Developing an Integrated Monitoring and Evaluation Framework: Evaluating Success of Land-Based Sources of Pollution Management on Culebra Island, Puerto Rico

April 2021

Developed by NOAA's Restoration Center and Coral Reef Conservation Program in collaboration with our partners

ACKNOWLEDGMENTS

This document was prepared by Lisa Vandiver[1], Kris Kaufman[1], Susie Rice[2], Rob Ferguson[2], and Leanne Poussard[2].

Special thanks to the Subject Matter Experts for their feedback, contributions to content, and ongoing support to refine and enhance the outcomes of this Monitoring and Evaluation Framework. These experts include: Abimarie Otaño-Cruz[3], Ana Roman[4], Angel Melendez[5], Anne Kitchell[6], Aurora Justiniano[2], Carlos Ramos[7], Chris Jeffrey[8], Curt Storlazzi[9], Dave Whitall[8], Dave Eslinger[10], David Cuevas[11]; Edwin A. Hernández-Delgado[3], Don Field[8], Eileen Alicia[2], Erica Towle[12], Ernesto Diaz[5], Francisco Pagan[2], Grace Robiou[11], Hudson Slay[11], Izabela Wojtenko[11], Jaime Lopez[11], Jennifer Koss[2], Jessica Tipton[13], John McCombs[10], Julia Royster[1], Kaitlyn Brucker[11], Kim Edwards[8], Mariana Quiñones Rosado[14], Mark Finkbeiner[10], Melissa Gonzalez[14], Michael Nemeth[1], Michelle Pico[15], Mike Wessel[16], Miguel Canals[17], Miguel Figuerola[5], Nate Herold[10], Nicolas Gomez[3], Nicholas Rosenau[11], Nigel Pickering[18], Polly Hicks[1], Ricardo Colon[5], Roberto Viqueira[14], Sarah Groves[8], Sean Griffin[1], Shan Burkhalter[10], Shay Viehman[8], Shelby Butz[11], Susan Silander[4], Tania Metz[5], Tim Battista[8], Tom Moore[1], Trent Biggs[19], and William Hernandez.[20] Additional thanks to Stephanie Robinson[10] for her facilitation services which, undoubtedly, led to successful meetings.

This framework would not have been possible without the past and ongoing support from our partners in restoration including: Protectores de Cuencas, Horsley Witten Group, Ridge to Reefs, Sociedad Ambiente Marino, CORALations, Municipality of Culebra, Autoridad de Conservación y Desarrollo de Culebra, Puerto Rico's Department of Natural and Environmental Resources, United States Fish and Wildlife Service, and National Fish and Wildlife Foundation.

---

[1] NOAA Restoration Center

[2] NOAA Coral Reef Conservation Program

[3] Sociedad Ambiente Marino

[4] United States Fish and Wildlife Service

[5] Puerto Rico's Department of Environmental and Natural Resources

[6] Horsley Witten Group

[7] University of Texas - Austin

[8] NOAA National Center for Coastal Ocean Science

[9] United States Geological Survey

[10] NOAA Office for Coastal Management

[11] United States Environmental Protection Agency

[12] NOAA National Coral Reef Monitoring Program

[13] Clemson University

[14] Protectores de Cuencas

[15] National Fish and Wildlife Foundation

[16] Inferential Consulting

[17] Caribbean Coastal and Ocean Observing System (CariCOOS)

