Scientific Monitoring Plan for Nature-Based Solutions at Tyndall Air Force Base, Panama City, FL

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Cover photo: Eroding salt marsh at the Living Shoreline project site on East Bay. Photo Credit: Christine Angelini.

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1. Introduction

1.1 Project Description

On October 10, 2018, Hurricane Michael made landfall as a Category 5 hurricane, causing catastrophic wind and storm-surge damage at Tyndall Air Force Base (TAFB). Following this devastating event, the United States Air Force (USAF) made a commitment to build back stronger and more resilient through a combination of sustainable master planning, higher standards for elevation and wind speed, integrated stormwater management, traditional engineering approaches, and nature-based coastal resilience efforts. The "Nature-Based Solutions at Tyndall Air Force Base" project includes the construction of four nature-based solutions (NBS) features to increase the resilience of Tyndall AFB from shoreline erosion and land degradation while creating environmental benefits and conservation outcomes.

The rebuilding of TAFB in the Florida Panhandle following its near destruction in 2018 offers a unique opportunity to make a critical defense facility more resilient to future storms and variable sea levels. As part of a larger, layered, coastal defense strategy, the NBS features implemented at Tyndall will increase the reliability of the base's critical operations now threatened by coastal hazards, provide habitat for a diversity of resident and migratory fish and wildlife, and indirectly support the local marine and base-dependent economic sectors. More specifically, stabilizing and expanding coastal habitats surrounding the base is a central part of this overall strategy that strives to achieve the resilience objectives at TAFB while also creating beneficial social, economic, and environmental outcomes.

The construction of NBS features is central to the overall coastal resilience strategy at TAFB. The four project types and three locations described herein are important because they have the potential to protect mission assurance and critical base functions while enhancing adjacent estuarine and coastal habitats. The collective design, construction, and monitoring of these NBS features is the foundational initiation of the layered coastal defense strategy at TAFB. Lessons learned from their design and performance monitoring will inform long-term flood exposure modeling and provide baseline information necessary for the design and implementation of future NBS features at TAFB and similar installations.

This scientific monitoring plan outlines the core metrics and describes the methodologies that will be used to track project performance, quantify ecosystem services, and evaluate the effect and extent of each NBS design on identified measures of coastal resiliency. The plan was developed through a collaborative process among the Tyndall Coastal Advisory Group, a team of technical advisors internal to The Nature Conservancy (TNC) assembled to inform the scientific aspects of coastal resilience project monitoring, experts in ecology hydrodynamics at the University of Florida Center for Coastal Solutions (UF-CCS), and experts in wave-sediment interactions and geospatial monitoring from the US Naval Research Lab (NRL). The project monitoring team includes UF-CCS and NRL with technical and field support from TNC's Gulf Program. Additional review and subject matter input was provided by Mississippi State University (MSU), Rutgers University (RU), Florida Fish and Wildlife Conservation Commission (FWC), and St. Andrew and St. Joseph Bays Estuary Program (SASJBEP). The project is funded to date by the Readiness and Environmental Protection and Integration Program (REPI), the National Fish and Wildlife Foundation - National Coastal Resilience Fund (NFWF-NCRF), and U.S. Treasury RESTORE Act Award to Bay County, Florida.

1.2 Project Team and Responsibilities

Below we summarize the project team that has overseen the development of this comprehensive monitoring plan and will oversee its implementation.

Table 1. Project Team Contact List

Name	Company/Institution	Role	Email
Jeff DeQuattro	TNC	Project Director	jdequattro@tnc.org
Katie Konchar	TNC	TNC Lead / Project Manager & Project Scientific Manager	katie.konchar@tnc.org
Christine Shepard	TNC	Project Scientific Director	cshepard@tnc.org
Andrew Altieri	UF-CCS	UF CCS Lead / Project Manager	andrew.altieri@essie.ufl.edu
Patrick Saldaña	UF-CCS	Field Lead	psaldana@ufl.edu
Carter DuVal	Naval Research Lab	NRL Lead / Geospatial Monitoring Lead	carter.b.duval.civ@us.navy.mil
Stephanie Dohner	Naval Research Lab	Field Lead	stephanie.m.dohner.civ@us.navy.mil

1.3 Project Locations

The initial implementation of nature-based solutions at TAFB will occur at three separate project locations along the base's shoreline. Design surveys, modeling, engineering planning, and permitting of the three projects were funded by REPI via NFWF Award No. #73433 and include a 1,200-foot Living Shoreline **(LSL),** a 2,000-foot Oyster Reef Breakwater **(ORB)** located in East Bay, and a 3,500-foot network of Submerged Shoreline Stabilization **(SSS)** structures located in Saint Andrew Sound. A fourth project funded by U.S. Treasury RESTORE Act award to Bay County integrates a 5-acre Seagrass Enhancement project at the SSS project site **(Fig. 1).** These NBS projects are foundational investments in enhancing coastal resilience at TAFB and will be expanded beyond their initial footprints in future phases of implementation.

Subtidal oyster reefs formed primarily by the Eastern oyster (*Crassostrea virginica*), seagrass meadows dominated by *Halodule wrightii*, *Ruppia maritima* and *Thalassia testudinum*, and fringing *Spartina alterniflora* and *Juncus romerianus*-dominated salt marsh habitat define the shallow subtidal and intertidal shoreline edge along East Bay where the LSL and ORB projects are located. The East Bay estuary is defined by spring tides with a vertical amplitude of ~ 0.67 m and neap tides of ~ 0.06 m (Brim, M. & Handley, L., 2006), average salinities of ~20 PSU with maximums of ~35 PSU (averages between 2016 – 2022, data source: Florida Department of Environmental Protection's Watershed Information Network). Salinities are higher at the LSL site near the inlet connecting East Bay to the Gulf of America than the more brackish ORB site positioned further from the inlet. The average water temperature is 26 °C, with maximums of ~ 35 °C, and minimums of ~ 10 °C.

In the shallow waters in Saint Andrew Sound (SSS location), seagrass meadows dominated by *Syringodium filiforme* and *Thalassia testudinum* are prevalent and sandy beaches and low-lying dune ecosystems define the shoreline. In Saint Andrew Sound, salinity is higher than inside the Bay due to the direct connection to the Gulf of America, although no data is available for the SSS site. Tidal currents and wave action are also higher due to exposure to the Gulf of America. Mean lower-low tide in Saint Andrew Bay is around -0.21 m depth with respect to MSL (data obtained from NOAA buoy station no. 8729108).

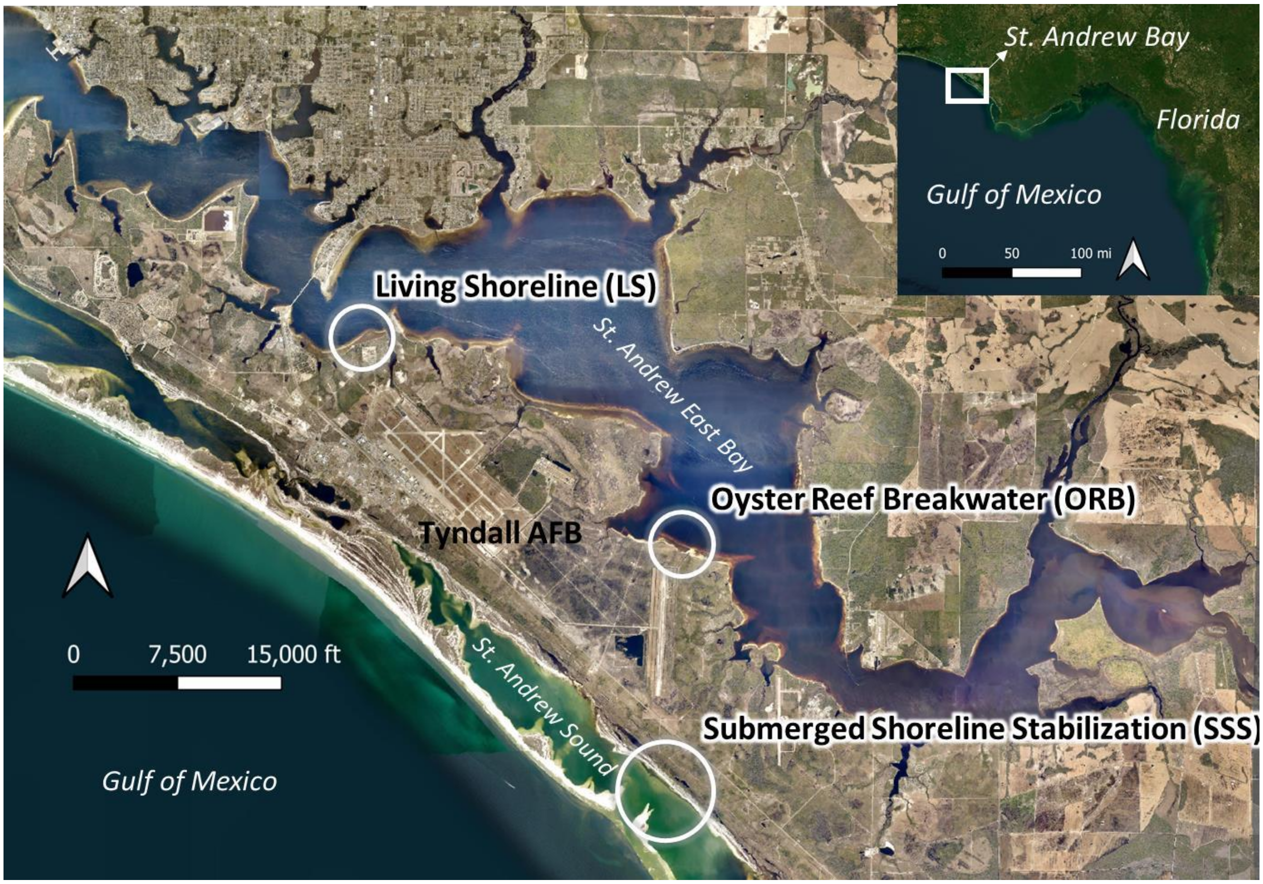

Fig. 1. Locations of the keystone nature-based solutions projects at Tyndall Air Force Base. The Living Shoreline (LSL) and Oyster Reef Breakwater (ORB) are in East Bay; the Submerged Shoreline Stabilization (SSS) and Seagrass Enhancement are in Saint Andrew Sound, along the shoreline of Tyndall Air force Base (30°04'48.1"N 85°35'18.9"W). Aerial image source: ESRI 2018.

The *Living Shoreline – LSL* (**Fig. 2**) and *Oyster Reef Breakwater - ORB* (**Fig. 3**) sites are in areas characterized by continuous seagrass meadows (subtidal and low intertidal) and marshes in the higher elevations in East Bay (**Fig. 1**). The shoreline in both locations had stretches with marsh vegetation (*Juncus* and *Spartina*) which overlapped with seagrass in some places, and in other places a bare stretch occurred between the seagrass and the marsh edge (**Fig. 2 and 3**). Other stretches were classified as eroded cliffs with ghost forests (dead forest) and no marsh present, which indicates that there has been shoreline retreat in the past. The *Submerged Shoreline Stabilization and Seagrass Enhancement – SSS* site (**Fig. 4)** is located on the Gulf side behind barrier islands and is characterized by patchy subtidal seagrass meadows, beaches, and dunes (**Fig. 1**). The proposed aerial footprints of the projects are all subtidal, ranging between -6 to -12 ft in the LSL, -3 to -6 ft in the ORB and -3 to -10 ft in the SSS. Boat access is necessary to monitor the LSL and ORB sites, while the SSS site can be accessed from the beach.

