Draft Version 5

BCarbon Living Shoreline Blue Carbon Protocol

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1.0 INTRODUCTION

BCarbon is a nonprofit organization creating nature-based pathways to net-zero goals that strengthen rural economies, and generate co-benefits including soil regeneration, improved water quality and water management, and increased biodiversity. With input from stakeholders including landowners, scientific experts, government officials, environmental organizations, and industry representatives, BCarbon develops standardized protocols to support the issuance and registration of carbon credits associated with carbon sequestration in soils, forests, and aquatic ecosystems.

The BCarbon Living Shoreline Protocol ("the Protocol") describes the technical approach required by BCarbon to certify greenhouse gas (GHG) removals and enhance "blue carbon" sequestration from installing and operating "coastal regenerative and protective living shorelines" ("Living Shorelines"). As administrator of the Protocol, BCarbon's goal is to ensure the complete, consistent, transparent, accurate, and conservative quantification and verification of GHG emission reductions associated with a Living Shoreline project. The Protocol is designed to operate within a "digital MRV" framework enabling automated, real-time data onboarding and data processing, quantification, and verifications. The BCarbon dMRV framework is integrated with a registry that tracks the complete lifecycle of certified projects from project approvals, and issuance, serialization, transferring and retirement of credits.

Project developers and BCarbon use this protocol to quantify and verify the greenhouse gas reductions associated with Living Shoreline projects that enable salt marshes, sea grasses, and mangroves to retain and regenerate their natural capacities for carbon sequestration.

Two types of blue carbon credits can be quantified using this Protocol:

1 – Protected Wetlands Carbon

- The GHG emissions that are projected to be avoided over 50 years by the Living Shoreline's protection of the organic carbon stored in the wetlands within the Project Area

2 – Regenerating Wetlands Carbon

- Atmospheric CO2 that is removed and sequestered in regenerating wetlands within the Project Area, by new net soil accretion, and in some cases, new plant growth, and/or new oyster reefs. Associated credits can be awarded on an annual basis following Living Shoreline construction.

The protocol also introduces important "co-benefits" of Living Shoreline projects such as habitat protection and increased biodiversity In future updates to this protocol, BCarbon will continue to assess how best to incorporate co-benefits into the crediting process.

This version of the Protocol applies only to projects in Texas. BCarbon will periodically review the Protocol to extend applicability to other states in the U.S. and potentially other countries, and to update the technical requirements and guidance to reflect advances in monitoring, modeling, technologies, regulations, and other relevant information.

Support for small landowners is one of BCarbon's key principles. Small landowners are encouraged to apply for financial and logistical assistance to meet the Protocol's requirements. BCarbon will periodically review the Protocol to incorporate further measures of support and assistance to underrepresented and under-resourced groups.

1.1 Coastal Ecosystems Both Mitigate and Are Threatened by Climate Change

1Vegetated wetlands bind soil and deposited sediments in dense root systems, preventing erosion of essential and otherwise vulnerable coastal ecosystems by absorbing both continuous and more intense storm-related energy of ocean and tidal waves. In the same way, coastal wetlands, including salt marshes, mangrove forests, and seagrass meadows also absorb and store large quantities of carbon dioxide (CO2) from the atmosphere in their branches, leaves, roots and in underlying soils.[1]

Compared to mature tropical forests, where carbon storage occurs largely aboveground, coastal wetlands sequester carbon in deep soil horizons at a rate ten to fifty times higher,[2,3] and store three-five times more carbon per equivalent area. These ecosystems have been estimated to offset between 0.9% and 2.6% of total anthropogenic CO2 emissions globally.

Wetlands naturally retreat and regenerate in cycles that equilibrate over time. However, wetland habitats have lost more than a third of their area over the past half-century due to increased development, poor stormwater management, and deforestation and destruction of wetlands and riparian zones, and climate change. Without shoreline protection, vegetation drowns and dies, and root systems degrade, destabilizing underlying soil.

Today we are witnessing rapid losses of wetlands that remove natural flood protection and threaten water quality for tens of millions of Americans that live in coastal counties, costing billions of dollars of economic losses year after year[4]. These losses are projected to accelerate with higher sea levels that will “drown” many coastal wetland ecosystems[5] and with increasing frequency and intensity of storm events that can rapidly convert compromised wetlands into open water.[6,7] If wetlands are not protected, and erosion patterns continue to accelerate, large amounts of stored carbon will be released into the atmosphere during a time when there is scientific consensus and urgency for rapid, large-scale reductions in GHG emissions.[8]

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[1] The Pew Charitable Trusts. “Coastal 'Blue Carbon': An Important Tool for Combating Climate Change.” The Pew Charitable Trusts, October 1, 2021. https://www.pewtrusts.org/en/research-and-analysis/issue-briefs/2021/09/coastal-blue-carbon-an-important-tool-for-combating-climate-change.

[2] Nellemann, Christian, and Emily Corcoran, eds. *Blue Carbon: The Role of Healthy Oceans in Binding Carbon ; a Rapid Response Assessment.* UNEP, 2009.

[3] Bridgham, Scott D., J. Patrick Megonigal, Jason K. Keller, Norman B. Bliss, and Carl Trettin. “The Carbon Balance of North American Wetlands.” *Wetlands* 26, no. 4 (December 2006): 889–916. https://doi.org/10.1672/0277-5212(2006)26[889:tcbona]2.0.co;2.

[4] Taylor, Charles A., and Hannah Druckenmiller. "Wetlands, Flooding, and the Clean Water Act." *American Economic Review* 112, no. 4 (2022): 1334-63. https://doi.org/10.1257/aer.20210497.

[5] Borchert, Sinéad M., et al. “Coastal Wetland Adaptation to Sea Level Rise: Quantifying Potential for Landward Migration and Coastal Squeeze.” Journal of Applied Ecology 1, no. 12 (2018): https://doi.org/10.1111/1365-2664.13169.

[6] Titus, J. G. SEA LEVEL RISE AND WETLAND LOSS: AN OVERVIEW. 35 (1988).

[7] Emanuel, K. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* **436**, 686–688 (2005).

[8] “High-Quality Blue Carbon Principles and Guidance.” UNFCCC. United Nations, 2022. https://climatechampions.unfccc.int/wp-content/uploads/2022/11/HQBC-PG_FINAL_11.8.2022.pdf?trk=public_post_comment-text.

1.2 Living Shorelines Protect and Regenerate Carbon Reservoirs

The modern living shoreline concept was first applied to erosion control projects in the Chesapeake Bay and has since expanded to coastal regions throughout the U.S. and elsewhere.[9] A variety of techniques using natural or biodegradable materials such as stone, sand, oyster shells, and/or coir logs are typically used, often in conjunction with planting of native species.[10]

Evidence from existing projects indicates that properly constructed, living shorelines can:

- Stop the erosion of the toe of the wetlands, thereby preventing the potential loss of large amounts of carbon stored in wetland soils; [11]
- Protect landward portions of the wetlands that would otherwise erode in future decades from wave energy as the shoreline continues to recede;[12,13,14] and
- Depending on the surrounding environment and structural design, Living Shorelines can support the regeneration of wetlands and habitat creation. Plants in protected shorelines can provide additional stability by trapping sediments which would otherwise be exported and oxidized in adjacent estuarine waters, resulting in a vertical increase ("accretion") of the wetland (Figure 1).

The certification of blue carbon credits under this Protocol is based on preventing projected loss of wetlands due to accelerated rates of erosion caused by regular wave energy and sea-level rise. Living Shoreline Projects developed under this protocol are designed to extend the health and life span of existing wetlands by slowing and stabilizing shoreline erosion, improving resilience to future sea level rise, and restoring the natural transmission of sediment, which in turn supports the growth of plants, oyster reefs, and other organic carbon reservoirs. Specifically, projects will be engineered to protect the toe of the wetlands at the water's edge, which is below the living root zone and is the most susceptible to erosion. Projects will be monitored for their performance in not only stabilizing shorelines but in regenerating and expanding the existing wetlands, preserving, enhancing, or creating habitat. For more information on the protection mechanism of the Protocol's Living Shorelines, see Appendix C.