[18] Washington State University

[19] San Diego State University

[20] University of Puerto Rico

TABLE OF CONTENTS

GLOSSARY OF ACRONYMS

Autoridad de Conservación y Desarrollo de Culebra (ACDEC)
Best Management Practices (BMPs)
Caribbean Coastal and Ocean Observing System (CariCOOS)
Chlorophyll a (Chl a)
Colored Dissolved Organic Matter (CDOM)
Crustose Coralline Algae (CCA)
Floating Treatment Wetlands (FTWs)
Habitat Focus Area (HFA)
Horsley Witten Group (HWG)
Land-Based Sources of Pollution (LBSP)
Monitoring and Evaluation Framework (M&E Framework)
Multiple Lines of Evidence (MLE)
National Coral Reef Monitoring Program (NCRMP)
National Fish and Wildlife Foundation (NFWF)
National Oceanic and Atmospheric Administration (NOAA)
NOAA Coral Reef Conservation Program (NOAA CRCP)
NOAA National Center for Coastal Ocean Science (NOAA NCCOS)
NOAA Office of Habitat Conservation (NOAA OHC)
NOAA Restoration Center (NOAA RC)
Photosynthetic Active Radiation (PAR)
Protectores de Cuencas (PDC)
Puerto Rico's Aqueduct and Sewer Authority (PRASA)
Puerto Rico's Department of Natural and Environmental Resources (DNER)
Sociedad Ambiente Marino (SAM)
Subject Matter Experts (SME)
Suspended Solid Concentration (SSC)
University of Puerto Rico (UPR)
Total Nitrogen (TN)
Total Phosphorus (TP)
Total Suspended Solid (TSS)
U.S. Environmental Protection Agency (EPA)
U.S. Fish and Wildlife Service (USFWS)
U.S. Geological Survey (USGS)
U.S. Coral Reef Task Force (USCRTF)
Wastewater Treatment Plant (WWTP)
Watershed Management Plan (WMP)

EXECUTIVE SUMMARY

The current document provides an update on the ongoing effort to develop an Integrated Monitoring and Evaluation Framework that will provide the basis for evaluating success of land-based sources of pollution (LBSP) management on Culebra. In 2020, NOAA managers convened a group of subject matter experts (SMEs) for recommendations on cost-effective monitoring approaches to collect data to inform evaluation questions and determine LBSP management success. LBSP management outcomes and goals were identified across multiple spatial scales: BMP/Site, Watershed, and Nearshore Ecosystem (Table 1). Corresponding evaluation questions were used to select indicators that are most sensitive to LBSP threats and, therefore, are most likely to provide meaningful data (over time and space) to address the questions. In addition, methodological considerations were discussed for each indicator. Using a Multiple Lines of Evidence (MLE) approach, it is anticipated that priority indicators could be monitored to collectively evaluate ecosystem response to LBSP management actions on Culebra (Lenwood and Giddings 2000).

Existing data gaps - particularly in the nearshore ecosystem - highlight the need for additional investigations to inform the development of a comprehensive, integrated M&E Framework. These investigations will provide crucial information for developing long-term monitoring plans but will also cause short-term delays to setting baselines in the nearshore ecosystem. NOAA is developing and funding investigations to:

- **Identify priority locations for fixed-site monitoring** that will provide the greatest opportunity for detecting change over space and time as a result of LBSP management actions
- **Determine the scope and scale of nearshore monitoring required** to provide the greatest potential for detecting change over time, while minimizing costs, to ensure commitment to long-term monitoring to evaluate success of LBSP management actions
- **Develop a range of funding levels and monitoring outcomes** that provides the structure needed to evaluate LBSP management success at modest funding levels (i.e., monitor changes in stressors) while providing aspirational monitoring goals (i.e., monitor changes in habitat response) to encourage partnerships to advance integrated monitoring across multiple spatial and temporal scales.

Together, this information will provide the details needed for understanding the full breadth and depth of monitoring needed to evaluate (and detect) change over space and time. It is anticipated that these analyses will be completed within 6 months to 1 year.

This document also identifies initial monitoring priorities at BMP/site, watershed, and nearshore spatial scales to establish baselines and track changes to LBSP stressors, pollutant exposure, and habitat response. Funding has been acquired to monitor a subset of priorities for at least one year (Appendix A). In summary, the tasks and studies funded will establish identify priority fixed stations for monitoring LBSP stressors, pollutant exposures, and seagrass habitat response over time. These sites will represent a range of LBSP stressors and management levels to inform baseline benthic habitat risk assessments while also assisting in the identification of potential ecological tipping points. Funding has also been secured to collect data at these sites for at least one year to provide metrics for tracking LBSP stressors and pollutant exposures (i.e., water quality, sedimentation) through time. This information, combined with the implementation of LBSP management actions, will provide the basis for evaluating project success and identifying maintenance needs and/or corrective actions. In addition, this data will support the development of a baseline for our restoration sites (and downstream drainage areas) while also highlighting potential metrics and tipping points at which a cumulative LBSP stressors lead to measurable increases in coastal habitat exposure. Ideally, funding and/or resources for seagrass habitat monitoring would be secured in the near future to allow for integrated monitoring across LBSP stressors, pollutant exposures, and seagrass habitat response within the same time frame. This data, combined with stressor and exposure data, would allow managers to begin to develop linkages among stressors, exposures, and habitat metrics begin to identify potential ecologically-relevant targets for LBSP management actions.