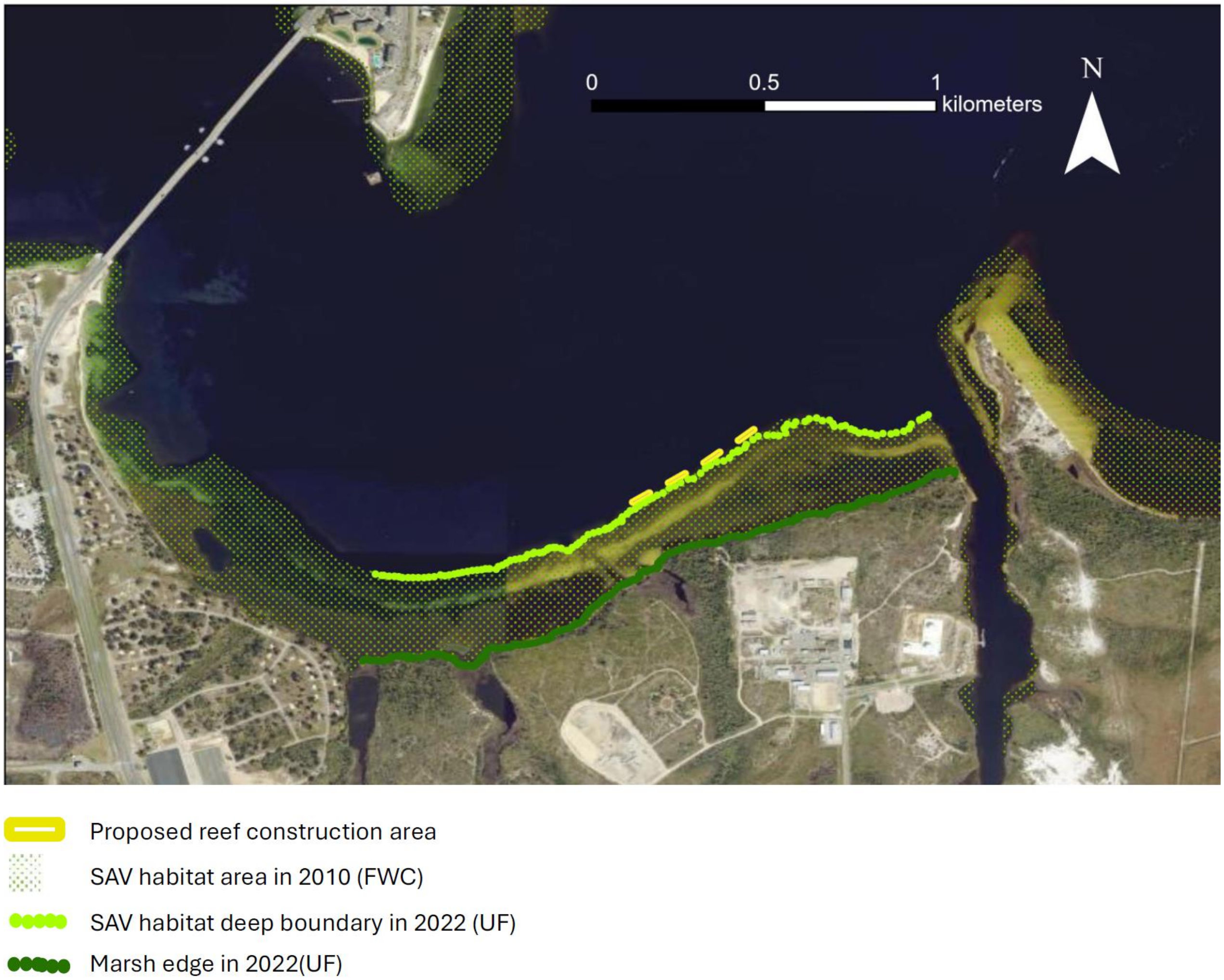

Fig. 2. General overview of the Living Shoreline Project site. Green dotted area is the submerged aquatic vegetation (SAV) habitat in 2010 (FWC geodata.myfwc.com); Bright green line is the SAV boundary in 2022 (UF); Dark green line along the shoreline is the shoreline boundary in 2022 (UF); Yellow polygons depict the 90% design footprint of the breakwater structures (Jacobs); Aerial image source: Tyndall AFB 2022.

Fig. 3. General overview of the Oyster Reef Breakwater Project site. Green dotted area is the SAV habitat in 2010 (FWC geodata.myfwc.com); Dark green line is the waterward SAV boundary in 2022 (UF); Dots along the shoreline represent the shoreline boundary and type of habitat (marsh edge, ghost forest, or eroded cliff); Blue polygons depict the 90% design footprint of the breakwater structures (Jacobs); Aerial image source: ESRI 2025.

Fig. 4. General overview of the Submerged Shoreline Stabilization and Seagrass Enhancement Project site. Green dotted area is the SAV habitat in 2010 (FWC geodata.myfwc.com); Bright green line is the continuous SAV boundary in 2022 (UF); Yellow polygons depict the 90% design footprint of the breakwater structures (Jacobs); Aerial image source: ESRI 2025.

1.4 Metrics and Methodology Overview

Upon review of a library of nature-based solution monitoring resources and consultation with a panel of subject matter experts, a suite of core metrics that will be evaluated as a part of this Monitoring Plan were selected for the following purposes: to track the structural integrity of the deployed structures; to evaluate their functional performance in attenuating waves and stabilizing sediments; to quantify their effects on key species and adjacent habitats; and to assess their potential social and economic benefits. **Table 2** shows a summary of the metrics to be collected, when and where they will be collected (i.e., along permanent transects or selected sampling stations) and the proposed frequency of monitoring events.

We include in this Plan metrics defined as **Project Performance Metrics** (i.e., Integrity of the reefs and oyster recruitment), **Adjacent Habitat/Species Metrics** (i.e., creation of new habitat or expansion of existing habitat such as submerged aquatic vegetation (SAV)), and **Social or Economic Outcomes Metrics** (i.e., increase in coastal protection value). These metrics encompass universal and restoration goal-based metrics, as defined in the Oyster Habitat Restoration Monitoring and Assessment Handbook (Baggett et al. 2014). Universal metrics are considered essential for every oyster habitat project, regardless of the project goals. In contrast, restoration goal-based metrics are specific to the ecosystem service-based restoration goals motivating the three projects and will be valuable in providing quantitative information on their delivery of key ecosystem services.

Data collection

This monitoring plan outlines monitoring metrics specific to each NBS project type and location prior to and following project implementation/construction. Pre-construction monitoring applies to the 12 mo. immediately prior to project implementation, while post construction monitoring applies across three consecutive years following project implementation.

Some metrics will be monitored along fixed transects (**Table 2**). Transects to monitor oyster and invertebrate communities on the reefs will be oriented perpendicular to the crest of each reef. Transects to monitor adjacent submerged aquatic vegetation habitat will be oriented parallel with the shoreline and span the bathymetric gradient from the shoreline to the deployed structures, consistent with methods proposed in Baggett et al. (2014). The final location of the reef transects is contingent on the final location of the deployed structures. Reference transects will be located outside the reef impact area and will be determined based on UF's hydrodynamic modeling following completion of project final designs. Other metrics will be collected in fixed stations not related to the permanent transects (**Table 2**). The number and type of sampling stations are dependent on the metric. See **Section 2.2.1, 2.2.2 and 2.2.3** for metric and the associated sampling protocol for the LSL, ORB, and SSS projects, respectively.

The perpendicular monitoring transects will be permanently marked with polyvinyl chloride (PVC) pipes in the landward edge and with surface floats attached to a PVC pipe in the subtidal portions of the transect. Individual quadrats for SAV and marsh monitoring will be marked with PVC pipes for the duration of the monitoring period, after which time they will be removed. Because the assessment of oyster density and shell height metrics require destructive methods, these metrics will be collected from randomized plots close to the permanent transects.

In addition to monitoring transects, some geospatial metrics will be collected via acoustics (subaqueous) or optical imagery (subaerial) using predefined survey strategies. These methods will result in partial or total coverage of the project areas and can be subsampled along the monitoring transects to provide spatially consistent reference points for comparison between data types and sampling dates.

Ecological field data metrics will be collected with datasheets pre-formatted for each metric, and representative photographs will be taken where appropriate. The end points of each transect and location of each plot within each transect will be taken with a handheld GPS (3-5m accuracy). When completing datasheets, biologists will assign a unique identifier (referred to as the Sampling ID) to indicate the following information:

1. Location (Living Shoreline = LSL, Oyster Breakwater Reef=OBR, Submerged Shoreline Stabilization= SSS)
2. Project area (P) or Control area (C), Transect Number (T#) and, where appropriate, the identifier of the meter mark where sample or data is collected (Q#)
3. Methodology/Parameter Sampled (letter code provided in Table 2); and
4. Eight-digit Date (yyyymmdd).

For example, if a datasheet is completed within the Project area in the Living Shoreline, for sampling station number 4 for oyster density on August 18, 2020, the Sampling ID will be “LSL-P-T4Q3-

OD20200818." This naming convention will ensure the data from each sampling station are organized, searchable, and easily compared over time.

The identifier convention for the geospatial data collected during the project (i.e., Shoreline position, Topo-bathymetric profile, Marsh waterward extent, and SAV areal extent) will include the Location, Project Area (if relevant), Methodology/Parameter sampled, and eight-digit date, as described above. Extracted profiles or transects coinciding with ecological data will follow the same naming convention for synergy.

The hydrodynamic and water quality data will be collected by moored instruments deployed for several weeks at a time. The file names for these data sets will include the Location, Project Area, Transect Number, Methodology, Parameter Sampled and both eight-digit start and end date of the deployment.

Statistical analysis

Because the monitoring will follow a BACI (Before-After-Control-Impact) design, data for each metric will be analyzed to evaluate the statistical significance of changes between i) the project and the control areas and ii) before-and-after construction. Overall, the SSS site is designed for Before-After statistical analysis while the LSL and ORB sites will include a reference reef near the construction site and therefore are suitable for full BACI analysis.

1.5 Tyndall Air Force Base Nature Based Solutions – Summary of Metrics

Table 2. Summary of metrics. Purpose for monitoring: PP= Project Performance; AH= Adjacent Habitat/Species; and SE= Social & Economic Outcomes. Proposed frequency: Pre-construction monitoring will occur within the 12 months immediately prior to project implementation; Post construction monitoring applies across three consecutive years following project implementation. Project sites: LSL = *Living Shoreline;* ORB = *Oyster Reef Breakwater*; and SSS = *Submerged Shoreline Stabilization*. Lead entities: NRL= US Naval Research Lab and/or CCS = University of Florida Center for Coastal Solutions.

Metric	Purpose	Proposed frequency	Sampling Locations	Project Site	Lead Entity
Reef areal dimension (RA)	PP	Within 6 mo., then 1, 2 & 3 yrs. post-constr.; post-storm	Whole reef area + reference	ORB; LSL; SSS	NRL
Reef height (RH)	PP	Within 6 mo., then 1, 2 & 3 yrs. post-constr.; post-storm	Whole reef area + reference (Assumes reefs >1m deep)	ORB; LSL; SSS	NRL
Reef rugosity (RU)	PP	Within 6 mo., then 1, 2 & 3 yrs. post-constr.; post-storm	Whole reef area + reference: (Assumes reefs >1 m deep)	ORB; LSL	NRL
Oyster density (OD)	PP	Within 6 mo., then 1, 2 & 3 yrs. post-constr.	Quadrats adjacent to permanent transects on reefs + reference	ORB; LSL	CCS
Oyster shell height (OH)	PP	Within 6 mo., then 1, 2 & 3 yrs. post-constr.	Quadrats adjacent to permanent transects on reefs + reference	ORB; LSL	CCS
Density of sessile Invertebrates (DI)	AH	Within 6 mo., then 1, 2 & 3 yrs. post-constr.	Quadrats adjacent to permanent transects on reefs + reference	ORB; LSL; SSS	CCS
Percent cover of reef substrate (by cover types) (CR)	PP	Once pre-const., within 6 mo., then 1, 2 & 3 yrs. post-constr.	Quadrats in permanent transects on reefs + control + reference	ORB; LSL; SSS	CCS
Water quality (WQ)	PP	Continuously pre-const. (up to 12 mo.); Continuously post-const. (up to 36 mo.); post-storm	Fixed sampling stations; profiles during annual surveys coinciding with ecological transects	ORB; LSL	NRL
Shoreline position (SL)	AH & SE	Once pre-const., within 6 mo., then 1, 2, & 3 yrs. post constr.; post-storm	Continuous along the project's shoreline area of impact + control	ORB; LSL; SSS	NRL
Topo-bathymetric profile (TP)	AH & SE	Once pre-const., within 6 mo., then 1, 2, & 3 yrs. post constr.; post-storm	Continuous along the breakwater reefs and adjacent nearshore area to the shoreline + control	ORB; LSL; SSS	NRL
Marsh waterward extent (ME)	AH	Once pre-constr. & annually post-const for 3 years; post-storm	Continuous along the project's marsh area of impact + control	ORB; LSL	NRL
SAV areal extent (SA)	AH	Once pre-constr. & annually post-const for 3 years	Continuous across the SAV area between structures and the shoreline + control	ORB; LSL; SSS	NRL & CCS
Percent cover of SAV (SAVC)	AH	Once pre-constr. & annually post-const for 3 years	Quadrats in permanent transects + control	ORB; LSL; SSS	CCS & NRL
Wave height and tidal currents (W)	AH	Once pre-const., within 6 mo., then 1, 2, & 3 yrs. post-const.	Fixed arrays	ORB; LSL; SSS	NRL

2. Living Shoreline Monitoring Plan

The *Living Shoreline – LSL* (**Fig. 5**) site is in East Bay near the Highway 98 Dupont Bridge and directly adjacent to the Tyndall Fuel Depot on Fred Bayou. The project is located 600-1,000 feet offshore and adjacent to contiguous seagrass meadows as well as salt marshes in the higher tidal elevations. The LSL project spans 1,268 feet of shoreline and includes four 212 ft. submerged limestone breakwater reefs in water ranging from 8 to 10 feet in depth. This LSL is designed to attenuate 55-65% of wave energy immediately behind the structures and 20% across the adjacent near shore area and enhance ~25 acres of intertidal and benthic habitat.

