settings:</u> Most of the PNW's tidal wetlands exist in relatively sheltered landscape settings (the "sheltered coast" of bays and river systems, as opposed to the outer coast where wave and storm action is high). The erosion that threatens coastal wetlands in the Gulf of Mexico, for example, is unlikely to threaten our tidal wetlands because of this sheltered setting.
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> <u>Brackish tidal swamps:</u> The PNW outer coast once supported large areas of brackish forested and shrub tidal wetlands ("tidal swamps"). Brackish wetlands are less likely to release greenhouse gases (such as methane), compared to freshwater wetlands. In addition, tidal swamps generate large quantities of woody debris, which becomes buried and serves as another carbon storage mechanism. There is high potential to recover many of these altered tidal swamps through restoration actions (Brophy 2009, Brophy *et al*. 2011).
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> <u>System engineers:</u> In PNW tidal wetlands, system engineers such as beaver (Hood 2012) and Sitka spruce (Brophy 2009) create conditions highly conducive to organic matter accumulation.

Beaver dams in tidal wetlands raise water tables, increasing soil saturation. Sitka spruce root platforms support production of large woody debris which eventually becomes buried in the saturated soils below, adding to carbon stocks.

Large tide range and strong tidal/fluvial interactions: Compared to many other parts of the U.S., tide range is large in the Pacific Northwest. Large tide ranges and strong seasonal fluctuation in precipitation and river flow have led to the development of tidal wetland plant communities with broad tolerances for inundation and salinity. These broad tolerances may allow higher resilience to climate change and the associated changes in inundation and salinity.

Land values and land use types: In many agricultural areas of the Pacific Northwest coast, land values are relatively low compared to urban and rural residential landscapes, increasing opportunities for conservation and restoration of tidal wetlands.

PNW coastal blue carbon research needs are clear: while carbon sequestration rates and reliable long-term storage of carbon are likely high for PNW tidal wetlands, *land managers and carbon project developers still do not have the local data needed to quantify blue carbon sequestration rates and greenhouse gas emissions for PNW tidal wetland types.*

Pacific Northwest Coastal Blue Carbon Working Group

Pacific Northwest research scientists, restoration practitioners, conservation leaders, land managers, policy experts, and funding program leaders have formed a coastal blue carbon working group to organize our region's approach to coastal blue carbon research and policy development.

The mission of the working group is to:

> Develop coastal blue carbon as a conservation and management tool so the conservation and restoration of Pacific Northwest tidal wetlands' ecosystem functions can mitigate climate-related changes using carbon credit-markets and trades.

The goals of the working group are to:

1. Determine what policies, programs and methods are needed to facilitate blue carbon-supported restoration and conservation of tidal wetlands in the Pacific Northwest.
2. Describe the carbon market opportunities in the Pacific Northwest.
3. Describe other financial opportunities presented by coastal blue carbon.
4. Conduct the field-based research needed to quantify net carbon sequestration rates in Pacific Northwest tidal wetland types.
5. Develop biophysical research projects that provide the basis for quantifying the net value of carbon sequestration associated with tidal wetland conservation and restoration actions in the Pacific Northwest.
6. Work with policymakers and land managers to lay the groundwork for Pacific Northwest tidal wetland restoration to be supported (at least in part) by funding from voluntary and, when applicable, regulatory blue carbon markets.

Purpose of the Biophysical Research Framework

This biophysical research framework is focused mainly on addressing the PNW Coastal Blue Carbon Working Group's Goals 3 and 4 described above while suggesting links to the work of social and economic scientists, policy experts, and land managers. The purpose of the framework is to coordinate the efforts of research scientists interested in quantifying carbon sequestration rates and greenhouse gas (GHG) emissions in the suite of Pacific Northwest tidal wetland classes most suited to carbon finance-supported restoration, enhancement and conservation actions. The results of this research will form the basis for the valuation of coastal blue carbon credits to be used by land managers to support the development of carbon-financed habitat restoration and conservation projects (if/when a state or federally regulated carbon market becomes a reality).

And since this research will need to be conducted as multiple projects funded by a variety of organizations, an important function of this framework will be to demonstrate to funding organizations that researchers are taking a collaborative approach to PNW coastal blue carbon research. To funders, the benefit of a regionally collaborative approach is the efficiency with which project funds are expended and the more immediately relevant and useful project outcomes. To researchers, the benefit of a collaborative approach is the greater competitive quality of individual research proposals tied to a coordinated regional effort compared with those developed within the context of a region-wide competitive "free-for-all."