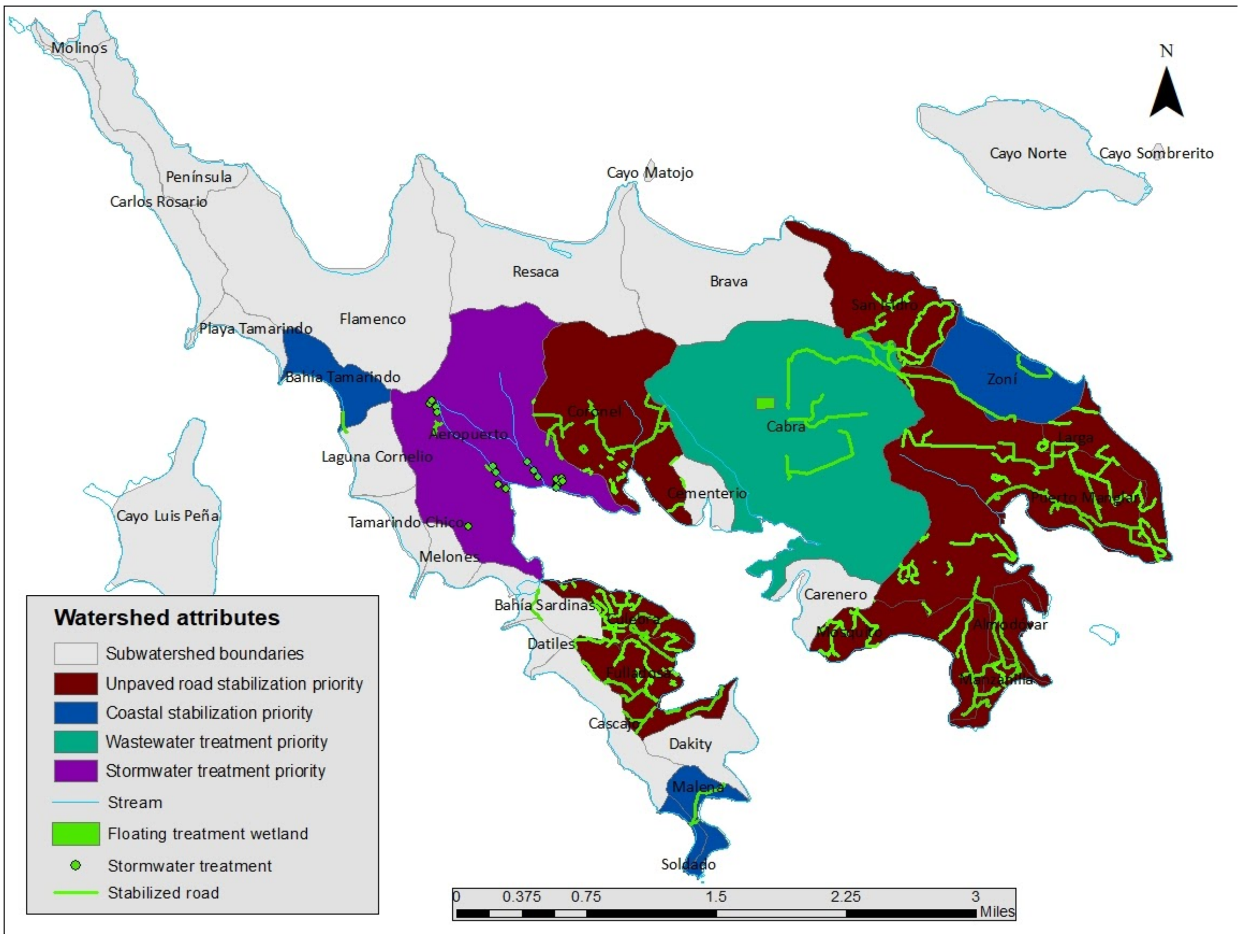
Although most of the M&E Framework has been drafted, there is still a need to ground-truth the recommendations highlighted within. Once this has been completed, the integrated M&E Framework should be complemented by a standardized approach for data management and data sharing amongst partners, as well as a means in which to identify and implement corrective actions or adaptive management.