The overall objectives of the LSL project include:

- Protecting 1,200 linear feet of shoreline from erosion during operational day-to-day conditions
- Attenuating 55-65% of wave energy during operational day-to-day conditions
- Creating 0.92 acres of subtidal reef habitat suitable for oyster growth
- Enhancing 19 acres of natural estuarine habitat by promoting sediment accretion
- Supporting marine species adaptation to variable sea levels

Scouting of the area performed by UF CCS in 2022 found that, at the LSL site, seagrass meadows are dominated by a mix of *Halodule wrightii* and *Ruppia maritima* followed by *Thalassia testudinum.* A sand bar occurs parallel to the coast around 150 m from the shore and within the seagrass meadow. Other organisms, such as sponges, are rare. Oysters are occasionally found attached to woody debris.

Four perpendicular permanent transects spanning the width of the project site behind the reef area and four in control areas will be marked and monitored at the LSL (**Fig. 5**). **Control** area in the LSL site will be monitored to document the conditions of an unimproved site to serve as a reference. Metrics to be collected at LSL and a description of the methodology proposed to measure each metric are provided below **Table 3.**

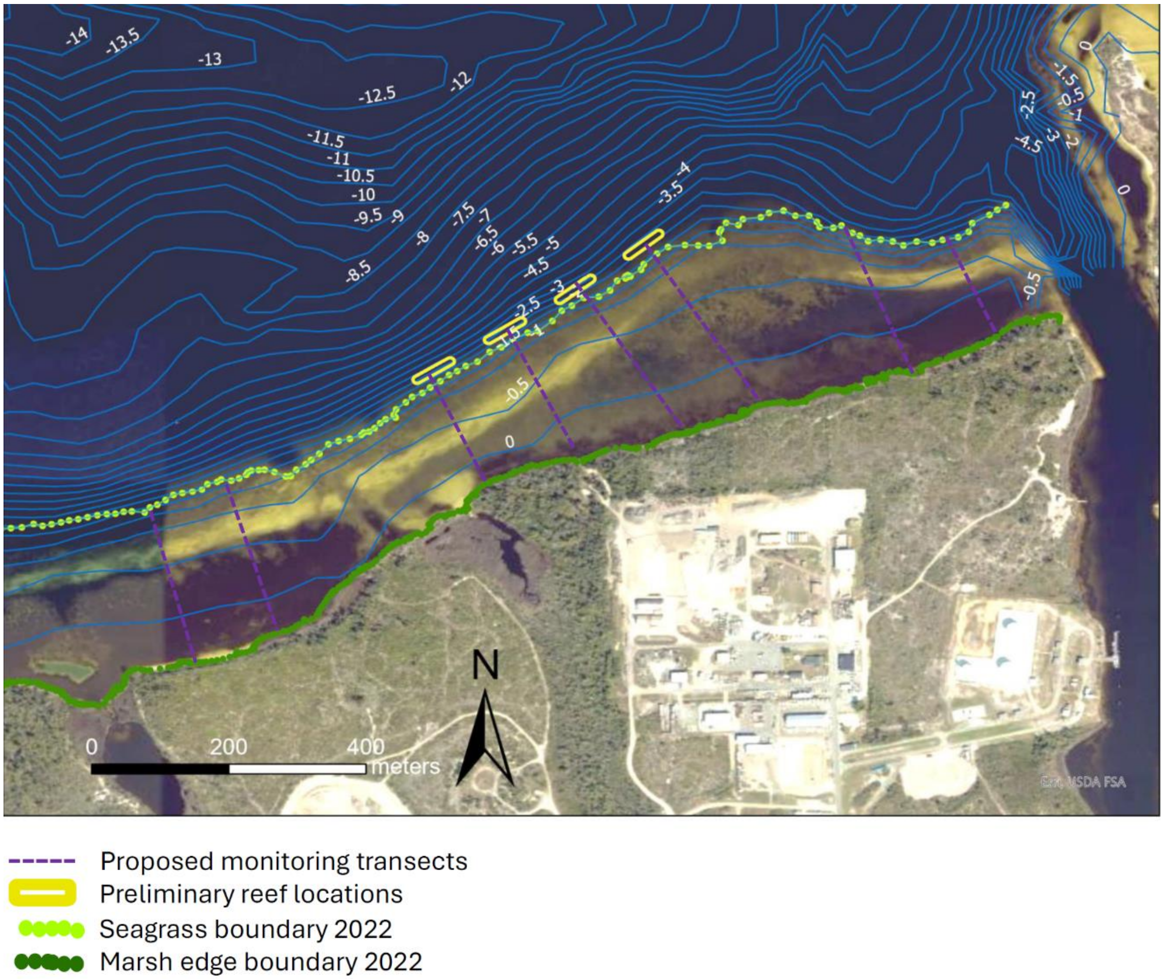

Fig. 5. Overhead view of the Living Shoreline site. Blue lines denote bathymetry; Yellow polygons depict the 90% design footprint of the breakwater structures (Jacobs). Proposed permanent transects in reef and control areas are represented by dark purple dashed lines. The final location of the reference transects will be outside the potential reef impact area and finalized based on UF's hydrodynamic modeling of the LSL design. Aerial image source: ESRI 2025.

2.1 Living Shoreline – Summary of Metrics

Table 3. Summary of metrics, codes, sampling locations, number of samples at each station/transect, number of stations/transects and total number of samples collected per monitoring event in the Living Shoreline.

Metric	# of samples at each station/transect	Number of stations or transects	Total # of samples /monitoring event
Reef areal dimension (RA)	NA	Whole reef area + reference	NA
Reef height (RH)	Continuous (assumes >1m depth)	Whole reef area + reference	Continuous (assumes >1m depth)
Reef rugosity (RU)	Continuous (assumes >1m depth)	Whole reef area + reference	Continuous (assumes >1m depth)
Oyster density (OD) & oyster shell height (OH)	3 quadrats/transect	8 transects (4 reef + 4 reference)	24
Density of sessile invertebrates (DI)	3 quadrats/transect	8 transects (4 reef + 4 reference)	24
Percent cover of reef substrate (by type) (CR)	6 quadrats/transect	12 transects (4 reef + 4 control + 4 reference)	72
Water quality (WQ)	Combination of time series & transects	1 station; 8 transects	NA
Shoreline position (SL)	Continuous	NA	NA
Topo-bathymetric profile (TP)	Continuous	NA	NA
Marsh waterward extent (ME)	Continuous	NA	NA
SAV areal extent (SA)	Continuous	NA	NA
Percent cover of SAV (by species) (SAVC)	4 plots/transect x 4 depths= 16 plots in a block	4 blocks of parallel transects in reef impact area + 4 in control	128
Wave height and tidal currents (W)	Hourly	2 arrays; 1 shore-parallel, 1 shore-perpendicular	TBD. Dependent upon the sampling frequency and duration (e.g., hourly sampling for 8 weeks =1344 samples)

2.2 Reef Areal Dimension (RA)

Where: Each constructed reef and their respective reference site reef

When: Within six months post-construction and annually thereafter for a minimum of three years, with additional measurements taken after events that could alter reef height (e.g., hurricanes, vessel strikes).

Lead entity: NRL

How: Reef area is critical to estimating the health and persistence of the reef over time and the quality of ecosystem services the reef provides (MarineGeo, 2021).

Reef aerial dimensions will be obtained from bathymetric maps (Baggett et al. 2014; see Section 3.1). Bathymetry maps with decimeter resolution will be obtained by NRL from a multibeam sonar system (NORBIT - iWBMSh STX) mounted to a vessel or autonomous vehicle. Bathymetric positioning will be obtained by using an RTK-enabled WaveMaster POSMV with subdecimetric position accuracy. The resolution of the horizontal plane will depend on the density of soundings and may be improved by increasing the number of transects and/or repeating transects. The transects will cover the reef structures and the surrounding area to assess sediment erosion or accretion. The areal extent of the reefs will be extracted from the bathymetry maps by semi-supervised classification of the bathymetric derivatives using GIS. Slope and aspect will be calculated by NRL from the bathymetric surfaces, and the boundary of the reef will be identified by slope and elevation changes between the nearfield bay or ocean bottom and the reef structures. The annual change in reef area will be assessed by comparing measurements in sequential years.

Why: Reef areal dimension will be used to assess whether the structures maintain a stable position over time, increase in areal dimension via colonization by oysters and other benthic fauna, and maintain structural integrity over performance time.

2.3 Reef Height (RH)

Where: Each constructed reef and their respective reference site reef

When: Within six months post-construction and annually thereafter for a minimum of three years, with additional measurements taken after events that could alter reef height (e.g., hurricanes, vessel strikes).

Lead entity: NRL

How: Reef height is a measure of the height of the reef off the bottom substrate and is reported as mean height and minimum and maximum heights (Baggett et al. 2014; Section 3.2, pg. 13). Height will be obtained from the bathymetry maps collected for the "reef area" using GIS. Elevation data from the bathymetry maps will be obtained for specific points on the reef top and adjacent bottom points. The mean reef height will be reported as the distance from the top of the reef to the adjacent bottom elevation (in meters) for the selected pairs of points along each reef. From these measurements, annual changes in reef height will be calculated for each site.

Why: Reef height will be used to assess whether the structures maintain a stable position over time, increase in height via colonization by oysters and other benthic fauna, and maintain structural integrity over time performance.

2.4 Reef Rugosity (RU)

Where: Each constructed reef and their respective reference site reefs

When: Within six months post-construction and annually thereafter for a minimum of three years, with additional measurements taken after events that could alter reef height (e.g., hurricanes, vessel strikes).

Lead entity: NRL

How: Reef rugosity is a measure of habitat complexity. Higher rugosity and therefore higher habitat complexity can be linked to increased cover or refuge and biodiversity (MarineGeo, 2021). Bathymetry maps with decimeter resolution will be obtained by NRL from a multibeam sonar system (NORBIT - iWBMSh STX) mounted to a vessel or autonomous vehicle. Bathymetric positioning will be obtained by using an RTK-enabled WaveMaster POSMV with subdecimetric positional accuracy. The transects will cover the reef structures to assess reef rugosity. Resolution will be improved as necessary by increasing the number of transects and/or repeating transects. Rugosity will be estimated from bathymetric surfaces using GIS.

Why: Reef rugosity is an important indicator of structural function because it predicts the ability of the structure to serve as habitat and interact with water flow and sediment transport.