This framework is focused on the biophysical research to be conducted in support of these principles; *a separate but related research framework will be developed by "market side" researchers —social and economic scientists— to investigate and characterize the feasibility of using carbon financing mechanisms to support tidal wetland restoration, enhancement and conservation actions on both public and private lands in the Pacific Northwest.*

This research framework will be strengthened by working group members' review of the research approaches undertaken by researchers in other states, regions, and nations. Relevant lessons learned from those projects (including modeling, monitoring, field verification, etc.) will be applied to this Pacific Northwest approach to coastal blue carbon research.

Geographic Scope

The biophysical science team of the Pacific Northwest Coastal Blue Carbon Working Group will conduct its research in the U.S. Pacific Northwest coastal area from the Strait of Juan de Fuca to Cape Mendocino. Because tidal wetland habitats can vary significantly among subregions within this area, the team will be divided into three technical teams who focus their work on each of three subregions: Outer Coast, Lower Columbia and Puget Sound (Figure 1).

Pacific Northwest Tidal Wetland Habitat Types

The biophysical science team of the Pacific Northwest Coastal Blue Carbon Working Group will conduct its research in *current and former* tidal wetland habitat types that support emergent and aquatic vegetation; those habitats whose anaerobic, peaty soils accumulate and permanently store emergent marsh and swamp plant material along with other organic material (e.g., macroalgae) and thus sequester carbon. These wetland types include seagrass beds, emergent tidal marsh, scrub-shrub tidal wetland, and forested tidal wetland.

When historically degraded (e.g., diked, drained and converted to agricultural uses), these tidal wetlands are well suited for restoration and enhancement activities supported by carbon finance mechanisms such as those recognized by the Verified Carbon Standard. Relatively undisturbed ("least disturbed") examples of these habitats are well suited for habitat conservation actions also supported by carbon finance mechanisms. These habitat types are described according to the biotic component of the Coastal and Marine Ecological Classification Standard (CMECS) habitat classification scheme (Table 1).