PURPOSE

Ultimately, this document will outline an integrated Monitoring and Evaluation Framework (M&E Framework) to evaluate success of land-based sources of pollution (LBSP) management on Culebra towards the overarching goal of improving Culebra's nearshore coastal ecosystem. Implementation of the Framework will provide datasets that will be used to evaluate success of LBSP management actions and identify potential corrective actions needed; either in the design and implementation of Best Management Practices (BMPs) or as it relates to the scale of restoration needed to elicit a watershed- or coastal ecosystem-level impact. This Framework is being developed in collaboration with an interdisciplinary group of subject matter experts (SMEs) to ensure the monitoring and evaluation recommendations provided are relevant to LBSP management goals and incorporate existing knowledge about the Culebra ecosystem at large. Through engaging this group of SMEs in the development of this framework, the hope is to enhance awareness of data needs and the potential of finding novel, cost-effective partnerships for implementing the Monitoring and Evaluation Framework. Most importantly, this Framework will outline monitoring priorities for existing NOAA funding as well as opportunities for partners to enhance monitoring outcomes to evaluate LBSP management success across multiple scales**.** In its present state, the document provides a status update on the M&E Framework and includes updates regarding ongoing NOAA funded analyses to address data gaps. Monitoring recommendations provided in the Appendices are in varied stages of draft forms and should only be used to understand present thinking on various monitoring elements. We will continue to consult with SMEs to fully flesh out and review the content provided in the Appendices over time.

MANAGEMENT BACKGROUND

The coral reef ecosystems of Culebra are some of the more pristine habitats within the northeastern portions of Puerto Rico (Hernández-Delgado and Sabat, 2000). However, long-term monitoring has shown approximately 30 to 50% decline in percent coral cover in Culebra since 1986 (Hernández-Delgado et al. in preparation). Research suggests that the decline in coral cover may be associated with increased land-based sources of pollution (LBSP) resulting from recent coastal development (Ramos-Scharrón et al., 2012).



In 2013, Culebra's Integrated Watershed Management Plan (WMP) identified primary sources of pollution and opportunities for watershed restoration which established initial priorities for investments in LBSP management on Culebra Island. Through the use of the Watershed Treatment Model and *in situ* Illicit Discharge, Detection, and Elimination methods, unpaved roads, failing septic systems and the Culebra wastewater treatment plant (WWTP) were found to be primary contributors of sediment and nutrient loads into Culebra's nearshore coastal ecosystem respectively. In 2014/2015, Culebra was designated as part of the Caribbean region's Habitat Focus Area which provided opportunities to 'scale up' LBSP management and provide measurable benefits to coastal habitats and resources. NOAA, in turn, re-evaluated the actions identified in the WMP and prioritized LBSP management investments on those that could provide measurable outcomes. In general, these actions included: stabilizing bare soils and 28 miles of unpaved roads, stabilizing and reducing impacts on the coastal zone, enhancing stormwater treatment in areas prone to pollution, and working with Puerto

Rico's Aqueduct and Sewer Authority (PRASA) to design and implement tertiary treatment at the WWTP. NOAA's investments across these four actions (i.e., unpaved road stabilization, coastal stabilization, stormwater treatment, and wastewater treatment) were targeted to those locations which would provide the greatest pollutant reduction and benefit to coastal resources (see Figure 1). These actions are underpinned with the need to work closely with the municipality of Culebra and the community to enhance long-term stewardship of the island and its coastal resources. This includes providing tools (like education, training, development standards) to practitioners, municipal staff, and homeowners to ensure long term maintenance of the actions implemented on the island.

Through a combination of National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Conservation Program (CRCP), Restoration Center (RC), and Office of Habitat Conservation (OHC); U.S. Fish and Wildlife Service (USFWS); Puerto Rico's Department of Natural and Environmental Resources (DNER), and National Fish and Wildlife Foundation (NFWF) funding, 55% of NOAA's LBSP management priorities have been installed with 100% of the priorities funded to date. Since NOAA CRCP's initial investment in LBSP management practices on Culebra in 2011 NOAA and partners have been able to: stabilize 15.1 miles of unpaved roads, prevent approximately 51 metric tons of sediment delivery to the nearshore coast per year, train and employ Culebra municipal staff to maintain these roads, develop and implement BMP maintenance agreements with landowners, and develop unpaved road standards and guidance manual for the Caribbean. This work by NOAA and partners has resulted in altering the communities Island-wide perception of 'unpaved road' construction where private landowners are now requesting construction of roads that meet these new standards.