2.5 Oyster Density and Oyster Shell Height (OD, OH)

Where: 4 transects across constructed reefs + 4 transects across reference reefs with 3 quadrats per transect (**Fig. 5**)

When: Live and dead oyster density and live oyster shell height measurements will be taken within 6 months of construction and annually thereafter in the same season for a minimum of three years.

Lead entity: UF-CCS

How: Oyster density is the number of live or dead oysters per m^2. Oyster density provides information about oyster population size, survivorship and recruitment (Baggett et al, 2014). Three 0.25 x 0.25 m quadrats will be haphazardly placed close to the permanent perpendicular monitoring transects at three different positions for destructive monitoring post-construction. One quadrat will be placed on the shoreward face of the reef at an intermediate height, a second quadrat will be placed on the top of the reef, and a third quadrat will be placed on the seaward face of the reef, also at an intermediate height. The quadrats will be made of flexible material such as nylon webbing so they can bend and adapt to the 3D form of the reef. Sampling on reference transects will follow the same protocol, except that quadrats will be haphazardly placed along transects laid across existing natural reefs. Following the Florida Fish and

Wildlife Conservation Commission Oyster Monitoring Procedures (FWRI, 2021) and MarineGeo (2021), divers will remove all oysters and cultch material to wrist depth within each 0.25 x 0.25 m quadrat and place the cultch and oysters in bags. Bags will be returned to the vessel. On the vessel, 1) the samples will be placed in a tray with water, 2) oysters will be separated from the other benthos, 3) live and dead oysters larger than 10mm will be counted, 4) the shell height of 50 haphazardly selected live oysters per quadrat (or all live oysters if fewer than 50 in quadrat) will be measured with calipers, and 5) the other benthos will be put in labelled bags and frozen for later identification in the lab. The oysters will then be returned to the water. Dead oyster density will include open oysters and scars and will be used to assess if there is oyster mortality. To estimate the size frequency distribution of oysters on the reef, oyster sizes will be binned into 5 mm size classes following Baggett et al. (2014, Section 3.3). Mollusk species that can be found during the monitoring are summarized in FWC's 2021 "Oyster Monitoring Procedures" (Oyster Integrated Mapping and Monitoring Program - Chapter 11 (myfwc.com)).

Results from the project sites will be compared to the control area. Size frequency distributions within 15 - 25% for all size classes of those measured at similar sites reported in the literature are considered as demonstrating successful reef function (e.g., DARPA reefs, FWC's Oyster Reef Habitat Restoration in West Bay, St. Andrew Bay, FL). Suitable reference reefs will be selected for monitoring near the constructed reefs in the vicinity of Little Oyster Point.

Why: Oyster recruitment, persistence, and size distribution are important indicators of functions of structures because oysters filter water, create complex habitat, and serve as a food resource for wildlife. Knowledge of oyster populations is therefore an important aspect of quantifying whether these secondary benefits are accrued following project implementation.

2.6 Density and Biomass of Sessile Invertebrates (DI)

Where: 4 transects across constructed reefs + 4 transects across reference reefs with 3 quadrats per transect (**Fig. 5)**

When: Within 6 months post-construction, and annually thereafter in the same season for a minimum of 3 years.

Lead entity: UF-CCS

How: Samples of sessile invertebrates will be obtained from the oyster density/size distribution quadrat samples as described above. In the lab, sessile macroinvertebrates will be identified to the lowest taxonomic level practical and selected relevant species will be counted to calculate individuals/m^2. All organisms will be blotted with a dry paper towel and will be weighed together by taxonomic category to obtain a wet weight (g/m^2) (of each taxonomic category) for each sample. In both the control areas and pre-construction reef sites, any sessile invertebrate on the surface of the sandy bottom within the 0.25 x 0.25 m sampling plots described above will be collected. Results from the project sites will be compared to both the control area and reference sites in a before-and-after context.

Why: Invertebrates are an important indicator of secondary production, biodiversity, and they provide food resources for fish, wildlife, and other organisms. Their abundance is therefore an indicator of ecological function and benefits associated with project implementation.

2.7 Percent Cover of Reef Substrate (CR)

Where: 4 transects across reefs + 4 control transects + 4 transects across reference reefs with 6 quadrats per transect (**Fig. 5)**

When: Pre-construction, within 6 months post construction and annually thereafter in the same season for a minimum of three years. As feasible, additional measurements will be taken after events that could alter mollusk/oyster survival (e.g., hurricanes, heat wave, extreme rainfall).

Lead entity: UF-CCS

How: Within the 0.5 x 0.5 m quadrats along permanent transects laid perpendicularly across the reefs (Baggett et al. 2014; Section 5.7 and MarineGeo 2021), UF-CCS will record a visual estimation of the percentage coverage of reef substrate by cover type (including living oysters, sessile invertebrates, algae, and non-living hard substrate). The same observer will collect all data for this metric to support consistency in data collection. Percent coverage estimates and a photo of the quadrat will be made at each sampling time point. When possible, sessile invertebrates that could not be identified will be collected as a voucher. If organisms are layered (one on top of each other), the percentage cover can add up to more than 100%. Results from the project sites will be compared to both the control area and in a before-and after context.

Why: Measurement of the percent cover of reef substrate (both living and non-living) provides a rapid visual estimate of the habitat available for oyster settlement and the benthic community assemblage. Percent cover (which differs from the reef areal dimensions metric) will aid the interpretation of the other reef-focused metrics data and the overall trajectory of the restoration project.

2.8 Water Quality (WQ)

Where: 1 fixed station, 4 transects across reefs + 2 control transects + 2 reference transects

When: Continuous for 12 months pre-construction and up to 36 months post-construction. Transect point measurements concomitant with annual geospatial and ecological surveys.

Lead entity: NRL

How: Deployment of a suite containing one moored multi-parameter sonde, one optical backscatter sensor, and one hydrometeorological data buoy. The multi-parameter sonde consists of fluorometers moored to the bay floor at both sites to capture the immediate conditions affecting the area. Turbidity and luminosity will be monitored at vertical intervals of 1cm for 35cm using at a minimum a Lindorm SediMeter SM4P profiler mounted to the bay floor. The data buoy will also transmit real-time wave and meteorological data for determining potential storm events requiring a post-event response. Additionally, water quality parameters will be assessed using a handheld multi-parameter sonde (YSI ProDSS) when performing other geospatial and ecological surveys. Monitored parameters will focus on those related to oyster recruitment and survival such as temperature, conductivity, pH, chlorophyll a, CDOM, DO, and luminosity. Results from the project sites will be compared to both the control area and in a before-and after context.

Why: In other parts of Northwest Florida, increasing temperatures and turbidity, episodes of hypoxia, and changing salinity regimes are suspected factors driving oyster mortality events. Continuous water quality monitoring will provide insight into factors that may affect oysters colonizing installed oyster reef structures and/or adjacent seagrass habitat within East Bay and can thus inform adaptive management of the Living Shoreline and Oyster Reef Breakwater project locations.

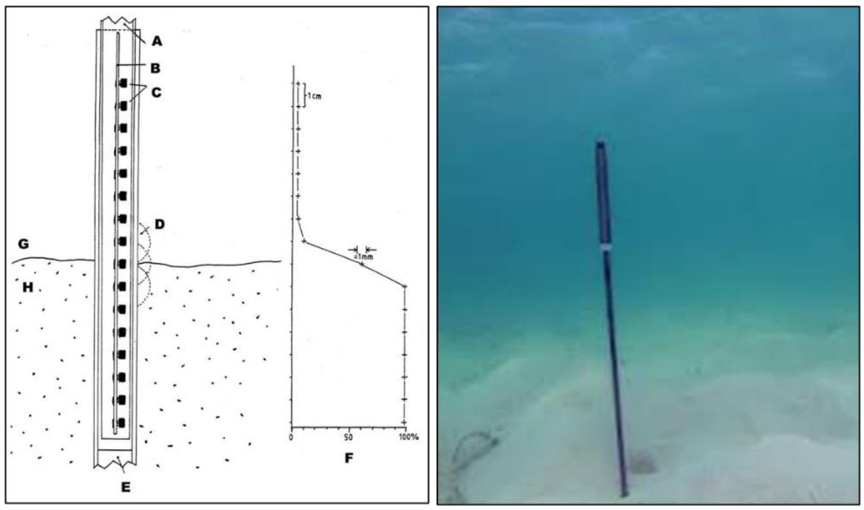

Fig. 6. Schematic of the vertical optical array used by the Lindorm SediMeter systems to measure near bed turbidity and precise seabed elevation (left). A deployed SediMeter SM4 in a shallow, sandy bed similar to the sites in this proposal (image credit: Lindorm, LLC).

2.9 Shoreline Position (SL)

Where: Continuous along the project's shoreline area of impact and control site

When: Once pre-construction, within six months and annually thereafter for a minimum of three years post construction, and after events like hurricanes.

Lead entity: NRL

How: Topographic maps with centimetric resolution will be obtained from a fixed-wing UAS system (Wingtra VTOL) with RTK-positioning. Shoreline position will be taken as the zero meter contour from the UAS digitized elevation model (DEM) using GIS. Positions will then be compared between surveys to determine changes in shoreline position.

Why: Shoreline position is an indicator of wave attenuation and sediment trapping. These are critical monitoring metrics to determine the effects of the installation on the adjacent shoreline.

2.10 Topo-bathymetric Profile (TP)

Where: Continuous along the breakwater reefs and adjacent nearshore area to the shoreline and control site

When: Once pre-construction, within six months and annually thereafter for a minimum of three years post construction, and after events like hurricanes.

Lead entity: NRL

How: Topo-bathymetric maps with centrimetric resolution will be obtained from a fixed-wing UAS system (Wingtra VTOL) and multibeam sonar, both with RTK-positioning. Shoreline profiles will be extracted from the combined DEMs based on GPS position using GIS. Profile elevations will be compared between surveys to determine elevation changes across the project area and reference site.

Why: Profile elevation change is an indicator of wave attenuation and sediment trapping. These are critical monitoring metrics to determine the effects of the installation on the adjacent shoreline.

2.11 Marsh Waterward Extent (ME)

Where: Continuous along the project's marsh area of impact and control site

When: Once pre-construction, annually thereafter for a minimum of three years post construction, and after severe events (e.g., hurricanes).

Lead entity: NRL

How: Visual imagery with centimetric resolution will be obtained from a fixed-wing UAS system (Wingtra VTOL) using RTK-GPS positioning. Images will be mosaicked into a georeferenced image of the project area. The project area image will be analyzed using semi-automated GIS methods to delineate the marsh waterward extent based on pixel frequency analysis. This method leverages spectral bands to distinguish vegetation (green and blue) from sediments (white and brown). The marsh extent is determined as the georeferenced line between the vegetation and shore sediments.

Why: Marsh vegetation root systems provide robust reinforcement of shorelines and stabilize sediment to prevent erosion. The marsh also provides specialized habitat for migratory bird species, mussels, crabs, and nursery habitat for fin fish young. Marsh waterward extent will be monitored to measure if and how the NBS projects impact the extent of adjacent marsh boundary.

2.12 Submerged Aquatic Vegetation Areal Extent (SAVA)

Where: Continuous across the SAV area between the structures to the shoreline and control site

When: Within 12 months prior to construction within the seagrass growing season (April-Sept), and annually thereafter for a minimum of three years after construction in the same season.

Lead entity: NRL (remote sensing) & UF-CCS (ground truthing)

How: For shallow areas with sufficient water clarity, UAS imagery will be used to delineate the submerged aquatic vegetation (SAV) boundaries (Chabot et al. 2016). Multibeam sonar surveys will be used in areas where water clarity is insufficient for UAS-based detection if water depth permits sonar surveying. Like marsh waterward extent, spectral bands and the use of spectral indices in GIS analysis will generate a georeferenced SAV boundary. Alternatively, multibeam backscatter (water column and bed returns) will be analyzed for intensity differences between sediments and SAV to determine the SAV boundary (Norton, 2019). The boundary can be a combination of UAS and sonar data or a single platform depending on conditions for each survey. All final data products will be comparable and usable for boundary change analysis. The boundary will be defined as the furthest seaward extent of vegetation. If needed, in situ ground-truthing of the SAV boundary will be performed by UF snorkelers or divers followed by a kayak with a mounted GPS.