[9] Office of Habitat Conservation - NOAA Restoration Center. "Living Shorelines." ArcGIS StoryMaps. Esri, July 14, 2022. https://storymaps.arcgis.com/stories/edc3cc67b37f43a5a815202f81768911.

[10] Texas General Land Office, Allen Engineering and Science, and Harte Research Institute. "A Guide to Living Shorelines in Texas." The Texas General Land Office, 2020. https://www.glo.texas.gov/livingshorelines/.

[11] Lane, R. R., Hunter, R. G. & Day, J. W. Impacts of Climate Change on Western Gulf of Mexico Coastal Wetlands and Evaluation of The Use of Living Shorelines for Wetland Sustainability. 138 (2022).

[12] Polk, Mariko A., Rachel K. Gittman, Carter S. Smith, and Devon O. Eulie. "Coastal resilience surges as living shorelines reduce lateral erosion of salt marshes." Integrated Environmental Assessment and Management 18, no. 1 (2022): 82-98.

[13] Isdell, Robert E., Donna Marie Bilkovic, Amanda G. Guthrie, Molly M. Mitchell, Randolph M. Chambers, Matthias Leu, and Carl Hershner. "Living shorelines achieve functional equivalence to natural fringe marshes across multiple ecological metrics." *PeerJ* 9 (2021): e11815.

[14] Polk, Mariko A., and Devon O. Eulie. "Effectiveness of living shorelines as an erosion control method in North Carolina." *Estuaries and Coasts* 41, no. 8 (2018): 2212-2222.

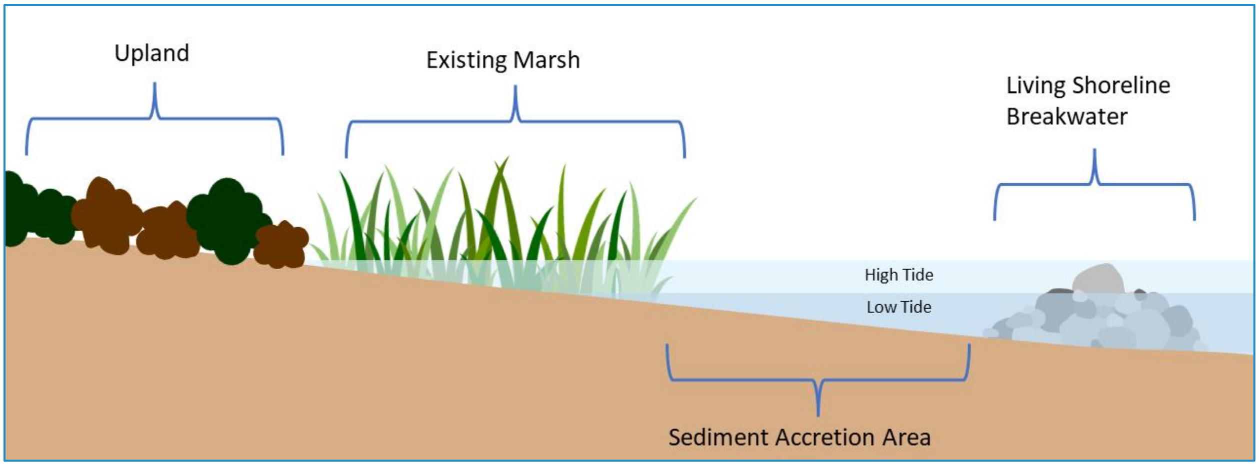

Figure 2 Schematic drawing of a Living Shoreline

1.3 Definitions

Term	*Definition*
Additionality	An evaluation used in carbon markets to demonstrate that the results of a crediting initiative would not have occurred in absence of the incentive of carbon credits. A project is considered "additional" if it would not have happened in a business-as-usual scenario without the crediting project; it is "non-additional" if it would have still occurred.
Blue carbon	Carbon stored in the above and belowground biomass and sediment of coastal and marine environments.
Blue carbon credit	A credit awarded for the growth and/or conservation of carbon-absorbing plants in coastal ecosystems.
Carbon dioxide equivalent (CO2e)	A standard unit of measure to express the impact of each different greenhouse gas in terms of the amount of CO_2 that would create the same amount of global warming.
Digital MRV (d-MRV)	An advanced methodology for Monitoring, Reporting and Verification (MRV) that applies digital technologies to streamline data collection, processing, and quality control in the issuance of GHG emission credits.
GHG Sink	Physical unit or process that removes a GHG from the atmosphere.
GHG Reservoir	Physical unit or component of the biosphere, geosphere or hydrosphere with the capability to store or accumulate a GHG removed from the atmosphere by a GHG sink or captured from a GHG source.
Living Shoreline Projects	Living shorelines incorporate substantial natural or nature-based features, potentially combined with hard structural components, to provide shoreline protection and stabilization while maintaining ecosystem functions.
Mean high water contour	The average of all the high water levels observed over the National Tidal Datum Epoch.
Mean Low water contour	The average of all the low water heights observed over the National Tidal Datum Epoch.
Oyster spat	Oyster larvae permanently attached to a surface which will grow into an adult oyster.
Project activity	1) The installation of a Living Shoreline eligible for carbon credits under this Protocol 2) Maintenace and operation of a Living Shoreline
Project developer	The entity that seeks to build the living shoreline or owns the project after transfer of ownership.

Term	*Definition*
Regenerating Carbon Credits	Atmospheric CO2 is removed and sequestered in regenerating wetlands within the Project Area, by new net soil accretion, and in some cases, new plant growth, and/or new oyster reefs.
SLAMM	The Sea Level Affecting Marshes Model (SLAMM) is a mathematical model that uses digital elevation data and other information to simulate potential impacts of long-term sea level rise on wetlands and shorelines.
SLAMM 2075 boundary line	The SLAMM modeling was completed to be consistent with the future condition SLR scenarios identified for the overall Sea Level Rise and Recurrent Flood Study. These include a 3.0 ft increase in sea level by approximately 2075.
Soil organic carbon stock	The organic carbon stock, as determined by acceptable field and/or laboratory methods of soil organic carbon concentration and bulk density on properly collected samples, for the fraction of the soil sample that passes through a 2 mm sieve.
Protected Carbon Credits	The GHG emissions that are projected to be avoided over 50 years by the Living Shoreline's protection of the organic carbon stored in the wetlands within the Project Area.
Stratification	Stratification is a process where the site is divided into sub-areas based on similar soil characteristics such as texture, minerology, aspect, and overlying vegetation. Proper stratification may reduce the number of samples necessary to characterize baseline carbon content with the necessary accuracy and improve the reliability of the measurement of the change in carbon content over time.
Toe of the Wetland	Outer bayward edge of the vegetated wetlands including associated intact, uneroded marsh soils platform.
USACE	United States Army Corps of Engineers.
Vertical Accretion	The deposition of sediments and expansion of soils in marshes that allows the marsh platform to maintain its position relative to rising sea levels.

2.0 PROJECT ACTIVITIES

Figure 2 illustrates the steps Project Developers and BCarbon will follow in designing and operating Living Shoreline Projects under this Protocol, including the issuance and registration of blue carbon credits.