Despite these LBSP management successes, NOAA has had limited ability to quantify the ecological benefit of these investments. Historically NOAA has allocated less than 3% of project funds toward monitoring which has been insufficient for collecting data needed to evaluate performance of management actions (Appendix A). In addition, the LBSP management approach requires a combination of BMPs (or treatment train) to divert flow off of erodible surfaces, slow flow down, promote infiltration, and - where possible - trap sediments on site. This treatment train limits the direct measurement of BMP performance, as there are no well-defined locations to measure pre- vs post-implementation sediment loads. Therefore, evaluations of BMP effectiveness require a suite of spatially and temporally integrated measurements through empirical experiments, hydrologic and sediment modeling, combined with in situ field monitoring. Initial investments in monitoring highlight the need for an integrated monitoring approach to evaluate the performance of LBSP management investments on the island.

FOUNDATIONS FOR A MONITORING AND EVALUATION FRAMEWORK

An integrated monitoring framework to evaluate LBSP management success and identify adaptive management needs requires a foundation of information, including:

- Conceptual Benthic Habitat Risk Assessment for Target Pollutants
- Management Theory of Change
- Management Goals, Outcomes, and Evaluation Questions
- Develop Monitoring Protocols that are Most Sensitive to Management Actions
- Multiple Lines of Evidence to Evaluate Management Success

Foundational information, and the status of our current knowledge, is described further in the following sections.

Conceptual Benthic Habitat Risk Assessment for Target Pollutants

It is well known and understood that land-based sources of pollution have both direct and indirect adverse impacts to seagrass and coral reef habitats. Coastal development and tourism are the primary source of pollutant **stressors** on Culebra (Figure 2)**.** In particular, construction on the island alters the natural land cover to bare soils and unpaved roads which are particularly vulnerable to erosion. In addition, undertreated sewage from the Culebra Wastewater Treatment Plant, septic systems, and vessels are sources of pathogens and nutrients which is exacerbated with increased population densities during tourist seasons. These land alterations result in increases in stormwater runoff and sewage discharge resulting in increased sediment and nutrient loads into receiving coastal waters bodies. Increases in stressors from the land, result in increased pollutant **exposure** in the coastal environment resulting in physical and chemical changes. These changes include impairments to water quality, such increases in pollutant concentrations, associated increases in light attenuation, and decreases in water clarity. In addition, increases in terrigenous sediment discharged into coastal waters alters benthic substrate and can physically smother benthic habitats. Once the pollutant exposure reaches a certain point, it will elicit a habitat and/or resource **response**. Oftentimes these pollutant thresholds are mediated by site specific conditions such as residence time, legacy contamination, and other external factors. In general though, once these exposure levels are exceeded you can anticipate ecosystems responses such as algal blooms, decreases in seagrass health and abundance, and decreases in coral health and abundance.

CONCEPTUAL MODEL OF IMPACTS

<table>
<tr><th>STRESSOR
(Coastal Development)</th><th>EXPOSURE
(Physical / Chemical Changes)</th><th>RESPONSE
(Habitat and Resource Changes)</th></tr>
<tr><td>Increased population density</td><td rowspan="3">Impaired nearshore water quality
• < Water clarity
• > Light attenuation
• > Suspended Solids
• > Turbidity
• > Nutrients (N, P)
• > Microbial contamination</td><td>Increased chlorophyll a</td></tr>
<tr><td>Altered land cover
• > Bare soils
• > Unpaved Roads</td><td rowspan="2">Decreased seagrass health and abundance
• > Epiphytic growth on seagrass
• > Macroalgal cover
• < Seagrass cover
• < Shoot density
• < Deep edge of seagrass bed
• < Habitat area</td></tr>
<tr><td>Undertreated sewage
• WWTP
• Septic
• Vessels</td></tr>
<tr><td>Increased pollutant (sediment, nutrient, microbial) load
• > stormwater runoff
• > sewage discharge</td><td>Increased terrigenous sedimentation</td><td>Decreased coral health and abundance
• < Live coral cover
• > Macroalgal cover
• < Coral recruitment
• < Coral biodiversity
• > Colony mortality?</td></tr>
</table>

Figure 2: Benthic Habitat Risk Assessment which provides the conceptual understanding of the sources of pollutant stressors, resultant physical and chemical changes to coastal environment from pollutant exposure, and associated habitat and resource response.