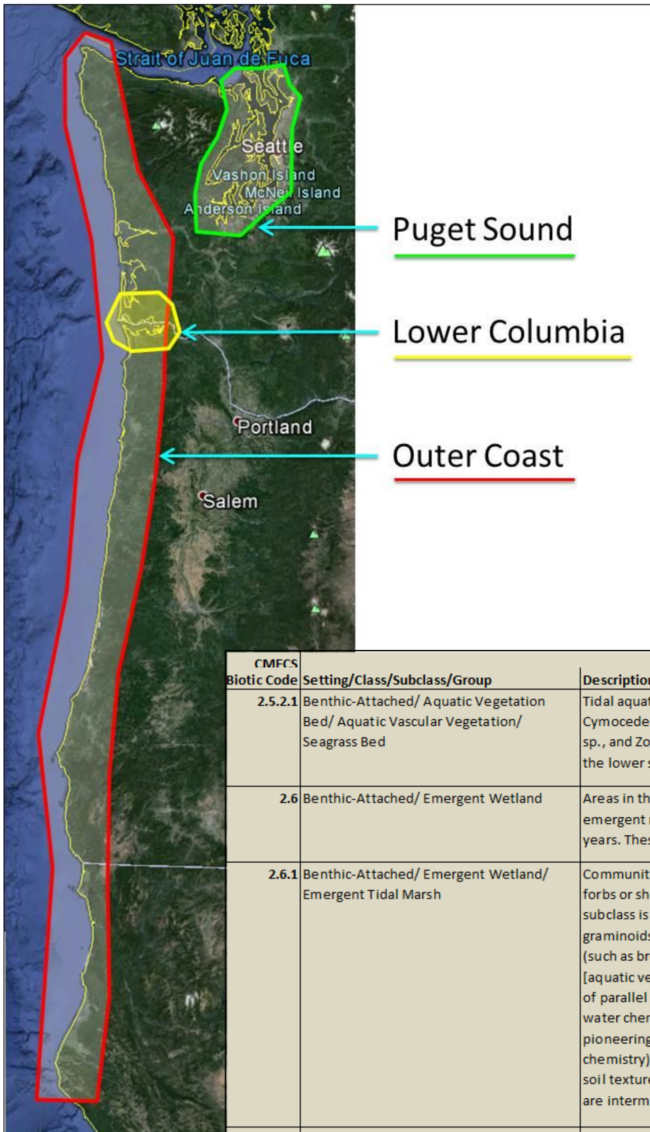

Figure 1. Geographic areas for blue carbon research in the Pacific Northwest

CMECS Biotic Code	Setting/Class/Subclass/Group	Description
2.5.2.1	Benthic-Attached/ Aquatic Vegetation Bed/ Aquatic Vascular Vegetation/ Seagrass Bed	Tidal aquatic vegetation beds dominated by any number of seagrass or eelgrass species, including Cymocedea sp., Halodule sp., Thalassia sp., Halophilla sp., Vallisnera sp., Ruppia sp., Phyllospadix sp., and Zostera sp. Seagrass beds may occur in true marine salinities, and they may extend into the lower salinity zones of estuaries.
2.6	Benthic-Attached/ Emergent Wetland	Areas in this class are characterized by erect, rooted, herbaceous hydrophytes—excluding emergent mosses and lichens. This vegetation is present for most of the growing season in most years. These wetlands are usually dominated by perennial plants.
2.6.1	Benthic-Attached/ Emergent Wetland/ Emergent Tidal Marsh	Communities dominated by emergent, halophytic, herbaceous vegetation (with occasional woody forbs or shrubs) along lowwave-energy, intertidal areas of estuaries and rivers. Vegetation in this subclass is composed of emergent aquatic macrophytes, especially halophytic species—chiefly graminoids (such as rushes, reeds, grasses and sedges), shrubs, and other herbaceous species (such as broad-leaved emergent macrophytes, rooted floating-leaved and submergent species [aquatic vegetation], and macroscopic algae). The vegetation is usually arranged in distinct zones of parallel patterns, which occur in response to gradients of tidal flooding frequency and duration, water chemistry, or other disturbances. Tides may expose mudflats that contain a sparse mix of pioneering forb and graminoid species. Salinity levels (which control many aspects of salt-marsh chemistry) vary depending on a complexity of factors, including frequency of inundation, rainfall, soil texture, freshwater influence, fossil salt deposits, and more. Salt marshes often grade into (or are intermixed with) scrubshrub wetlands in higher areas.
2.6.1.1	Benthic-Attached/ Emergent Wetland/ Emergent Tidal Marsh/ Brackish Marsh	Marshes dominated by species with a wide range of salinity tolerance. Depending on the salinity levels (0.5-30), more or less salt-intolerant species may be present.
2.7	Benthic-Attached/ Scrub-Shrub Wetland	Emergent wetland areas dominated by woody vegetation that is generally less than 6 meters tall. Characteristic species include true shrubs, young trees, and trees or shrubs that are small or stunted due to environmental conditions. Scrub-Shrub Wetland includes the shrub-dominated portions of high salt marshes-as well as stunted or low mangrove communities.
2.7.1	Benthic-Attached/ Scrub-Shrub Wetland/ Tidal Scrub-Shrub Wetland	Estuarine or tidal riverine areas dominated by shrub vegetation that has less than 10% tree cover.
2.7.1.1	Benthic-Attached/ Scrub-Shrub Wetland/ Tidal Scrub-Shrub Wetland/ Brackish Tidal	Tidal areas dominated by shrub or immature tree species that are less than 6 meters tall and have a range of salt tolerance. Salinity may range from 0.5-30 (PSS).
2.8	Benthic-Attached/ Forested Wetland	Areas in this class are characterized by woody vegetation that is generally 6 meters or taller.
2.8.1	Benthic-Attached/ Forested Wetland/ Tidal Forest-Woodland	Estuarine or tidal riverine areas with greater than 10% tree cover.

Table 1. Tidal wetland habitat types in the Pacific Northwest according to CMECS biotic component (DLCD 2014).

Environmental Drivers Affecting Carbon Storage in PNW Tidal Wetlands

Not all tidal wetlands store the same amount of carbon, or store it at the same rate. The factors that control how much carbon is stored ("environmental drivers") will be incorporated into the Research Framework, allowing accurate quantification of carbon sequestration in different habitat classes and conditions. Environmental drivers likely to affect carbon storage in PNW tidal wetlands are listed below.