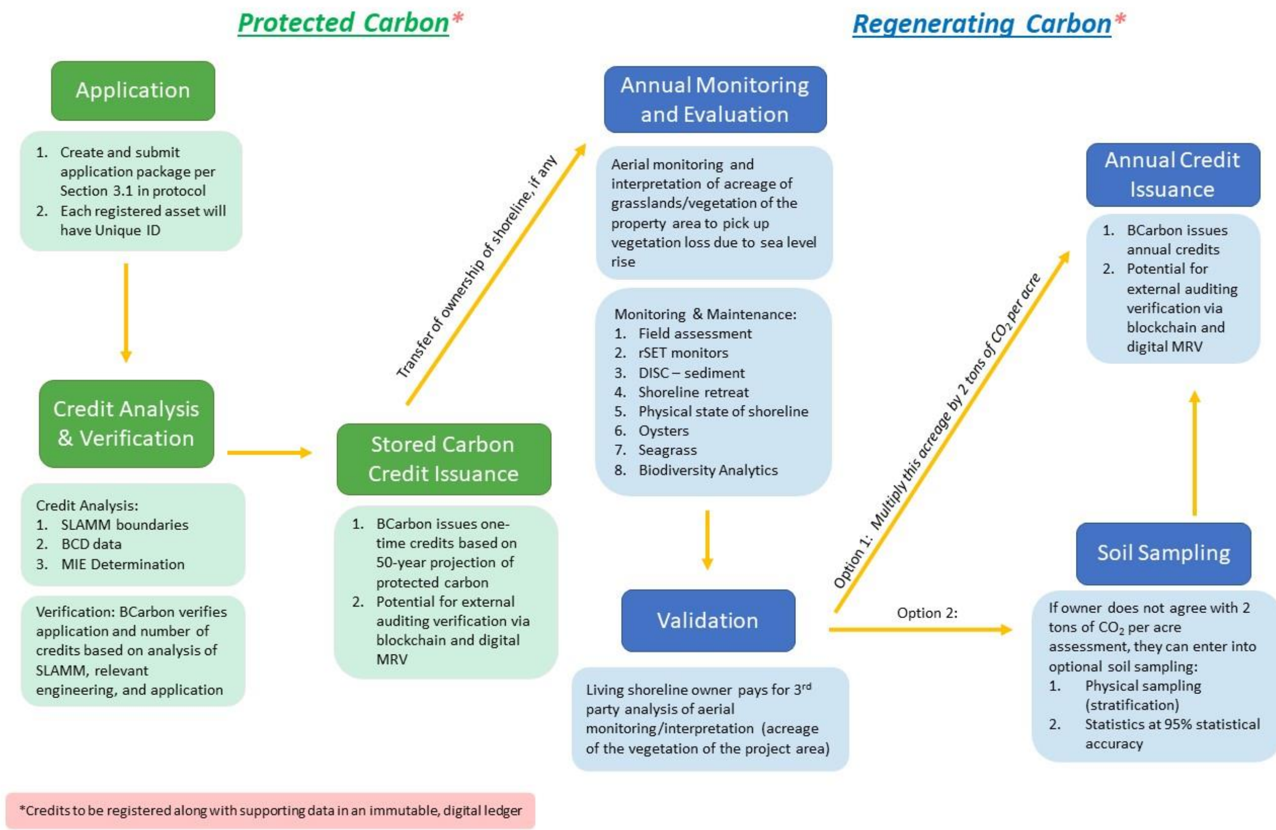

Figure 2 BCarbon Protocol Flowchart.

3.0 APPLICATION OVERVIEW

3.1 Project Submission

Project Developer will submit to BCarbon:

1- A “USACE Package” which will eventually be submitted, pending review by BCarbon, to the U.S. Army Corps of Engineers (USACE) for the USACE approval of the construction of the Living Shoreline.
2- “BCarbon Package” that includes the following:
- Engineering Report that:
  - details the Living Shoreline structure design (see 6.1)
  - summarizes analyses of system parameters (e.g., erosion history, tidal range), hydrodynamic parameters (e.g., waves, wakes, currents, storm surge), and terrestrial parameters (e.g., upland slope, shoreline slope, width)
- Engineer’s Statement of Cost (see 6.2.1) Operation Plan which will detail:
  - Land ownership
  - Deployment and construction timeline

  - Permits and regulatory approvals
  - Insurance coverage plan on the structures (see 6.4)
  - Proposed operations plan for the monitoring and maintenance of the Living Shoreline over a 50-year term (see 6.3)
  - Financial reserves dedicated by the Project Developer(s) to maintain the structure and manage the reinvestment into the wetlands.
- Project Parameter description, as detailed in Section 4, including:
  - Project area and boundary (4.1)
  - Site analysis (4.2)

3.2 BCarbon Review

Within 30 days of submitting the USACE Package and BCarbon Package to BCarbon (“Submission Package”), BCarbon will inform the Developer if they have a complete Submission Package. If not, BCarbon will request the additional materials from the project developer needed to complete the Submission Package.

- Within 60 days of BCarbon acknowledging they have a complete Submission Package they will notify the Developer that they either have 1) a tentatively approved project pending USACE’s feedback/approval or 2) they will notify the developer of the deficiencies in their Submission Package.
- If the Developer decides to address the deficiencies in the Submission Package, then they will resubmit their Submission Package as defined above.

3.2.1 Submission Review Criteria

The internal review by BCarbon’s team will review the viability of the proposed project including the proposed engineered structure. This internal check may include but is not limited to:

- Working with contracted project engineers to validate the specifics of the project design
- Working with GIS specialists to confirm the extent of SLAMM’s coverage of stored carbon (see 3.5.2)
- Working with wetland scientists to affirm the extent of wetland protection afforded by the project
- Running internal mathematical checks in support of the number of credits proposed by project developers

As more projects are submitted for review and developed, BCarbon will review the application process to maximize efficiency.

4.0 PROJECT REGISTRATION

4.1 Project Boundary/Project Area Definition

Registration of a Living Shoreline Project requires establishing the Project Boundary and the Project Area. The **Project Boundary** is the set of geographic coordinates that delineates the **Project Area,** which is the total physical area that the Project is designed to protect.

The Project Area is determined as follows:Step 1: Define the Project Boundary from geographic coordinates derived from GIS shape files. which extend 2 miles inland from the Living Shoreline;

Step 2: Define the Wetland Boundary as the intersection of the Project Boundary, with areas denoted as wetlands in the 2019 National Wetland Inventory dataset (or as updated);

Step 3: Define Project Area by removal from the Wetland Boundary:

1. all areas that have a submerged to un-submerged areal ratio below 10% as modeled by the MEI SLAMM scenario laid out in Section 7.1)
2. the footprint of man-made structures as of the date of Project submission. The full acreage of the Project Area is creditable under this protocol.

All of the carbon delineated in the Texas Blue Carbon Database within the Project Area is used for determining the number of credits allocated to the Project as outlined in Sections 7 and 8.

BCarbon will provide technical guidance on how it will evaluate Project Applications.

4.2 Site Analysis

Documentation of a full site analysis of the ecological conditions present at the proposed Living Shoreline is required. Where previous wetland retreat or marsh alteration has occurred, the analysis should include an assessment of contributing factors for damage to the wetlands to inform the protection strategy. The elements listed below shall be included in the site analysis report.

- Site descriptions
  - The wetlands to be protected shall be clearly identified, along with associated uplands.
  - Site visit logs, photographs, existing wetland delineations, vegetation assessments, National Wetland Inventory (NWI), and NRCS soils data are examples of relevant data.
- Percent vegetative cover
  - An assessment shall be submitted of the percentage of vegetative cover using remote sensing, aerial photography, or drone-based imagery. If available, historical imagery should be analyzed to discern changes over time. A field survey of wetland health should also be conducted.
- Native plant species that would be suitable for including in the project, including those that can replace invasive plant species that are established in the area
- Ortho-imagery
  - Aerial analysis of shoreline retreat should be provided showing the pattern of loss over time, alongside a qualitative description of the landscape changes the project is being designed to protect against.
- Buildability criteria
  - Details regarding the construction of the Living Shoreline shall be submitted including an assessment of how construction materials will be transported to the site and strategies for project construction that will minimize damage to the wetlands and surrounding bay bottom habitats. The following questions should be addressed in the description:

    - Can building materials be staged near the site?
    - Are there suitable upland locations that can be used to stage materials?
    - Can the project be constructed from the edge of the shoreline, or does it have to be built from the water?
    - Are there existing deep-water channels nearby that could be used to facilitate construction?
    - How variable is water depth at different times of year to access the site?
- Bathymetry
  - Information shall be submitted regarding the bathymetry/water depth along the shoreline. The mean low water (MLW) and mean high water (MHW) contour shall also be identified.
- Wave analysis
  - Analysis of wind-driven fetch, wave energy, shoreline directionality, and frequency of exposure to high energy conditions shall be provided. Attention should be focused on wind-driven fetch during low water conditions, which causes the most severe erosion of the wetland toe.
- Alternatives analysisf
  - Information shall be submitted regarding design alternatives, plus consideration of Action vs. No Action alternatives relative to the proposed solution. Attention should be paid to the proposed design’s effect on limiting erosion and stimulating sedimentation of the shoreline, and how these benefits would evolve over the lifetime of the project.
- Oyster reefs
  - Information shall be submitted regarding the presence or absence of oyster reefs. This information is necessary to evaluate the potential for the project area to naturally recruit oysters.
  - This shall include desktop and field survey maps of oyster resources.
- Seagrass beds
  - Information shall be submitted regarding the presence or absence of seagrass beds.
  - This shall include desktop and field survey maps of seagrass beds.
- Threatened and Endangered Species Assessment
  - Information shall be submitted regarding the presence or absence of endangered and threatened species.
  - This can be accomplished by a desktop analysis supplemented by a live site survey, especially in the case of Black Rail and sea turtle species.
- Cultural Resources Assessment
  - Information shall be submitted regarding the presence or absence of cultural resources/important archeological sites.
  - This can be accomplished by a desktop analysis supplemented by a live site survey (if required by the Texas Historical Commission).
- LSLS Survey by Licensed State Land Surveyor
  - This is required to establish the extent of State submerged land ownership at the project site. The LSLS survey defines the extent of Mean High or Higher Water, which, with some specific exceptions, is the upper limit of the State’s interest in each property.
- Geotechnical survey
  - This may be necessary as part of project pre-engineering if there is a determination by the Project Developer or BCarbon that soils on the site will not support certain project types.

4.3 Digital MRV Recording

The Project Area is assigned a Unique ID which allows access to for "digital MRV" (d-MRV) and asset data that records:

- the complete crediting "lifecycle" of the Project including the Project Boundary, Wetlands Boundary, and Project Area determinations under Section 4.1, credit issuances, transfers and retirements;
- relevant information from field monitoring, emission factors, data refinements, verifications, and other relevant inputs;
- the complete profile of physical and environmental attributes of the Project including the environmental conditions determined from the site analysis outlined in Section 4.2;
- the environmental performance of the Project over time including the credits for "Protected Wetland Carbon" and "Regenerating Wetland Carbon" and relevant metrics representing biodiversity, habitat resilience, water quality, and other performance indicators.

"Roles-based" access to d-MRV asset data is provided through a 3rd party registry that is integrated with B-Carbon to participants in the generation and market application of the B-Carbon credits including owners of primary data (e.g., land owners, Project Developers) and secondary data (e.g., environmental monitoring systems), data refiners, and 3rd party auditors.

5.0 DEMONSTRATING ADDITIONALITY

The physical structure of the living shoreline provides inherent additionality, in that its construction, and thus the resultant wetland protection, would not have occurred in absence of the Protocol and its associated carbon credits. However, project Developers must also demonstrate that:

- pertinent laws and regulations have been reviewed and that none mandate the project activities
- no compensatory mitigation credits or other carbon offsets have been generated from restoration, creation, enhancement and/or preservation of the wetlands and connected upland areas /or other natural resources in the Project Area.

In cases where a local government agency, or a public-private partnership has or is intending to initiate a wetland mitigation project, or other shoreline protection activity in the Project Area, even if funds have been authorized, the Project may still meet the Additionality requirement provided that implementation funding has not been appropriated.

6.0 LIVING SHORELINE REQUIREMENTS

6.1 DESIGN

Living Shoreline projects shall be designed for the following outcomes:

1) Reduce wave energy and protect against erosion at the toe of the wetland;

2) Stabilize soil organic carbon in underlying sediments for decades into the future; and

3) Even if wetland vegetation dies due to sea-level rise, ensure that a sill is created to impound sediment in bulk, with minimal loss, and kept in place as far landward as the SLAMM 2075 boundary line[15] behind the Living Shoreline.

Living Shorelines shall be designed to optimize sediment deposition behind the structure to help it respond to sea-level rise and high wave energies generated by storms. The primary protection

[15] SLAMM is described in detail in Appendix A.

for a given set of wetlands occurs below the average water line (low tide). The size, scale, and configuration of the Living Shoreline will be defined in the Signed Engineer's Statement, submitted to BCarbon, such that the Living Shoreline will achieve the objectives of this protocol. To support the deposition of sediment onto the wetland surface, tidal interchange should be encouraged via the use of structural breaks and/or porous construction materials. Such design strategies shall also factor in both anticipated sea-level rise and State of Texas leasing guidelines requiring shoreline structures to be emergent at all normal tide conditions.

All projects should be designed to encourage the recruitment of oysters, as oyster reefs may be able to outpace future rates of sea-level rise.[16] However, project specifications should not necessarily rely on oysters to function as coastal erosion protection at the completion of construction.

Construction design drawings must be submitted that identify the dimensions, placement, orientation, building materials, and construction methods used for the proposed Living Shoreline along the entire length of the shoreline to be protected.

6.2 Signed Engineer's Statements

6.2.1 Engineer's Statement of Cost

A sealed Engineer's Statement must be submitted to BCarbon that estimates the cost impacts of 4 major storm scenarios, being one from each of 4 storm intensities: Category 2, 3, 4 and 5 as defined in the table below.

Within each intensity level, the Developer can choose any scenario of storm, provided that its track must pass over the Living Shoreline. The Engineer should then estimate the cost of restoring the effectiveness of the Living Shoreline at protecting the wetlands from edge erosion to a level similar to its as-designed or as-built condition. The Engineer should acknowledge any assumptions with regard to factors such as wave condition and water level.

In addition to these 4 estimates, the Engineer's Statement shall also (i) affirm that the project is designed with the intent to withstand storms less intense than a Category 2 storm and that the estimated cost for restoration for storms less than Category 2 is estimated to be negligible based upon the project design.

Storm Scenarios	**1-minute Maximum Sustained Wind Speed and Central Pressure**
Category 2 Storm	96 miles per hour and 980 millibars
Category 3 Storm	111 miles per hour and 965 millibars
Category 4 Storm	130 miles per hour and 945 millibars
Category 5 Storm	157 miles per hour and 920 millibars

[16] Lane, R. R., Hunter, R. G. & Day, J. W. Impacts of Climate Change on Western Gulf of Mexico Coastal Wetlands and Evaluation of The Use of Living Shorelines for Wetland Sustainability. 138 (2022).

6.2.2 Engineer's Statement of Construction

After the project has been constructed, the Project Developer must submit a sealed Engineer's Statement that certifies that the project has been constructed as designed.

6.3 Long-term Monitoring and Maintenance

Living Shoreline projects must:

1) monitor the horizontal and vertical extent of sediment accretion and determine the net balance of horizontal accretion/erosion up to the Project Boundary (the boundary line of wetland protection).

2) monitor the relative health and extent of the protected wetland using aerial reconnaissance of vegetation.

3) monitor water quality (including dissolved oxygen, salinity and turbidity) in the Project Area and in the immediate vicinity as required by federal, state or local permits, or as specified by BCarbon.

4) monitor the structure of the living shoreline to verify its continued physical integrity and complete any required maintenance via the principle of adaptive management.

For more information on long-term monitoring methodologies including use of rSETS and feldspar marker horizons, see Appendix D

6.4 Insurance Requirements

A key reversal risk for the blue carbon credits issued under this protocol is the potential for the shoreline project itself to be destroyed in the future. Rather than buffer credits being taken from the total volume of credits certified under this protocol, an insurance policy ensuring the ongoing maintenance of the Living Shoreline must be established The owner of the Living Shoreline is required to carry property insurance in an amount sufficient to cover the cost estimates in the Engineer's Statement in the event the Living Shoreline experiences any of the 4 storm scenarios.