Although the conceptual model of LBSP impacts is generally understood, there is a need to collect data to inform our understanding between the linkages of stressors, exposures, and response for Culebra.

This information, collected along a spectrum of LBSP stressors, can serve as a good baseline for our restoration sites while also highlighting potential metrics and tipping points at which a stressor leads to coastal habitat exposure and exposure leads to habitat response. This information, combined with Culebra's LBSP management actions, can begin to inform potential ecological targets for our restoration.

Management Theory of Change

The risk assessment model provides a framework for understanding how pollutants are impacting Culebra's coastal habitats. This then informs how and where we prioritize watershed restoration to reduce pollutant loadings (or stressors). Through targeted restoration we hope to see measurable reductions in pollutant exposures over time and ultimately an improvement in the physical and chemical environment along the coast. This, in turn, should result in improvements to the nearshore seagrass and coral reefs habitats - and the resources that depend on them (Figure 3). These linkages between pollutant reductions and nearshore coastal ecosystem response provide the basis for the development of management goals and outcomes across space and time.

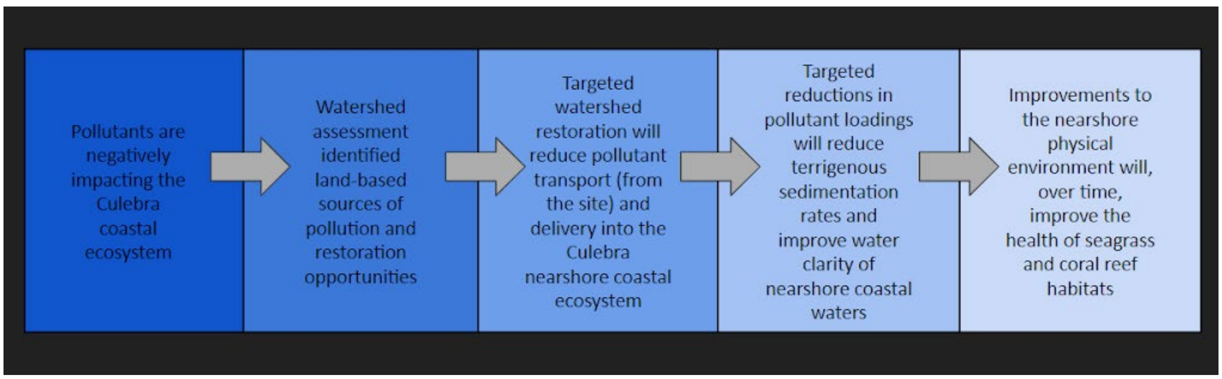


Figure 3: Theory of change which establishes the conceptual framework for the rationale of how management of land-based sources of pollution on Culebra can reduce stressors and resultant coastal habitat exposures to improve coastal habitats and make them more resilient to future threats.

Management Goals, Outcomes, and Evaluation Questions

Table 1 outlines the LBSP management outcomes and goals to reduce pollutant stressors from land to reduce pollutant exposures in coastal environments to elicit a change in habitat response. In summary, by 2025 pollutant stressors will be reduced through implementation of all of the NOAA priority LBSP management actions. Given the likelihood of legacy contamination, it is anticipated that there will be a lag between the reduction in stressors delivered from the land to a reduction in pollutant exposures in the coastal environment. For planning purposes, improvements to coastal water quality and reductions in terrigenous sedimentation were assumed to occur by 2030. Similarly, it is anticipated that there will be a lag between the reduction in pollutant exposures and the corresponding habitat response, which is assumed to occur by 2035. Evaluation questions were developed for each of the goals to provide a means of assessing change over time and ultimately evaluating success towards our management outcomes and goals. The management goals, outcomes, and evaluation questions were used to guide decision-making on those measurements (indicators, locations) that will be most sensitive to detecting change in LBSP threats over time and space.