- Weather and climate
- Combined tidal/fluvial inundation regime

  Factors affecting inundation regime:
  - Marsh/swamp surface elevation and geomorphic setting
  - Historic and predicted rates of local relative sea level change
  - Historic and predicted changes in river discharge volumes
  - Intensity and frequency of major storms
- Geomorphic setting, which affects:
  - Fluvial inputs
  - Tidal/fluvial current velocities
  - Rates and seasonal patterns of mineral sedimentation and vertical accretion
  - Rates and seasonal patterns of allocthonous carbon inputs
  - Surface and subsurface hydrology
  - Wind/wave energy/erosion
  - Tectonic uplift/subsidence rates
- Historic and current land use (e.g., agricultural grazing lands) which affects:
  - Site hydrology/drainage
  - Soil disturbance (from grazing, tillage, road construction)
  - Sedimentation
  - Vegetation cover
- Presence of ecosystem engineers
  - Beaver
  - Sitka spruce
  - Invasive species (e.g., burrowing isopod- *Sphaeroma quoianum*)
- Groundwater hydrology
  - Shallow water tables and associated anaerobic soils
  - Seasonal groundwater patterns
  - Daily groundwater patterns
- Channel water salinity
- Soil characteristics
  - Aerobiosis/anaerobiosis (redox)
  - Salinity
  - Nitrogen and sulfate concentration
  - Texture, bulk density, and compaction
  - Temperature
- Wetland class (marsh, scrub-shrub, forested) and vegetation community (including invasive species), which affect:
  - Above and belowground organic matter production
  - Phenological patterns (e.g., annual senescence or lack thereof)
  - Potential for LWD storage

Overall Approach to Biophysical PNW Coastal Blue Carbon Research

1. Determine how existing Verified Carbon Standard (VCS) methods will be applied to evaluating Pacific Northwest coastal blue carbon credits. Identify any region-specific VCS methods adjustments needed (e.g., methods for determining baseline scenarios, appropriate stratification criteria, development of regionally-appropriate monitoring methods, etc.).
2. Identify the key environmental drivers (e.g., from list above) likely to have the largest effect on carbon sequestration in PNW wetlands.
3. Compile a list of uncertainties/data gaps relevant to existing methods (e.g. data on carbon sequestration rates and GHG emissions from the full range of Pacific Northwest tidal wetland habitat types and salinity regimes).
4. Develop research projects to fill data gaps, adapt or modify (as needed) existing methods, develop additional methods, and field-test monitoring methods. Research projects will include:
   - Biophysical, social, and economic research; projects must articulate the policy, market, and economic circumstances and opportunities that drive the need for the research. *This biophysical research framework focuses mainly on the biophysical research goals, objectives and tasks associated with these research projects.*
   - "Least disturbed" reference tidal wetlands, tidal wetlands recovering due to restoration actions, and restorable former tidal wetlands converted to other functions (e.g., diked pasture lands) in the wetland types described above.
   - Wetlands with a range of characteristics responding to key environmental drivers identified in step 2 above.
5. Examine and clearly explain connections between research results and climate change resilience. Since many of the drivers affecting tidal wetlands carbon sequestration and flux rates are the same drivers that determine tidal wetlands' resilience to sea level rise, this research effort will be designed to advance our understanding of climate change resilience for Pacific Northwest tidal wetlands.

Biophysical Research Projects

Biophysical Project Research Goals

1. Build regionally meaningful, science-based coastal wetland carbon budgets to contribute to the national carbon accounting effort in response to Intergovernmental Panel on Climate Change guidance.
2. Apply tested/recommended methods and lessons learned from other regionally-significant coastal wetland carbon sequestration/GHG emissions quantification efforts.
3. Quantify the effects of key environmental drivers identified above on carbon sequestration and GHG emissions.
4. Relate research results to the resilience of research project sites to future sea level changes.

5. Working with economic researchers, provide a preliminary economic evaluation of the potential for carbon market and incentive mechanisms to support coastal wetland conservation and restoration.
6. Working with social and economic researchers, and policy professionals, use project results to engage locally, state, and regionally-relevant organizations and individuals to understand how carbon finance mechanisms can be incorporated into the productive management of coastal lands in the Pacific Northwest. Share lessons learned with national and international audiences.