7.0 QUANTIFICATION OF PROTECTED WETLAND CARBON

The amount of stored organic carbon in a wetland within a defined Project Area is calculated using Equation 1.

Equation #1a. Protected wetlands carbon

$$PWC_y = (MIE_y \cdot WCS_y) - PE_y$$

Where: **UNITS**

PWC_y	Protected wetlands carbon in Project Area *y*	CO2eq
$MIE_{i,y}$	Maximum inland extent in wetland *i* within Project Area *y*	acres
$WCS_{i,y}$	Wetland carbon stock in wetland *i* within Project Area *y*	CO2eq/acre
PE_y	Project emissions for project *y*	CO2eq

Equation #1b. Protected wetlands carbon

In cases with areas with different carbon stock (WCSi) within the same MIEi, the sum of each sub-area and its carbon stock shall be taken to arrive at the total amount of stored carbon.

$$PWC_y = \left(\sum_{x=1}^{n} MIE_x \cdot WCS_x\right) - PE_y$$

Where:		UNITS
PWC_y	Protected wetlands carbon in Project Area *y*	CO2eq
$MIE_{i,y}$	Maximum inland extent in wetland *i* within Project Area *y*	acres
$WCS_{i,y}$	Wetland carbon stock in wetland *i* within Project Area *y*	CO2eq/acre
n	The number of sub-areas within Project Area *y.* Sub-areas are defined as areas with distinct WCS_i values.	
MIE_x	Maximum inland extent in sub-area *x* in Project Area *y*	acres
WCS_x	Wetland carbon stock in sub-area *x* in Project Area *y*	
PE_y	Project emissions for project *y*	CO2eq

7.1 Maximum Inland Extent (MIE) Determination

The MIE represents the wetlands within the Project Area that are projected to be lost – either submerged or in the process of fragmenting and being submerged in the year 2075 in the absence of a Living Shoreline project. The MIE is determined by the Project Developer and verified by BCarbon from simulations of the High sea-level rise scenario in the “Sea Level Affecting Marshes Model” (SLAMM).[17]

7.1.1 MIE Verification and Reconciliation

Because each project area has specific characteristics that will influence how living shorelines and wetlands will be affected by sea level rise, BCarbon will verify the SLAMM assessment of protected carbon stocks for each project and, where necessary, reconcile the SLAMM projections with the known environmental conditions of the site.

For example, on a case-by-case basis, BCarbon may use site-specific data to modify the MIE that is projected by SLAMM where:

1- the model excludes open water areas because they were already transitioning to open water at the end date of the model run. An example of this type of habitat would be very shallow water mud flats inside an otherwise intact wetland.

2- the model excludes “fragmenting” coastal wetlands, as defined by the 2019 National Wetland Inventory dataset, that have a submerged to un-submerged areal ratio above 10% as modeled by the SLAMM High Sea Level scenario.[18]

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[17] SLAMM is a mathematical model that uses digital elevation data and other information to simulate the key processes involved in changes in wetlands and shorelines under different long-term sea level rise scenarios (see Appendix A).

[18] Ganju, Neil K., Zafer Defne, Matthew L. Kirwan, Sergio Fagherazzi, Andrea D’Alpaos, and Luca Carniello. "Spatially integrative metrics reveal hidden vulnerability of microtidal salt marshes." *Nature communications* 8, no. 1 (2017): 14156.

3- the model includes upland areas which are separated from the coast by major topographic, hydrologic, or anthropogenic changes, including lakes, dams, highways, or roadways.

In cases where the MIE determined by the Project Developer and BCarbon differ, BCarbon will review the differences and determine what if any adjustments are appropriate to reconcile the two determinations.

7.2 Determination of Wetland Carbon Stocks

The carbon content of wetlands is determined using the Texas Blue Carbon Database (BCD).[19] This database is a modified version of the US National Blue Carbon Database, originally created for the National Aeronautics and Space Administration (NASA).[20,21] Development of the modified database for Texas wetlands involved the following steps:

1) Tidal wetland locations and types were extracted from the National Wetland Inventory (NWI) database.
2) Measurements of organic matter fraction (OMF) and bulk density (BD) were extracted from the Soil Survey Geographic Database (SSURGO), and then used to compute the organic carbon density (OCD) and soil organic carbon stock, where possible, at 1-cm increments within individual SSURGO map units.
3) OCD and soil organic carbon stock were computed for individual wetland polygons by area-weighting map units within each wetland polygon.

   For further information on BCarbon's BCD, see appendix B.

7.2.1 Field Measurements

Where the output of the Texas BCD is considered by the Project Developer or BCarbon to only be a "best estimate", field measurements of soil organic carbon must be conducted using the following steps from the BCarbon Soil Carbon Protocol, modified appropriately for wetlands:[22]

Step 1: Stratification (Standard Procedure A)

Step 2: Initial Measurement (Standard Procedure B)

7.3 Project Emissions

Project emissions are GHG emissions that result from the construction and operation of the Living Shoreline. For this protocol, GHG emissions associated with the transport of stone, concrete, sand, rubble/debris, oyster shells, or other materials used to construct the Living Shoreline are included in the Project Emissions calculation outlined below in Equation 2.

Other potential sources of GHG emissions including extraction/mining of the materials, construction equipment, monitoring equipment, and maintenance and repairs, are considered to have *de minimis* impacts and are excluded from project emissions quantification in this protocol. Subsequent reviews of the protocol will assess including these other potential sources based on available data.

Equation 2: Project Emissions

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[19] Feagin, D. R. A. Texas Blue Carbon Database. (2023).

[20] US National Blue Carbon Database. https://bluecarbon.tamu.edu/.

[21] Hinson, Audra L., Rusty A. Feagin, Marian Eriksson, Raymond G. Najjar, Maria Herrmann, Thomas S. Bianchi, Michael Kemp, Jack A. Hutchings, Steve Crooks, and Thomas Boutton. "The spatial distribution of soil organic carbon in tidal wetland soils of the continental United States." *Global Change Biology* 23, no. 12 (2017): 5468-5480.

[22] BCarbon Soil Carbon Protocol. (2022).

$$PE_y = \Sigma\left(QMT_{y,i} \cdot D_{y,i} \cdot EFTM_y\right)$$

Where:		UNITS
$QMT_{y,i}$	Mass of Living Shoreline material *y* transported for Project *i*	metric tons
$D_{y,i}$	Distance that Living Shoreline material *y* is transported for Project *i*	miles
$EFTM_{y,}$	Emission factor for transportation mode used in Project *i* for Living Shoreline material *y*	tCO2eq/t-mile

If actual distances are not available from transportation suppliers, the Project Developer may use the shortest theoretical distance between source and project site, online maps, or published port-to-port travel distances.

Emission factors in terms of CO2 equivalent (tCO2eq) for different transport modes are calculated in Equation 3 using emission factors for the individual greenhouse gases that are associated with vehicle emission – CO2, methane (CH_4) and nitrous oxide (N_2O), listed in Table 1. Equation 3.

$$EFTM_y = EFTM_{y,CO_2} + \left(EFTM_{y,CH_4} \cdot GWP_{CH_4}\right) + \left(EFTM_{y,N_2O} \cdot GWP_{N_2O}\right)$$

Where:		UNITS
$EFTM_y$	Emission factor for transporting Living Shoreline material using transportation mode *y*	tCO2eq
$EFTM_{y,CO2}$	CO2 emission factor for transporting Living Shoreline material using transportation mode *y*	kg/ton-mile
$EFTM_{y,CH4}$	Methane emission factor for transporting Living Shoreline material using transportation mode *y*	g/ton-mile
GWP_{CH4}	100-year global warming potential of methane	See Table 1
$EFTM_{y,N20}$	Nitrous oxide emission factor for transporting Living Shoreline material using transportation mode *y*	g/ton-mile
GWP_{N2O}	100-year global warming potential of nitrous oxide	See Table 1

Table 1. Global warming potentials

Greenhouse Gas	GWP	Reference
CH_4	32	Range of 28-36 in IPCC (2021) AR6
N_2O	273	IPCC (2021) AR6

Note that the 100-year GWP for CO2 is 1 and is therefore not needed as an adjustment to calculate tCO2e in Equation 3.