Why: SAV are ecosystem indicators for water quality and support species diversity as a unique benthic habitat and food source for animals such as sea turtles and manatees. Tracking the extent of meadows alongside water quality metrics indicates the health of this habitat. SAV extent will be monitored to measure if and how the NBS projects impact the extent of adjacent SAV.

2.13 Percent Cover of Submerged Aquatic Vegetation (SAVC)

Where: 4 zones directly inshore of the reefs and 4 zones in control area

When: Within 12 months prior to construction within the seagrass growing season (April-Sept), and annually thereafter for a minimum of three years after construction in the same season.

Lead entity: NRL (remote sensing) & UF-CCS (ground truthing)

How: Measurement of SAV percent cover by species can indicate if the reefs are promoting changes in SAV community and cover. The percent cover of SAV relative to bare sediment will be estimated from the UAS and sonar imagery by NRL. In addition, *in situ* data will be obtained by UF-CCS divers for ground truthing percent cover as well as identifying species-specific cover. *In situ* data will be collected along permanent transects parallel to the shore at different distances from the reefs. Parallel transects will provide higher replication at the same depth. This represents a stratified random design, with each parallel transect sampling a given depth zone. The final location of these transects is contingent on the final reef designs.

Transect location: Permanent transects parallel to the shore will be marked at 4 depths: 1) along the 0% seagrass edge, 2) 100 m landwards of the 0% seagrass edge; 3) 200 m landwards the 0% seagrass edge; and 4) 300 m landwards of the 0% seagrass edge or shallowest subtidal seagrass edge (**Fig. 7**). If seagrass expansion is observed, a new transect will be added closer to the reefs. Each parallel transect will consist of four (4) plots of 0.5 x 0.5 m, marked permanently with PVC stakes. Four blocks of parallel transects will be located behind the reefs and four in the control area (**Fig. 7**).

Percent cover separated by different SAV species, percent cover of algae by species, percent cover of detritus, percent bare cover, percent cover of other species (i.e. sponges, oysters), sediment type (shelly sand, sand, muddy sand, muddy), epibiota rating (clean, light, moderate, heavy), epibiota type and shoot length in cm of 5 random shoots per species will be recorded for each 0.5 x 0.5m quadrat. A photo will be taken of each quadrat. The percentage of substrate covered by SAV per species within the quadrat will be conducted using the modified Braun-Blanquet scale outlined in Baggett et al., (2014), as follows:

- 0 = no seagrass present in quadrat
- 0.1 = a solitary shoot, <5% coverage
- 0.5 = less than 5 shoots, <5% coverage
- 1 = greater than 5 shoots, <5% coverage
- 2 = greater than 5 shoots, 5-25% coverage
- 3 = greater than 5 shoots, 25-50% coverage
- 4 = greater than 5 shoots, 50-75% coverage
- 5 = greater than 5 shoots, 75-100% coverage

Results from the project sites will be compared to both the control area and pre-construction values in a before-and-after context.

Why: Percent cover of SAV will be monitored to measure if and how the NBS projects impact the condition of adjacent SAV.

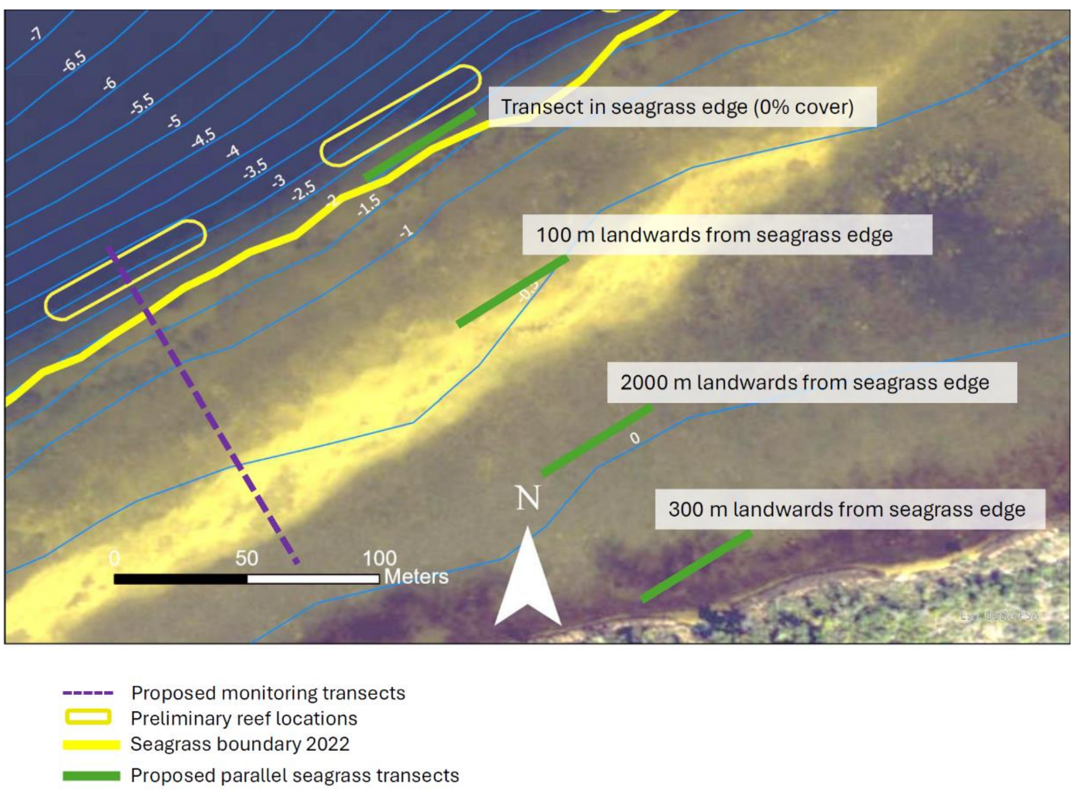

Fig. 7. Schematic example of the proposed parallel transects to monitor changes in SAV cover, at different distances from the reef, for both the LSL and ORB. Line blue lines denote bathymetry; Yellow polygons depict the 90% design footprint of the breakwater structures (Jacobs). Proposed permanent monitoring transects perpendicular to the breakwater structures and crossing both reef and control areas are represented by dark purple dashed lines.

Proposed permanent seagrass transects parallel to the breakwaters structures and shoreline are represented by solid green lines. Aerial image source: ESRI 2025.

2.14 Wave Height and Tidal Currents (W)

Where: At minimum, 1 sensor suite inshore of the constructed projects and 1 sensor suite offshore of the constructed projects

When: Pre-construction, within 6 months post-construction, and annually thereafter for a minimum of 3 years

Lead entity: NRL

How: Deployment of a suite of one instrumented bottom lander, four tilt-current meters, at minimum one optical or acoustic backscatter sensor, and at minimum one spotter or data buoys around the LSL (**Fig. 8**). Each lander may be equipped with a Conductivity, Temperature, Depth (CTD) sensor, and either turbidity sensors or multiparameter sondes. Deployments will occur for 8 weeks duration for acoustic sensors. Tilt-current meters, optical backscatter sensors, spotter buoys and water quality sensors may be deployed up to 12 months.

Why: Wave height and tidal currents are being measured to quantify how the submerged stabilization structures alter nearshore wave and current fields. This metric is useful for assessing whether the project is achieving two of the primary goals of mitigating wave energy and promoting sediment accretion.

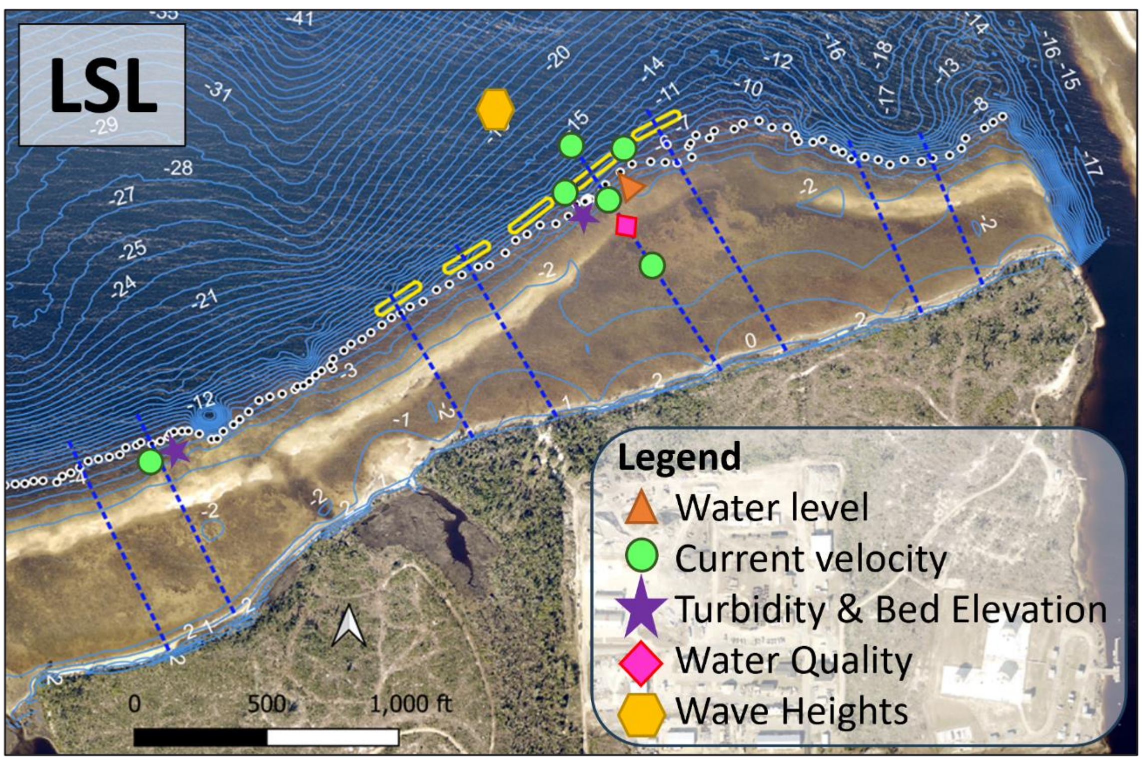

Fig. 8. Proposed configuration of instruments to be deployed by NRL at the Living Shoreline Project location.

3. Oyster Reef Breakwater Monitoring Plan

The *Oyster Reef Breakwater - ORB* (**Fig. 3**) site is also located in East Bay to the north of the drone runway. The project site is located 300-800 feet offshore and is also adjacent contiguous seagrass meadows as well as saltmarshes in the higher tidal elevations (**Fig. 1**). The ORB project spans 2,000 feet of shoreline and includes six 200 ft. limestone reefs in water ranging from 4 to 6 feet in depth. The ORB will support oyster recruitment and is designed to attenuate 80-90% of wave energy and enhance ~30 acres of intertidal and benthic habitat.

The overall objectives of the ORB project include:

- Protecting 2,000 linear feet of shoreline from erosion during operational day-to-day conditions
- Attenuating 80-90% of wave energy during operational day-to-day conditions
- Creating 1.35 acres of oyster reef habitat
- Enhancing 30 acres of natural estuarine habitat by promoting sediment accretion
- Supporting marine species' adaptation to variable sea levels

Scouting of the area performed by UF in 2022 found that at the ORB site, seagrass cover is dominated by a mix of *H. wrightii*, *R. maritima* and *T. testudinum*. The water in this location is the most turbid and tannin rich of all three sites. Other organisms, such as sponges, are rare. Oysters are occasionally found attached to woody debris.

Four perpendicular permanent transects in the project area and four in the control areas will be marked at the ORB. **Control** areas at the ORB will be monitored to document comparative conditions of an unimproved (unrestored site) (see dark blue dotted lines in **Fig. 9A**).