Biophysical Research Objectives

1. Select research project sites in the three geographic areas described above (Puget Sound, Lower Columbia, and PNW Outer Coast)(Figure 1) based on their representativeness of PNW tidal wetland characteristics (i.e., tidal wetland type, geomorphic setting, influence of key ecosystem drivers, land use status).
2. Validate field protocols for site-specific carbon budget accounting and address key methods-related questions, including:
    - What are the most cost-effective sampling approaches for monitoring changes in carbon storage and GHG fluxes in a diverse group of wetlands?
    - How will allochthonous and autochthonous carbon sources be quantified and accounted for in carbon budgets?
3. Quantify in "least disturbed," disturbed (e.g., diked and drained), and restored tidal wetland sites:
    - Existing soil carbon storage and rate of carbon sequestration, and determine whether those rates can be described by existing models (Mudd *et al.* 2009, Morris et al, 2012).
    - Quantities of carbon stored as biomass (living and dead, aboveground and belowground). Biomass carbon pools are likely to be particularly high for shrub and forested tidal wetlands.
    - The rate of carbon loss and GHG emissions; and determine whether predictive tools can be developed to characterize GHG fluxes in relation to environmental drivers. For example, dominant plant community type, which is linked to GHG-controlling soil biogeochemical factors (Bubier *et al.* 1995, Dias *et al.* 2010), can be readily characterized using remote sensing.
    - The ratio of allochthonous to autochthonous carbon sources. All autochthonous carbon can be accounted for as in-site carbon sequestration, but allochthonous carbon sequestration rates depend on differences in carbon decay rates in the source site vs. the wetland sink (Bridgham *et al.* 2006).
    - The fate of sequestered carbon in eroding estuarine wetland soils; determine how to factor this potential loss into estuarine wetland carbon budget accounting. To be accomplished through decomposition experiments and *in situ* transplant of wetland soil carbon to subtidal areas.
    - The relationships between key environmental drivers and the rates of carbon sequestration, GHG flux, and carbon inputs and outputs described above.

4. Contribute biophysical research results to help socio-economic researchers address key policy-related questions, including:

    - What are the barriers and opportunities to integrating tidal wetland carbon management within PNW climate change mitigation and adaption planning efforts?
    - What is the scale of the potential carbon market for tidal wetlands in the PNW? What data will be needed to implement a comprehensive economic assessment of carbon sequestration potential in the PNW region?
    - What are the potential social and economic barriers facing proponents of wetland carbon credits in working with private landowners, particularly agricultural interests?
    - What are the most effective practices for working with local and state planning agencies to incorporate climate mitigation and adaptation into local and regional sustainability and climate action plans?
    - How can resource management for blue carbon sequestration functions be integrated with climate change adaptation planning on the PNW coast? For example, restoration and conservation of tidal wetlands is already prioritized in many resource management agencies' climate change adaptation plans, and consideration of these wetlands' carbon sequestration functions could leverage funding and create opportunities for synergistic action.

Methods

Quantifying carbon sequestration rates in PNW tidal wetlands

Quantifying carbon sequestration potential in individual PNW tidal wetland types will be accomplished through field measurements and laboratory analysis of samples from representative locations within least disturbed, disturbed, and restored salt, brackish, and freshwater tidal wetlands. Of primary importance in the calculation of sequestration rates is measurement of soil carbon density and total soil volume (Crooks *et al.* 2014).

Sample Design, Field Sampling and Sample Processing

- Sample design within and across study sites will be stratified by key environmental drivers identified by the group, based on unique regional ecosystem characteristics and literature. For major classes of key drivers, replicate samples will be obtained within each class to allow determination of significant differences among classes. Examples of major classes within likely key drivers are tidal inundation regime (low marsh, high marsh, fluvially-dominated riverine tidal); vegetation class (emergent, scrub-shrub, forested); groundwater regime (continuously saturated, spring tide cycle saturation, seasonal wetland); and disturbance class (least-disturbed, disturbed, restored).
- Within strata, sample placement will be randomized to allow characterization of within-stratum variability.
- At least two replicate sediment cores will be collected at each sample location..
- Prior to coring, vegetation cover (percent cover) will be assessed at two scales. If plant cover is minimal, the presence of litter or bare soil will be noted.

1. A square subplot (0.25 m^2) will be established at the core sample location. For herbaceous vegetation in this subplot, percent cover by species and average plant height will be recorded.
2. A larger, circular plot (19.63 m^2) will assess vegetation within a 5 m radius from the core sample location. Percent cover by species within ths plot, and species and height class (ground, shrub, or tree) of overhanging vegetation will be recorded. For shrub and forested tidal wetlands, shrub stem densities and tree densities and diameters (dbh) will be recorded by species and overall canopy height will be estimated; diameter, height and condition of standing dead trees will be recorded. The quantity of aboveground woody debris (dead, downed wood) will be recorded (number of pieces, length, and diameter). Subplots may be used where stem or wood density is high.
3. Examples of cover and height classes are shown below.