Table 2. GHG emission factors for different transport modes*

Vehicle Type	CO2 Factor (kg/ton-mile)	CH_4 Factor (g/ton-mile)	N_2O Factor (g/ton-mile)
Medium- and Heavy-Duty Truck	0.211	0.0020	0.0049
Rail	0.022	0.0017	0.0006

Waterborne Craft	0.041	0.0183	0.0008
Aircraft	1.165	-	0.0359

Source: Emission Factors for Greenhouse Gas Inventories, Table 8, Scope 3, Category 4: Upstream Transportation and Distribution. U.S. Environmental Protection Agency GHG Emission Factors Hub. Last modified: April 2022.

7.4 Monitoring Durability of Wetlands Carbon Stocks

7.4.1 Shoreline Change Observations

The shoreline being protected shall be monitored to determine the effectiveness of Living Shoreline projects in limiting the erosion of the targeted wetlands over time. The total change in shoreline boundary, as well as the rate of change, shall be calculated as follows:[23]

(1) Identify the shoreline position in the year the Living Shoreline project is completed using remote sensing and/or aerial imagery sources such as National Agricultural Imagery Program (NAIP) georeferenced aerial photographs, Texas General Land Office imagery, or others and import the data into a GIS database.

(2) Create shore-parallel baselines in order to cast shore-perpendicular transects at 50-m intervals along the shoreline using the GIS-based extension software Digital Shoreline Analysis System (DSAS) version 5.0.[24]

(3) Determine the intersection of the transect lines with the initial and five-year interval shorelines to create GIS shape files containing (a) the total change, rates of change, and associated statistics of shoreline measurements and (b) the measurement transects bounded by the most landward and seaward historical shoreline position for each measurement site.

(4) Repeat steps 1 through 3 at five-year intervals over the duration of the fifty-year Living Shoreline project period.

(5) Calculate the total change in shoreline, rate of shoreline change, and their associated statistics over the fifty-year Living Shoreline project period.

7.4.2 Alternative Methods

The methods described in Sections 7.2 and 7.4.1 are the standard processes for measuring and monitoring wetlands carbon stocks, the use of which will expedite certification of blue carbon credits by BCarbon. Alternative methods to calculate wetlands carbon content may be used if they are reviewed and approved by BCarbon based on scientific information demonstrating that the proposed alternative methods provide a rigorous determination of wetlands carbon stocks.

[23] Paine, Jeffrey G, Tiffany Caudle, and John R Andrews. Rep. *Shoreline Movement and Beach and Dune Volumetrics along the Texas Gulf Coast, 1930s to 2019*, 2021.

[24] Himmelstoss, Emily A., Rachel E. Henderson, Meredith G. Kratzmann, and Amy S. Farris. *Digital shoreline analysis system (DSAS) version 5.0 user guide*. No. 2018-1179. US Geological Survey, 2018.

8.0 QUANTIFICATION OF REGENERATING WETLANDS CARBON

8.1 Regenerating Wetland Carbon Credit Application

On an annual basis, project developers will be eligible to apply for Regenerating Wetland Carbon credits on the basis of annual CO2 drawdown accomplished by vegetated marsh areas within the MIE. Developers must submit an application to BCarbon consisting of:

- Aerial imagery (following Section 7.4.1) of the Project Area sufficient to demonstrate and quantify the amount of vegetated area in the marsh;
- Interpretation of the aerial imagery regarding acreage of vegetation in the project area
- Third party analysis of aerial imagery and interpretation
- The process and results of Equation #4.

Equation #4

$$RWC_y = t \cdot VA_y \cdot W_{seq}$$

Where:		UNITS
RWC_y	Regenerated Wetland Carbon in Project Area *y*	tCO2e
t	Time since last measurement of RWCy	years
VA_y	Vegetated Area in Project Area *y*	acres
W_{seq}	Carbon sequestration rate of wetland	TCO2eq/acre/year

To determine W_{seq} to be used in Equation 4, Developers may either use the Default Value outlined in Section 8.1.1, or perform their own field measurements of SOC stock, as described in Section 8.1.2.

8.1.1 Carbon Sequestration Default Value

Synthesis by McLeod et al. (2011) of multiple studies report average long-term rates of carbon accumulation in sediments of coastal vegetated ecosystems (salt marshes, mangroves, seagrasses) between 138 and 226 grams of carbon per square meter per year which corresponds to an average rate of atmospheric carbon sequestration between 2 and 3.3 tons of CO2eq per acre per year. For purposes of this protocol, a conservative estimate of average wetland sequestration of 2.0 tons of carbon dioxide equivalent per acre per year may be used as a default in calculating the annual crediting of projects.[25] Owners seeking a carbon sequestration rate beyond the default rate can follow the Field Measurements procedure set out below in Section 8.2.

BCarbon will review the default carbon sequestration rate and make adjustments as needed based on newly available data.

[25] Mcleod, Elizabeth, Gail L. Chmura, Steven Bouillon, Rodney Salm, Mats Björk, Carlos M. Duarte, Catherine E. Lovelock, William H. Schlesinger, and Brian R. Silliman. "A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2." *Frontiers in Ecology and the Environment* 9, no. 10 (2011): 552-560.

8.1.2 Soil Carbon Field Measurements

For blue carbon credits to be issued at a rate higher than the default value in Section 8.1, the following measurement steps from the BCarbon Soil Carbon Protocol must be conducted, modified appropriately for wetlands:

Step 1: Stratification (Standard Procedure A)

Step 2: Initial Measurement (Standard Procedure B)

Step 3: True-up Measurements (Standard Procedure D)

8.2 BCarbon Review of Regenerated Wetland Carbon Credit Application

The internal review by BCarbon's team will verify the results of the Developer's aerial analysis and Equation #4. If the Developer has chosen to follow Section 8.1.2 rather than using the Default Value in 8.1.1, the BCarbon review process will also involve verifying and validating the methodology and results of this on-the-ground sampling.

8.3 Future directions for Regenerating Carbon Credits

8.3.1 Inland Expansion

The procedure laid out in Section 7.4.1 of this protocol shall also be conducted to track the total change and rate of change of the inland marsh edge position. This information will be used to assess and review the efficacy of Living Shoreline projects and potentially, to make adjustments as appropriate for the issuance of blue carbon credits for wetlands that have been able to migrate inland due to the protection given by the Living Shoreline. 8.3.2 Additional Carbon Sequestration via Seagrass and Oyster Reefs

In addition to increasing carbon sequestration via accretion of wetland soils and associated root systems and vegetation, Living Shorelines can create additional carbon storage "sinks" that could potentially generate additional sequestration credits:

- First, Living Shorelines may help clarify bay water and stabilize bay bottom sediments, providing improved conditions for propagation of seagrasses in bays where turbidity and unstable bottoms currently inhibit seagrass growth.

- Second, Living Shorelines can support oyster reef colonization that can directly sequester carbon in their shells and sediments beneath the reef.

As part of updates to this protocol, BCarbon will review the scientific literature and a variety of modeling and monitoring approaches that can potentially be used to quantify and verify carbon sequestration rates for oysters and seagrass beds within Living Shoreline projects.

9.0 ENVIRONMENTAL AND COMMUNITY CO-BENEFITS

As part of future updates to this protocol, BCarbon will review approaches to standardize how the ecological and community co-benefits of Living Shoreline projects can be characterized, verified, and incorporated into rating systems of corresponding carbon credits. Areas for further expansion are discussed in this section.