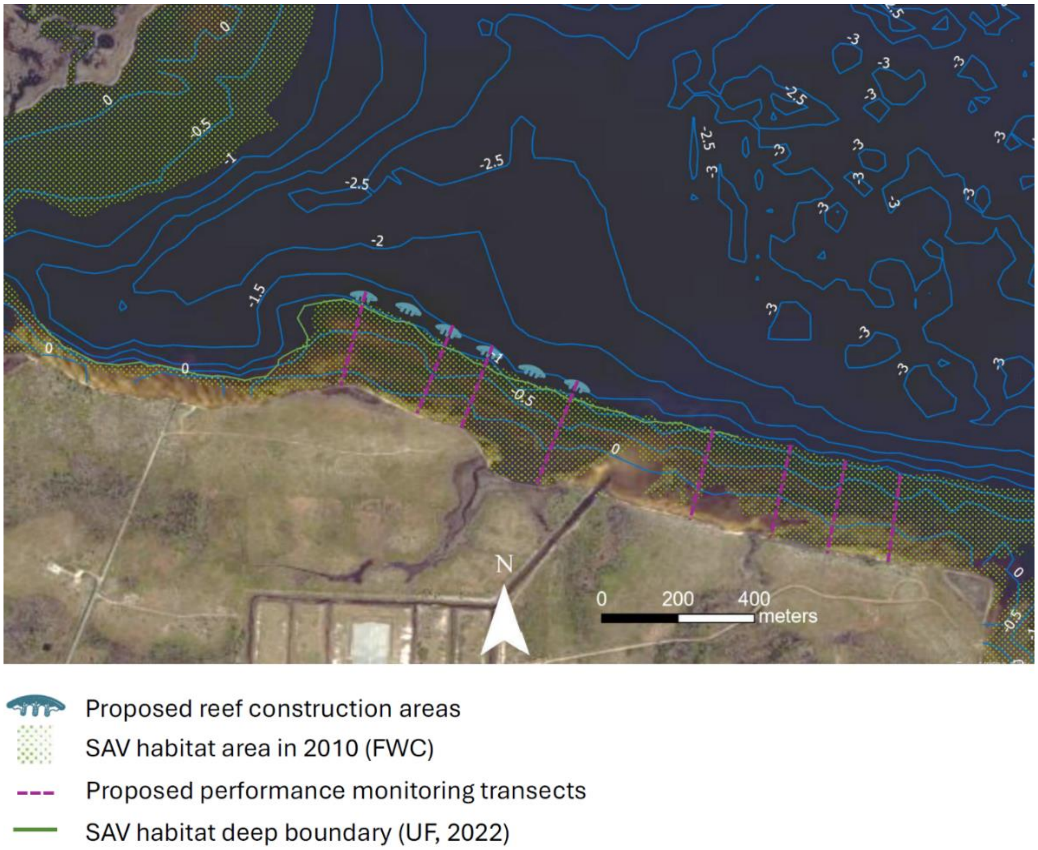

Fig. 9A. Position of Oyster Reef Breakwater Project. Blue polygons depict the 90% design footprint of the breakwater structures. Dark purple dashed lines represent permanent monitoring transects perpendicular to the shoreline and overlapping both the breakwater footprint and adjacent control areas. The final location of the reference transects will be decided after assessing the potential reef impact area based on the output of the hydrodynamic models (models not performed yet). Aerial image source: ESRI 2025.

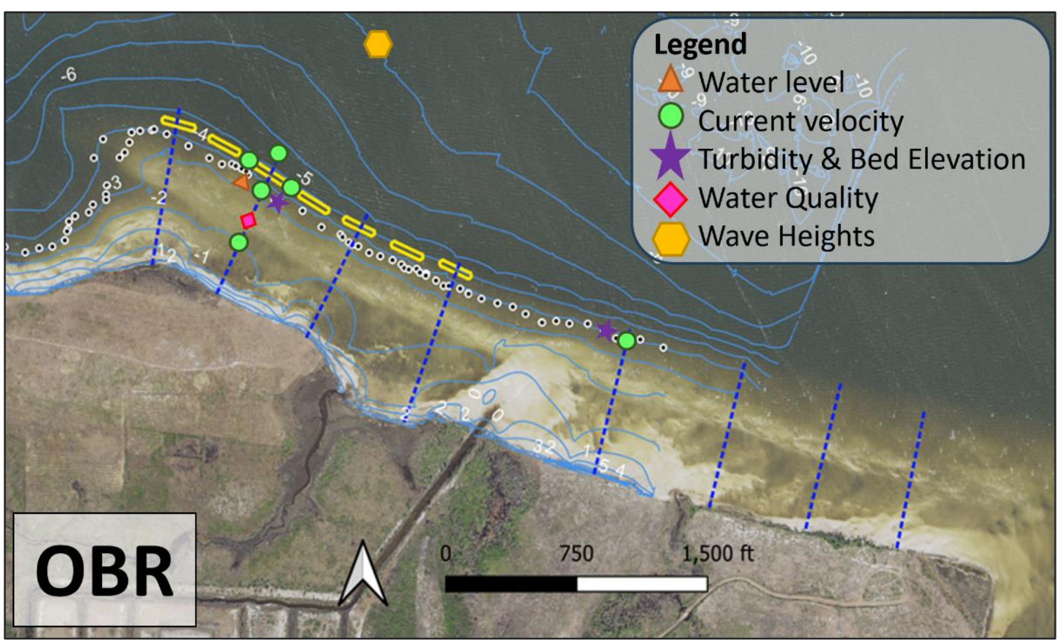

Figure 9B: Proposed configuration of instruments to be deployed by NRL at the Oyster Reef Breakwater Project location.

3.1 Oyster Reef Breakwater – Summary of Metrics

Metrics collected in the ORB site will be the same as those collected at the LSL. Please refer to sections 2.2-2.14 for methodological details.

Table 4. Summary of metrics, codes, sampling locations, number of samples at each station/transect, number of stations/transects and total number of samples collected per monitoring event in the Oyster Breakwater Reef.

Metric	# of samples at each station/transect	Number of stations or transects	Total # of samples /monitoring event
Reef areal dimension (RA)	Continuous	Whole reef area + reference	Continuous
Reef height (RH)	Continuous	Whole reef area + reference	Continuous
Reef rugosity (RU)	Continuous	Whole reef area + reference	Continuous
Oyster density (OD) & Oyster shell height (OH)	3 quadrats per transect	8 transects (4 reef + 4 reference)	24
Density of sessile invertebrates (DI)	3 quadrats per transect	8 transects (4 reef + 4 reference)	24
Percent cover of reef substrate (by type) (CR)	6 quadrats per transect	12 transects (4 reef + 4 control + 4 reference)	72
Water quality (WQ)	Combination of time series & transects	1 station; 8 transects	NA
Shoreline position (SL)	Continuous	NA	NA
Topo-bathymetric profile (TP)	Continuous	NA	NA
Marsh waterward extent (ME)	Continuous	NA	NA
SAV areal extent (SA)	Continuous	NA	NA
Percent cover of SAV (by species) (SAVC)	4 plots/transect x 4 depths= 16 plots in a block	4 blocks of parallel transects in constructed reef area + 4 in control area	128
Wave height and tidal currents (W)	Hourly	2 arrays	TBD. Dependent upon the sampling frequency and duration (e.g., hourly sampling for 8 weeks =1344 samples)

4. Submerged Shoreline Stabilization & Seagrass Enhancement Monitoring Plan

The *Submerged Shoreline Stabilization and Seagrass Enhancement – SSS* project site (**Fig. 4**) is in the Saint Andrew Sound on the Gulf side of TAFB peninsula. The site is also located to the south of the drone runway. As a result of its higher exposure to a more intense wave climate and more oceanic salinities, the site is characterized by different ecosystems compared to the Bay side projects. The SSS site is characterized by patchy subtidal seagrass meadows with beach areas and dunes onshore (**Fig. 1**). The project site is located between 200 and 600 feet offshore and is adjacent to the patchy seagrass meadows.

The SSS project spans 3,500 linear feet of shoreline and includes twelve 200 ft. limestone breakwater structures in water about 5 to 6 feet in depth. The SSS project is designed to attenuate 60-80% of wave energy and enhance ~30 acres of intertidal and benthic habitat. The project is also integrated with a 5-acre Seagrass Enhancement effort.

The overall objectives of SSS project include:

- Protecting 3,500 linear feet of shoreline from erosion during operational day-to-day conditions
- Attenuating 60-80% of wave energy during operational day-to-day conditions
- Creating 2.52 acres of subtidal reef habitat
- Enhancing 30 acres of natural estuarine habitat by promoting sediment accretion
- Protecting and/or enhancing 5 acres of existing seagrass meadows
- Supporting marine species' adaptation to variable sea levels

Due to differences in wave exposure of the locations surrounding the construction area at the SSS site, it is not possible to confirm the location of proper reference sites at this time. Consequently, monitoring efforts to evaluate the effects of the SSS project will focus strongly on before and after comparisons (e.g., measure wave attenuation before and after; quantify seagrass areal extent and composition before and after) within the project area and nearby control sites (**Fig. 10-Top**). Four perpendicular permanent transects in reef area and four in the adjacent control area will be marked at the SSS. Where feasible, reference areas further from the project site will be instrumented and monitored for water quality and topo-bathymetric changes (**Fig. 10-Bottom**). The final location of the reference transects will be decided after assessing the potential reef impact area based on the output of the hydrodynamic models..

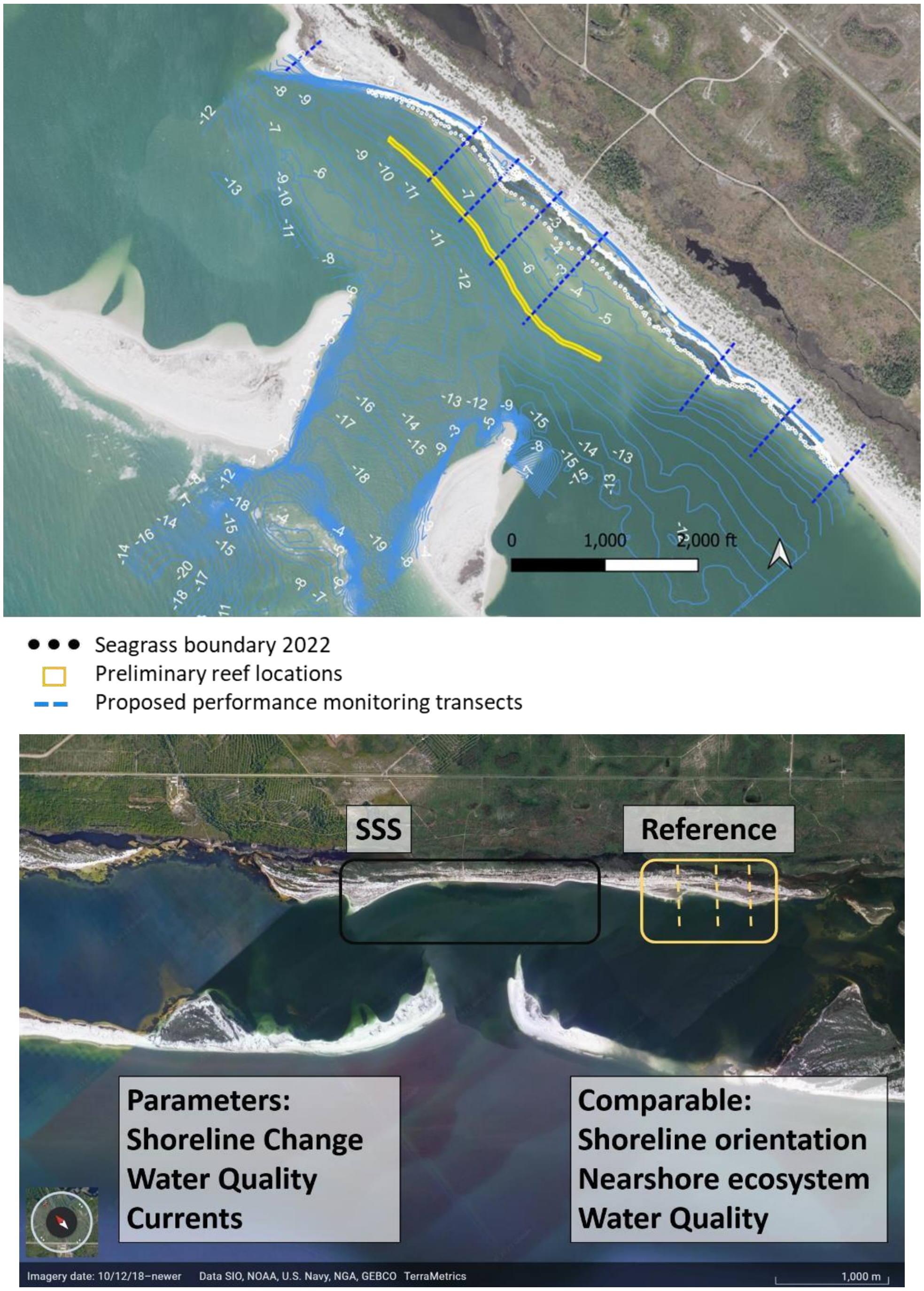

Fig. 10. Top: At the Submerged Shoreline Stabilization and Seagrass Enhancement Project site: Yellow line represents the generalized footprint of the breakwater structures; Blue dotted lines represent permanent monitoring transects perpendicular to the shoreline in reef area and adjacent control area; Aerial image source: Tyndall AFB 2022. Bottom: Alternative location for the placement of reference transects for physical variable monitoring. The final location of the reference transects will be decided after assessing the potential reef impact area based on the output of the hydrodynamic models (models not performed yet).