Vegetation Cover Class Values (%)	
1	Trace
2	0 – 5
3	6 – 10
4	11 – 25
5	26 – 50
6	51 – 75
7	76 – 95
8	96 – 100

Vegetation Height	Height Strata (m)
Ground	0 – 1
Shrub	1 – 4
Tree	> 4

- Replicate sediment core collection will consist of driving PVC coring tubes 10 cm in diameter to a depth of 60 to 90 cm. Cores will be frozen after transport to the lab, and sectioned at 2 cm intervals. After these samples have been dried at 60 °C for 96+ hrs, aliquots will be ground by a Wiley Mill for laboratory analysis.
- Approximately 15 g of sediment from sections at varying depths will be sampled within a subset of the cores to be analyzed for excess ^{210}Pb activity.

Laboratory Analysis

- Prior to grinding, the mineral mass of the oven-dried sediment will be determined to calculate bulk density using the known wet volume of the section. Loss on ignition will be used to measure the percent organic matter of each section, and the remainder is the percent mineral matter.
- Approximately 150 mg of the ground sediment will be analyzed for carbon content using a nitrogen and carbon analyzer (e.g., Thermo Electron Corp. FlashEA 1112). In order to assess quality control, a chemical standard and a soil standard will be analyzed prior to sample analysis; the soil standard will be reanalyzed every 10 samples; and 5% of the samples will be reanalyzed.
- Within a subset of the cores, long-term sediment accretion rates will be determined through the measurement of excess ^{210}Pb activity using a gamma ray spectrometer (e.g., Canberra Germanium Detector). Gamma emissions at 46 keV and 351 keV will be recorded by the associated software (e.g., Genie 2000) until the counting error rates for ^{210}Pb and ^{214}Pb fall below 10%, approximately 48 to 72 hrs. The excess ^{210}Pb activity is equivalent to the difference

between the activity measured at 46 keV (total ^{210}Pb activity) and 351 keV (supported ^{210}Pb activity). A calibration standard, composed of 0.75 g pitchblende silica-ore standard and 15 g of sample, will be analyzed for each sediment core to account for differences in counting efficiencies at differing energy levels.

Calculations

- Carbon density = Percent carbon content x Bulk density
- Carbon mass = Carbon density x Section thickness
- Sediment accretion rate = – λ/s
    1. λ is the half life of ^{210}Pb and s is the slope of a linear regression of the natural log of excess ^{210}Pb activity versus depth
- Carbon accumulation rate = Sediment accretion rate x Average carbon density

Sample design and statistical analyses

- Key environmental drivers will be treated as independent variables in statistical analysis. They may be fixed or random effects depending on sample design.
- For environmental drivers not used for stratification during sample design (such as soil texture, groundwater regime, and soil salinity), parametric statistics such as ANOVA and regression will be used to analyze relationships between driver levels and carbon accumulation metrics.

Quantifying net carbon flux

Quantifying the fate of sequestered carbon in eroding estuarine wetland soils

- *Example approach*: Conduct decomposition experiments and in situ transplant of marsh soil carbon to subtidal areas; need to determine how to factor this potential loss into estuarine wetland carbon budget accounting.

Quantifying GHG emissions in PNW tidal wetlands

- *Example approach*: Use static chambers and gas chromatography to examine gas fluxes of methane and nitrous oxide seasonally during the tidal cycle in restored and reference wetlands from freshwater to saline at project sites. Measure gas fluxes over 24 hours with continuous gas analysis (with infrared spectroscopy and laser spectroscopy) to identify diurnal patterns for scaling to annual carbon budgets. Correlate rates with tidal height, temperature, salinity, sulfate concentrations, soil %C and %N, and plant community composition.

Relating project results to climate change resilience

Guidance resulting from the research above will reflect relative sea level rise projections for the West Coast (NRC 2012), and prior research on tidal wetland equilibration to relative sea level rise (e.g. Cahoon et al. 2006). Tidal wetland sustainability in the face of climate change and sea level rise will affect future blue carbon functions, and this information will be emphasized in products to assist longterm planning and resource management.

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