In addition to sequestering carbon, properly engineered Living Shorelines conserve the hydrobiological connectivity of the coastal marine landscape and provide the same multitude of ecosystem services that stable coastal wetlands naturally provide:

- Erosion control
- Natural filtration of stormwater runoff and improved water quality of wetlands and associated bays
- Seagrasses and other critical habitat that support:
    - a rich diversity of fish, especially juvenile
    - epifaunal and infaunal invertebrates such as crabs, clams, oysters, mussels, and worms
    - resident waterfowl and migratory birds during critical life stages
- Resilience against storm surges and flooding

In addition to reduced risks from flooding and storms, established Living Shorelines will generate community benefits related to increased capacity for local territorial governance and natural resource management, as well as economic empowerment of community groups and increased employment opportunities in the project area through the promotion of technical knowledge for the maintenance and management of the project, the preservation, generation, and strengthening of ecotourism and recreation.

Appendix A: SLAMM (Sea Level Affecting Marshes Model)

Sea Level Affecting Marshes Model ("SLAMM"):

The Sea Level Affecting Marshes Model (SLAMM) was first developed in the 1980s with funding from the EPA. Version 2.0 of the program was used to simulate 20% of the coast of the contiguous United States for the 1991 EPA Report to Congress on the potential effects of global climate change. The model has been used by the U.S. EPA, USGS, The Nature Conservancy, National Wildlife Federation, and the U.S. Fish & Wildlife Service and has been applied to more than 100 National Wildlife Refuges in the U.S.

SLAMM has been frequently updated to keep pace with evolving research and continually develop a more accurate representation of different sea level rise scenarios. The most recent version of the model, developed by Warren Pinnacle in partnership with Environmental Science Associates with funding from The Nature Conservancy, is SLAMM 6.7. This version includes a substantial upgrade to the marsh-erosion component and the addition of carbon sequestration data including both the amount of carbon sequestered by wetlands as well as the carbon emissions through the loss of methane from freshwater habitats. SLAMM is still the leading industry standard for large-scale modeling.

The SLAMM model simulates the key processes involved in wetland conversions and shoreline modifications in the course of long-term sea level rise. Various conditions of accelerated sea level rise can be selected within the model to demonstrate the model's prediction of map distributions of wetlands affected. The six primary processes the model uses in addressing sea level rise scenarios include inundation, erosion, saturation, accretion, and salinity.

The model uses geometric and qualitative relationships to represent material transfer among coastal classes. Each site is divided into cells of equal area, and each landcover class within a cell is simulated separately. Map distributions of wetlands are predicted under conditions of accelerated sea level rise, with results summarized in spreadsheets and graphs.

HRI's SLAMM:

The Harte Research Institute (HRI) out of Texas A&M Corpus Christi has modified model inputs, integrating higher-resolution digital elevation models into SLAMM. BCarbon will use the HRI-modified model inputs as well as output information based on the 2100 scenario regressed to 2075, which indicates a 2-meter eustatic sea level rise by the year 2100 for project analysis. HRI's model has been utilized by the General Land Office (GLO) for their 2023 Texas Coastal Resiliency Plan to assess the resiliency of the Texas coast, specifically sea level rise impacts.

Appendix B: Texas Blue Carbon Database

BCarbon's Texas Blue Carbon Database (BCD) is used to calculate the number of tons of CO2eq, and thus the number of credits, a project is eligible for under the Living Shoreline protocol. This database was the outcome of years of government-funded and privately funded research by diverse teams of scientists from across the country, led in part by BCarbon stakeholder Dr. Rusty Feagin, professor in the Department of Ecology and Conservation Biology and the Department of Ocean Engineering at Texas A&M University (TAMU). This document outlines the sources and processes behind the wetland carbon stock database used in BCarbon's living shoreline protocol.

Timeline of events

The publicly funded portion of this research, taking place under NASA's Carbon Monitoring System (CMS) and Carbon Cycle and Ecosystems Program (CCEP), was funded via contracts NNX14AM37G and NNH14AY671 to Texas A&M AgriLife. While many important papers on wetland carbon were produced through these projects, the most critical to the BCD was Hinson et al. (2017), which documented the creation of a geodatabase known as CoBluCarb. Several years after this project, BCarbon commissioned Dr. Rusty Feagin, a co-investigator on Hinson et al. (2017), to use CoBluCarb to help them quantify the potential impacts of a carbon crediting program on the Texas Coast. Following CoBluCarb's methodology and structure as a foundation, Feagin expanded and clarified the database for the purposes of BCarbon's Texas-based living shoreline protocol. The timeline of these events, and their associated publications, are described in detail below.

Hinson AL, Feagin RA, Eriksson M, et al. The spatial distribution of soil organic carbon in tidal wetland soils of the continental United States. *Glob Change Biol.* 2017; 23:5468-5480. <u>https://doi.org/10.1111/gcb.13811</u>

From 2014-2018, Feagin led the Hinson et al. (2017) research project alongside his graduate student Hinson, ultimately producing a geodatabase (CoBluCarb) and high-resolution maps of soil organic carbon (SOC) distribution in US wetlands and estuaries. This CoBluCarb database became the foundation for the BCD used in BCarbon's Living Shoreline Protocol.

<u>Their process</u>

Hinson et al. (2017) used data from National Wetland Inventory (NWI) to extract tidal wetland locations and types in the US. They also used the US Soil Survey Geographic Database (SSURGO) to extract measurements of organic matter fraction (OMF), bulk density (BD), and, when available, SOC stock at 5 cm increments. With this data, they calculated the total carbon stock and organic carbon density at 5 cm vertical intervals from 0 to 300 cm depth, across over 600,000 US wetlands.

<u>Their verification</u>

After CoBluCarb had been created (see "process" above), Hinson et al. (2017) verified its accuracy by comparing its outputs to the measured SOC stock values reported in earlier, comprehensive literature. Looking at Ouyang and Lee (2014) and Chmura et al. (2003), the two most expansive published compilations of wetland carbon density known by the authors, the team regressed their CoBluCarb carbon density values against those found at the same spatial locations in these sources. They found the correlation between their dataset and the values from the literature to be potentially significant, though relatively low – in other words, CoBluCarb provided a more conservative estimate of wetland carbon stocks.

Their conclusions

Overall, their analysis led them to conclude that CoBluCarb likely provides the more spatially accurate, depth-explicit, methodologically consistent, and widely applicable stock estimate for the wetlands of the continental US, compared to alternative methodologies such as using individual studies (or meta-analyses) such as the ones by Ouyang and Lee (2014) and Chmura et al. (2003).

Feagin RA. Texas Blue Carbon Opportunities: Wetland Biogeochemistry and Carbon Offset Optimization Strategies. 2022.

In 2022, BCarbon commissioned a Texas-specific analysis of wetland blue carbon opportunities by Dr. Rusty Feagin. Feagin's report, "Texas Blue Carbon Opportunities," summarized the results from Hinson et al. (2017)'s CoBluCarb project and synthesized information on the potential economic value of blue carbon projects along the Texas coast based on peer-reviewed wetland carbon stock values and other stacked benefits. This report propelled BCarbon's Living Shoreline protocol forward and can be read in full here: https://drive.google.com/file/d/1eL7gz8Ht238EbWKim4IYb_qONQ9ZDtgO/view?usp=sharing

Feagin RA. Texas Blue Carbon Database. 2023.