4.1 Submerged Shoreline Stabilization – Summary of Metrics

The metrics to be collected at the SSS are summarized in **Table 5**. Please refer to sections 2.2.1.1 for methodological details. Submerged aquatic vegetation percent cover and wave height/tidal water currents have slight variations that are explained below.

Table 5. Summary of metrics, codes, sampling locations, number of samples at each station/transect, number of stations/transects and total number of samples collected per monitoring event in the Submerged Shoreline Stabilization.

Metric	# of samples at each station/transect	Number of stations or transects	Total # of samples collected /monitoring event
Reef areal dimensions (RA)	Continuous	Whole reef area + reference	Continuous
Reef height (RH)	Continuous	Whole reef area + reference	Continuous
Density of sessile invertebrates (DI)	3 quadrats/transect	8 transects (4 reef + 4 control)	24
Percent cover of reef substrate (by type) (CR)	6 quadrats/transect	8 transects (4 reef + 4 control)	48
Shoreline position	Continuous	NA	NA
Topo-bathymetric profile (TP)	Continuous	NA	NA
SAV areal extent (SAVA)	Continuous	NA	NA
Percent cover of SAV (by species) (SAVC)	4 plots/transect x 5 elevations = 20 plots in a block	4 blocks of parallel transects in reef + 4 in control	160
Wave height and tidal water flow (W)	Hourly	1 array	TBD

Scouting of the area performed by UF in 2022 found that the seagrass species at SSS include *Halodule wrightii*, *Syringodium filiforme, Thalassia testudinum* and *Halophila engelmannii.* The seagrass bed in SSS shows evidence of erosion and/or grazing (**Fig. 11**). Other organisms, such as sponges, tubeworms, clams, pen shells, tunicates, sand dollars, sea urchins, blue crabs, and mussels can be observed within the seagrass meadow.

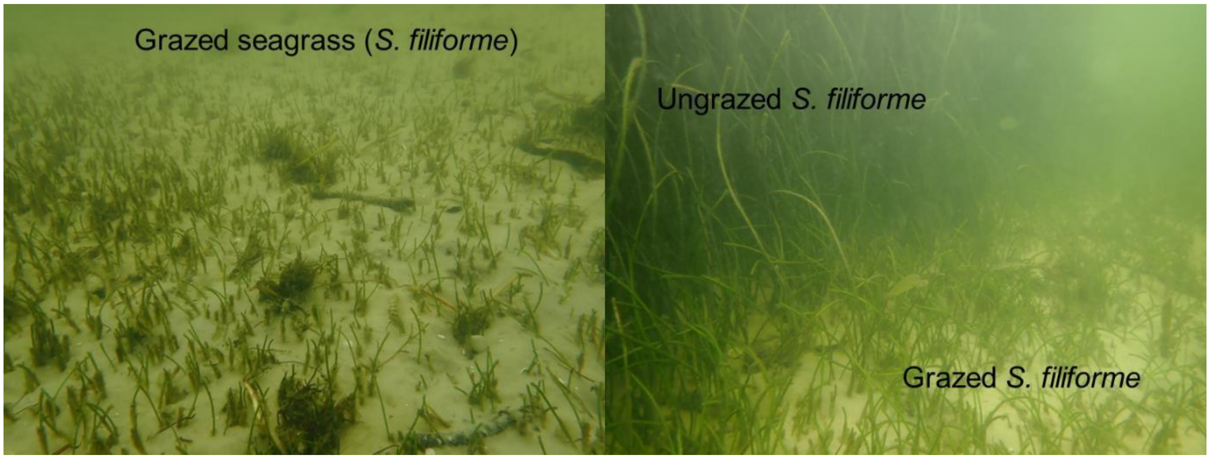

Fig. 11. Images of grazed seagrass (*S. filiforme*) in the Submerged Shoreline Stabilization location.

4.2 Percent Cover of Submerged Aquatic Vegetation (SAVC)

Where: 5 zones next to the reefs and 5 zones in adjacent area (no real control)

When: One year prior to construction within the seagrass growing season (June-Sept), and annually thereafter for a minimum of three years after construction.

Lead entity: UF-CCS and NRL

How: The percent (%) cover of SAV by species will be collected along permanent transects parallel to the shore at different distances from the reef edges. Four blocks of parallel transects will be located behind the reefs and four in the control area. Parallel transects will enable higher replication for the same depth of the reef. The final location of these transects is contingent on the installed reef configuration.

Transects location: At the SSS site, the seagrass has been heavily grazed and eroded resulting in an undefined edge. Measurement of SAV percent cover by species can indicate if the reefs are promoting changes in SAV community and cover. The percent cover of SAV relative to bare sediment will be estimated from the UAS imagery by NRL. In addition, *in situ* data will be obtained by UF-CCS divers for ground truthing percent cover as well identifying species-specific cover. In situ monitoring will include transects in the historic seagrass meadow to evaluate recovery. The parallel transects will be installed in in 5 zones: 1) non grazed seagrass edge; 2) 5 m landwards from non-grazed seagrass edge (only 5 m because the meadow is very narrow); 3) 5 m offshore from the non-grazed edge; 4) 15 m from non-grazed edge and 5) 25 m from non-grazed seagrass edge. Additional transects will be installed at deeper locations if seagrass expansion/recovery is observed. Within each quadrat, the same variables as for LSL will be collected. The proposed scheme for the transect locations is shown on **Fig. 12**.

Why: Percent cover of SAV will be monitored to measure if and how the NBS projects impact the adjacent SAV.

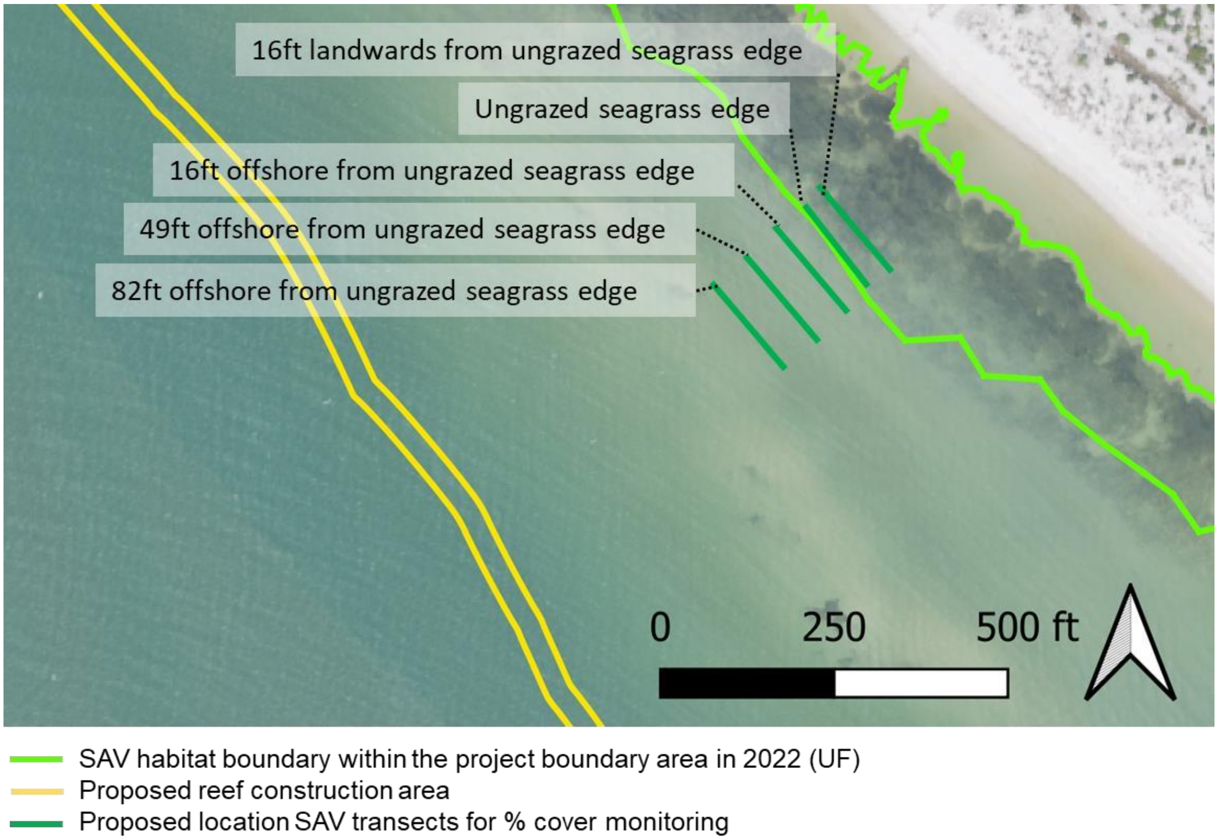

Fig. 12. Schematic example of the proposed parallel transects (dark green lines) to monitor changes in SAV % cover at the SSS, at different distances from the ungrazed seagrass edge.

4.3 Wave Height and Tidal Currents (W)

Where: Whole project area and reference site

When: Pre-construction, within 6 months post-construction, and annually thereafter (minimum 3 years)

Lead entity: NRL

How: Deployment of a suite of one instrumented bottom lander, four tilt-current meters, at minimum one optical or acoustic backscatter sensor, and at minimum one spotter or data buoys around the SSS (**Fig. 13**). Each lander may be equipped with a Conductivity, Temperature, Depth (CTD) sensor, and either turbidity sensors or multiparameter sondes. Deployments will occur for 8 weeks duration for acoustic sensors. Tilt-current meters, optical backscatter sensors, spotter buoys and water quality sensors may be deployed up to 12 months.

Why: Wave height and tidal currents are being measured to quantify how the submerged stabilization structures alter nearshore wave and current fields. This metric is useful for assessing whether the project is achieving two of the primary goals of mitigating wave energy and promoting sediment accretion.