Later in 2022, BCarbon commissioned a Texas-specific database created by Dr. Feagin to build off the capabilities of CoBluCarb and Feagin's findings in his BCarbon-funded preliminary report (above). The objective of the project was to use CoBluCarb's peer-reviewed, scientifically accepted method and approach to develop a Texas-specific database of wetland carbon stocks that was more comprehensive and more detailed than CoBluCarb had been. The key changes implemented were:

1. Updating the database to use the most current National Wetlands Inventory (NWI) and US Soil Survey Geographic Database (SSURGO) datasets, increasing the quality of source data used in the map compared to 2017's values and resolving many prior blind spot areas where no data was available.
2. Providing a gap-filled best estimate (properly marked as an approximation) of carbon stocks for the ~1-2% of wetland areas where SOC stock data was still unavailable via SSURGO, whereas CoBluCarb had listed these sites as "missing data."
3. Expanding the scope of the database to cover not only tidal wetlands, but also freshwater wetlands in the coastal zone.
4. Adding soil carbon data for uplands associated with wetland areas.

The result was a high-resolution database mapping the spatial distribution of soil organic carbon (SOC) in the wetlands of the Texas coast. The full Feagin report, including a walkthrough of the database and clear, step-by-step descriptions of process and results, can be found here: https://drive.google.com/file/d/1MUTw426iPw94LflZBFkXds6r13nncpx5/view?usp=share_link

Appendix C: Living Shoreline Protection Mechanism

Living Shorelines protect against erosion at the toe of the marsh which keeps soil organic carbon stable in underlying sediments for decades into the future. Even if wetland vegetation dies due to a rise in relative sea-level, most of the sediment behind the Living Shoreline will be held in place. In this scenario, the Living Shoreline creates a sill that reduces sediment loss and impounds it in bulk, as far landward as the SLAMM 2075 boundary line. This can be contrasted with a scenario without shoreline protection, where the vegetation drowns and dies and the root system degrades, causing the underlying soil to become unstable and highly erodible.

While the loss of some suspended sediment and organic matter by tidal action may continue through the gaps in the Living Shoreline, the Living Shoreline itself **will** reduce material movement into nearby bays and thereby reduce the release of CO2 into the atmosphere due to aerobic decomposition. This bulk reduction in the export of soil organic carbon is another source of additionality offered by the shoreline project beyond the more immediate (and traditionally accounted for) wave protection provided to the eroding edge of the wetland by the Living Shoreline.

Living Shorelines capture sediment and enhance deposition immediately behind the barrier. Thus, monitoring of the horizontal and vertical extent of sediment accretion will be conducted to assess the net balance of horizontal accretion/erosion up to the proposed boundary line of wetland protection. Additionally, aerial reconnaissance of vegetation will be used to monitor the relative health and extent of the protected wetland. Consistent monitoring across numerous built Living Shoreline projects will also lead to a much better scientific understanding of how these types of protective shorelines can be optimally designed to improve their capacity to protect wetlands carbon stocks. The monitoring specifics are further outlined in Section 7.4. of this protocol.

Appendix D: Long-term Monitoring Methodologies

Monitoring Surface Elevation

Wetland surface elevation, an indicator of overall wetland sustainability and health, as well as an indicator of soil and biomass accretion and associated carbon sequestration, is monitored using rod surface elevation tables (rSETs), portable mechanical leveling devices. rSETs are placed along the shoreline slated for living shoreline construction, fifty meters inland from the edge of the wetlands. At least one rSET station should be deployed for a parcel of wetlands less than 1000 acres, with additional stations deployed for areas greater than 1000 acres (i.e., an rSET station per 1000 acres). The following methods are modified from Callaway et al. 2013 and Lynch et al. 2015.[26,27]

<u>Stable Benchmark</u>

Rod surface elevation table (rSET) measurements require the establishment of a stable benchmark at the sampling location. A 15-mm (9/16-inch) diameter stainless steel rod should be pounded into the ground using a demolition hammer or jack hammer until substantial resistance is achieved.

<u>Attaching the rSET</u>

Once the benchmark has been established, it should be attached to the rSET receiver. A 15.2-cm (6-inch) diameter PVC pipe should be pounded 40 to 100 cm below the wetland surface depending on soil strength (lower strength soils need longer pipes), with the top 5 to 10 cm of the pipe above the wetland surface. The top 5 to 10 cm of soil is then removed from inside the pipe, a custom-made stainless steel receiver is attached to the benchmark in the PVC pipe, and then the entire pipe should then be filled with concrete or mortar, encasing the connection.

<u>Measuring using the rSET</u>

There are eight potential orientations for the attachment of the rSET to the benchmark. Measurements should be made at four of the eight potential orientations, with a compass used to identify the directions of the rSET arm for measurement. It is critical that the rSET be relocated to these exact same locations each time.

The rSET must be leveled in two directions using the attached bubble level. The pins should be lowered through the vegetation until it just touches the wetland surface. The pins should then be secured in place, and the height of each pin above the rSET plate or rSET arm measured with a metric ruler. To maintain the high level of precision that is desired in measuring changes in wetland surface elevation, the same rSET instrument must be used each time.

<u>Calculating Change in Elevation</u>

Changes in relative elevation are calculated by comparing changes of individual pin heights across sampling periods. An increase in pin height during a particular time interval corresponds to an increase in wetland surface elevation during that interval. Changes of individual pin heights

[26] Callaway, John C., Donald R. Cahoon, and James C. Lynch. "The surface elevation table–marker horizon method for measuring wetland accretion and elevation dynamics." *Methods in biogeochemistry of wetlands* 10 (2013): 901-917.

[27] Lynch, James C., Phillippe Hensel, and Donald R. Cahoon. *The surface elevation table and marker horizon technique: A protocol for monitoring wetland elevation dynamics*. No. NPS/NCBN/NRR—2015/1078. National Park Service, 2015.

can be calculated for specific intervals or cumulatively for longer periods. Once the data are reviewed for quality control, they should be formatted for statistical analysis. For this analysis, linear regression should be used at the position level across the entire time series to generate linear rates of change and should then be averaged across the rSET location.

Monitoring Vertical Accretion

Vertical sediment accretion will be monitored using feldspar marker horizons located every 200 meters along the shoreline slated for Living Shoreline construction, at sites 10, 25, and 50 meters inland from the edge of the wetlands.

Plots

Feldspar marker horizons should be established in 50- by 50-cm plots. Four plots should be established per station to obtain an estimate of the local variation in accretion rates at a given location. Plots should also be located adjacent to the rSET sampling platform. At the plot location, feldspar should be sprinkled evenly across the plot to provide a uniform, thin layer over the entire area. A 50- by 50-cm quadrat should be set up to allow rapid determination of the plot boundary. A 22.7-kg (50-lb) bag of feldspar typically will cover six to eight 50- by 50-cm plots to a depth of 0.5 cm. The corners of all feldspar plots should be marked with PVC posts or other permanent stakes so that they can be easily relocated. Plots should also be marked with a GPS unit to facilitate relocation.

Measurement Timing

Feldspar plots should be established at the same time that initial rSET measurements are made so that direct comparisons between wetland accretion and elevation can be made. The feldspar plots can be sampled any time after establishment and should be sampled each time the rSET is read. Sampling should be conducted annually.

Sample Collection

A single core should be randomly sampled within each plot, and four measurements of the soil depth should be made if the feldspar marker is visible. A cryocorer should be used. The cryoprobe should be inserted into the sediment at the random location to a depth of 10 cm. Flow of liquid N_2 from the dewar should then be initiated until the soil around the cryocorer is frozen. The popsicle of frozen soil should then be removed, scraped with a knife to more clearly identify the feldspar marker, and the depth from the sediment surface to the top of the feldspar layer should be measured on four sides of the frozen sample using a caliper.

Accretion Calculations

The data for the depth of sediment above the marker horizon should be averaged within each marker plot, first by averaging the multiple measurements for each core and then averaging across cores. Averages from replicate plots at a sampling location should be used to estimate the the mean and standard deviation for the number of plots at that location. This data will reflect the cumulative change in sediment accretion since the time of marker deployment.

Comparison of Marker Horizon and Surface Elevation Table Data

Shallow subsidence is indicated as the difference between vertical accretion and elevation change. Both data sources must be compared at the rSET plot level and across the exact same time interval. As with accretion and elevation change data, subsidence data should be calculated across multiple years to provide an annual rate of subsidence.