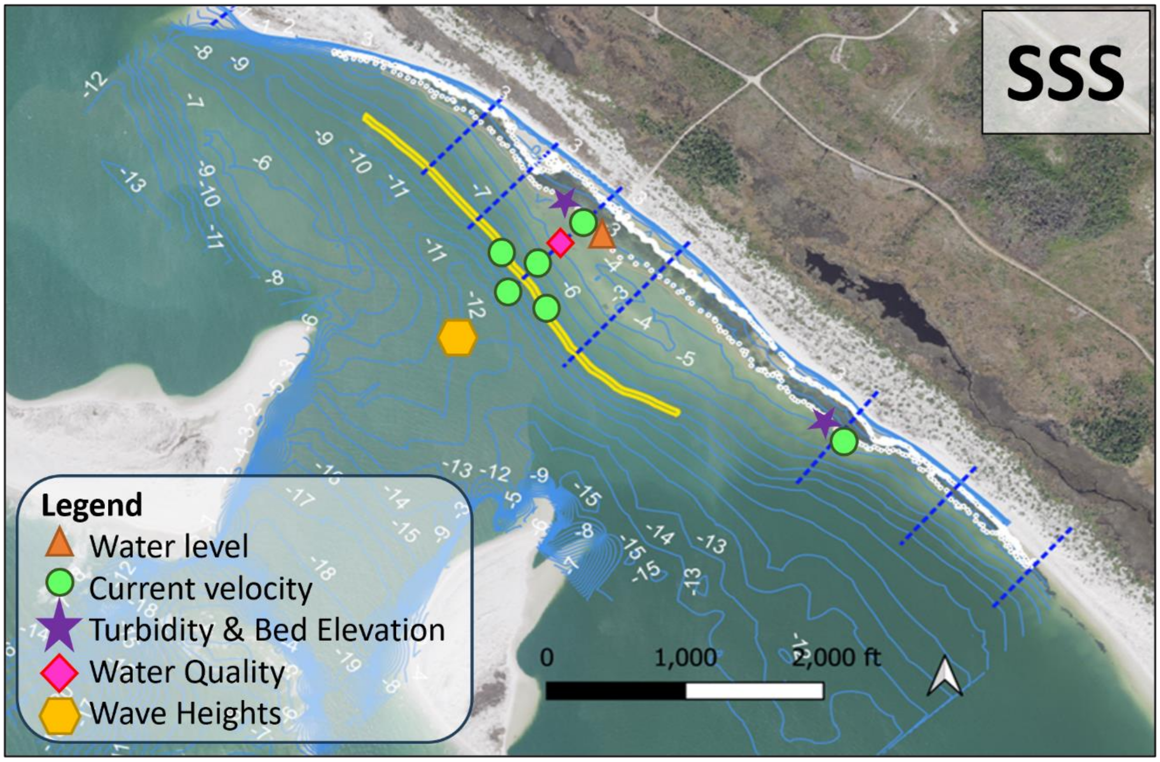

Fig 13. Proposed configuration of instruments to be deployed by NRL.

5. Monitoring Schedule

Table 6. Monitoring event schedule. Oyster density, invertebrates and vegetation monitoring will occur during the growing season (June-September).

Metrics	preconstruction	Within 6 months postconstruction	1yr post const.	2yr post const.	3yr post const.
Reef areal dimensions	-	1x	1x	1x	1x
Reef height	-	1x	1x	1x	1x
Reef rugosity	-	1x	1x	1x	1x
Oyster density	-	1x	1x	1x	1x
Oyster shell height	-	1x	1x	1x	1x
Density of sessile invertebrates (DI)	-	1x	1x	1x	1x
Percent cover of reef substrate (by type)	1x-	1x	1x	1x	1x
Water quality	Continuous	Continuous	Continuous	Continuous	Continuous
Shoreline position	1x	1x	1x	1x	1x
Topo-bathymetric profile	1x	1x	1x	1x	1x
Marsh waterward extent	1x	-	1x	1x	1x
SAV areal extent	1x	-	1x	1x	1x
Percent cover of SAV (by species)	1x	-	1x	1x	1x
Wave height and tidal currents	1x	1x	1x	1x	1x

6. Data Collection/Data Management

6.1 Logbooks

Every field survey team will keep a written or digital log of daily survey activities using a Rite-in-the-Rain logbook or spreadsheet. Complete and accurate logbooks are important for the following reasons:

- To ensure that data collection associated with field activities is sufficient to support successful completion of the project;
- To provide sufficient information so that someone not associated with the project can independently reconstruct the field activities later;
- To maintain quality control throughout the project;
- To document changes to or deviations from the work plan;
- To fulfill administrative needs of the project; and
- To support any potential legal proceedings.

Logbooks will meet the following criteria:

1. Pages will be consecutively numbered.
2. No pages will be removed for any reason, even if they are torn.
3. All field activities will be recorded or referenced.
4. All information will be legibly PRINTED in waterproof ink.
5. Corrections or changes will be made by <u>drawing a single line</u> through the entry (so it is still legible) and initialing the change or correction.
6. Entries should be made in logbooks as they occur. If this is not possible, the entries will be recorded as soon as possible thereafter, and the date and time of the notation will be recorded in addition to the time of the observation.
7. A single line will be drawn through the last line of each page in the logbook and then signed by the team member that recorded the data on that page. On the last page of each day's field activities, a single line should be drawn diagonally through any remaining blank lines on the page and then signed by the field team member that recorded data in the logbook.
8. Each successive daily entry will begin on a new blank page.
9. If a field team completes more than one logbook, each logbook will reference the existence of all other logbooks for the team (e.g., Book _ of _).
10. At the completion of each team's field effort, logbooks will be returned to the permanent project file and will not be used by other teams, regardless of how many blank pages remain.

The following information will be recorded in the logbook:

1. Title Page (first page of logbook)
    - Project name
    - Project number (i.e., billing code)
    - Team number
    - Team member names
    - Start/finish date
    - Book __ of __
2. First Page of Each Day

- Project number (top of the page)
- Project name (top of the page)
- Date (top of the page)
- Team number
- Team member names
- Discussion of daily safety meetings
- Proposed daily work summary (task and work locations)
- Weather
- Time of departure from the marina (or land-based meeting location, if traveling by land) on a 24-hour clock
- Time of arrival on site

3. Successive Pages
    - Project number (top of the page)
    - Date (top of the page)
    - Data and observations (including any phone conversations or meetings)
    - Signature of observer (at the bottom of the page)
4. Final Page of the Day
    - Project number (top of the page)
    - Date (top of the page)
    - Data and observations
    - End weather
    - Departure time from the field and arrival time back at the marina (or land-based meeting location), on a 24-hour clock
    - Signature of team member keeping the logbook
5. Documentation includes logging specific activities undertaken and their associated time of occurrence. After each transect line ID is written in the logbook, the team member will draw a box around it so that it stands out from other text. Examples of field survey documentation activities include:
    - Data sheet summaries
    - Persons contacted and discussions
    - Changes in instructions or activities that occur on site
    - Changes in weather conditions
    - Unusual features observed on Project or Control sites
    - Deviations from this Project Monitoring Plan and reason for the deviation
6. For logbook signatures, teams will ensure that:
    - Each page is initialed by the person making the last entry
    - When two or more individuals make entries on the same page, they both initial their entries
    - The last page for each day is signed by the team member keeping the logbook
7. For logs of transect line IDs and associated photos taken in the logbook:
    - Within the daily activities of the logbook, a log will be created where transect line IDs can be listed in chronological order of their collection. A brief description of transects will be included, as well as a description of any associated photos. This log will provide a quick, easy guide to data collected throughout the field rotation, and will be scanned and submitted to the E & E Project Manager daily, in lieu of a type-written daily log.

- In the logbook, a log of photos taken will be created. The team member will chronologically list all photos taken, and will include the associated transect line ID, a brief description, and the cardinal (e.g., N, S, E, W) or intermediate (e.g., NE, SE, NW, SW) direction of photo. This log will provide a quick, easy guide to photos collected throughout the field rotation, and will be scanned and submitted to the E & E Project Manager daily, in lieu of a type-written daily log.

Following each survey day, the field team will check the logbook against digital data sheets and global positioning system (GPS) data for accuracy for daily quality assurance/quality control (QA/QC). Teams will make a scan of all logbook pages daily and will verify that each scanned page is legible and includes the page number. These scanned copies will then be uploaded to the project folder, along with the remainder of the field team's daily data.

The field team will continue to use the same logbook for the duration of the project, or until all pages have been used. After a logbook is completed, the completed logbook will be returned to the project manager and added to the project file.

6.2 Data Collection/Data Management

(1) The types of data, software, and other materials to be produced.

In this project, the project team will collect data on response variables of several types: hydrodynamic (e.g., pressure, velocity, depth), geospatial data (e.g., land/bottom cover, ground/reef elevation), and biological (e.g., seagrass cover and height, oyster cover, size, and biomass, invertebrate abundance). Types of data and materials will include data sheets, field notes, GPS data, DGPS data, sonar image recordings, elevation / bathymetric measurements, video recordings and photographs.

(2) How the data will be acquired.

Data will be acquired using established methods available in peer-reviewed journals and published protocols as described in the monitoring plan above.

(3) Time and location of data acquisition, if scientifically pertinent.

Field data will be collected primarily in the main study in the vicinity of Tyndall Air Force Base including wetlands, constructed reefs, seagrass meadows, and bare sediment. Data will be collected at the specific project sites, and their associated control and references areas, as detailed in the monitoring plan above. Timing of data collection will be determined by seasonal dynamics, where possible (e.g., plant biomass will be measured within the relevant growing season.

(4) How the data will be processed.

Data will be processed according to standard techniques from the published literature. Data will first be QA/QC'ed as described below. Data will then be organized and formatted for export into analytical software. Tabular data will then be processed and analyzed using basic data management software (e.g., MS excel) and statistical software (e.g., R). Sonar data will be processed using 3rd party sonar mosaicking software (e.g., CTI SonarWiz, QPS Qimera). Geospatial data will be processed using geospatial software (e.g., ESRI ArcGIS).

(5) The file formats and the naming conventions that will be used.

Data will be stored in .csv, .asci or other relevant file formats. Ecological data will be recorded in field notebooks, entered into an electronic format, and saved as Microsoft Excel (.xlsx) and Comma Separated Value (.csv) files. Sonar and geospatial data will be saved in raster (e.g., geotiff), vector (.shp), .csv, or .asci files. Naming convention will be established by PIs before start of project using the CalTech process (https://authors.library.caltech.edu/records/mmnpf-cez11). Briefly, file names will include project name, data type, PI, and date in YYYYMMDD format.

(6) A description of the quality assurance and quality control measures during collection, analysis, and processing.

Once entered on the computer, the PIs will work with project staff to cross check all notebook and electronic data and at least two researchers will review each file for accuracy before it is uploaded to OneDrive, the University of Florida's cloud-based storage service, or NRL's internal servers. Data will be QA/QC'ed visually and using statistical techniques (e.g., to examine completeness of times series, evaluate existence of outlier values, and test distribution of values against standard samples and manufacture tolerances.)

(7) A description of dataset origin when existing data resources are used.

Geospatial data resources including land cover imagery from satellite and air-borne platforms will be acquired from public and commercial sources (e.g., Google Earth, Florida Fish and Wildlife Conservation Commission).

(8) A description of the standards to be used for data and metadata format and content.

Metadata, developed using the metadata templates provided by Georgia Coastal Ecosystems LTER (https://gce-lter.marsci.uga.edu/portal/), will also be created for all data recorded in the proposed project. Briefly, all files will include meta-data information on the date of collection, individuals who collected the data, site identification information, a summary of methods, units of measurement, and the equipment used to acquire the data.

(9) Appropriate timeframe for preservation.

All data will be saved in appropriate file types on laboratory computers and on external hard drives. All data will also be uploaded to OneDrive, the University of Florida's cloud-based storage service where it will be retained in perpetuity, or to NRL's internal servers where it will be retained in perpetuity. Original field and lab notebooks will be titled, data, scanned and stored in the PIs' laboratory. Monitoring data will also be uploaded, archived, and shared through **NFWF's Coastal Resilience Open Data Platform** within 2 years of acquisition or at the time of publication, whichever comes first.

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8. Health and Safety

Water quality hazards: Runoff from the airfield and other TAFB facilities enters the project areas. Water samples will be collected quarterly to assess health risks and necessary health mitigation steps. Full body wetsuits and dry suits (when possible) will be used by personnel spending extended periods of time in the water to reduce any exposure from the base runoff.

Harmful wildlife: As with all coastal waters, there are risks of harmful wildlife, including sharks and rays. Basic safety recommendations include avoiding murky water, deep channels and drop-offs, and areas where people are fishing or cleaning fish. Field personnel should shuffle feet while walking in water and avoid being in the water at sunrise and sunset.