Develop Monitoring Protocols that are Most Sensitive to Management Actions

LBSP pollutant sources and associated management actions are diffuse throughout Culebra's landscape. Furthermore, the island is ephemeral which means that pollutant delivery is largely event-based and variable over time and space. Subsequently it is particularly important to prioritize monitoring components early on to focus on those components of a monitoring framework that are most sensitive to LBSP threats to enhance the ability to detect change - over time and space – in response to LBSP management actions. These elements include:

- Identifying priority **indicators** that are sensitive to LBSP threats
- Identify **locations** most likely to detect changes in LBSP threats over time
- Identify **sample timing** (frequency, duration, seasonality, sample size, etc.) that capitalizes on those times that will be most sensitive to detecting changes in LBSP stressors, exposure, and responses over time

Development of these components of the monitoring protocol will require data collection and analyses which will be summarized and incorporated into the framework as they are completed. The general approach, and status, to building out these foundational components to the monitoring protocols are described in the corresponding sections below.

Priority Monitoring Indicators

In 2020, NOAA managers hosted a series of webinars to gather subject matter experts (SME) to identify priority indicators for all evaluation questions and discuss methodological considerations for monitoring the priority indicators. Through the use of working groups, SME's were asked to identify those parameters that are most sensitive to LBSP threats and therefore priority indicators for addressing management evaluation questions (Table 1). The indicators provide a measurable proxy for quantifying changes in stressors, exposures, and responses over time to evaluate management success. Stressor reduction will be quantified by comparing site-specific measurements of indicators between pre- and post-restoration. However, changes in pollutant exposure and corresponding changes in habitat response will be evaluated through comparisons of site-specific measurements of indicators at 'restored' sites to 'reference' sites. If measures of indicators at 'restored' sites are trending toward 'reference' sites this would suggest that pollutant exposures and habitat responses are improving as a result of management actions. Therefore, establishing baseline conditions of stressors, exposures, and responses will be key to the ability to successfully evaluate management success over time.

These indicators fall under one of two types: project tracking or effectiveness. Monitoring of project tracking indicators allows a level of quality assurance for project implementation and evaluates whether the project was executed as designed. Monitoring of effectiveness indicators provides the opportunity to evaluate physical and biological changes related to LBSP management overtime and identify any needs for corrective actions. In summary, changes in stressors will be assessed through both project tracking (area stabilized, percent function) and effectiveness indicators (nutrient and sediment load reduction), while changes in exposure and response will be monitored through effectiveness indicators only.

Priority Monitoring Locations

Monitoring of priority indicators should occur at fixed-site monitoring locations - across multiple spatial scales - with some consistent frequency and duration to provide the data necessary to evaluate success of LBSP management efforts on Culebra. Identification of priority fixed-site monitoring locations at the site-, watershed-, and nearshore-scales will be key to (1) ensuring the greatest opportunity for detecting change over space and time and (2) coordinating monitoring across space and time to evaluate LBSP success at multiple spatial scales.

Priority fixed-site monitoring locations will be identified largely based on the proportion of restoration relative to the watershed and the timing of restoration implementation. Those watersheds - and receiving nearshore ecosystems - with the greatest proportion of restoration relative to the watershed area (and pollutant source) and sequencing of restoration actions that provide adequate time for baseline monitoring will provide the greatest opportunity to evaluate response to watershed restoration over time. The area, and proportion pollutant source, being treated by unpaved road stabilization and wastewater treatment (i.e. Floating Treatment Wetlands), relative to other LBSP management actions, are likely to elicit a watershed scale response (Figure 2). *Subsequently unpaved road stabilization and wastewater treatment are priorities for monitoring, at all spatial scales, to evaluate the success of LBSP management across Culebra.*

Additional considerations, and ongoing efforts, to identify priority fixed-site monitoring locations at the BMP, watershed, and nearshore-scales are detailed in the corresponding sections below.

Priority BMP and Watershed fixed-site monitoring locations

Priority BMP and watershed monitoring locations should be identified to evaluate BMP (i.e., unpaved road stabilization, floating treatment wetlands) and watershed pollutant reduction efficiencies of LBSP management strategies over time. To the degree possible, identification of priority monitoring locations should consider the potential to build off of existing BMP and watershed scale data to ensure cost-effective monitoring approaches while addressing key data gaps. For BMPs, monitoring at sediment ponds and the floating treatment wetlands provide a logistically feasible opportunity for monitoring that would enhance existing monitoring efforts. At the watershed scale, Culebra (Punta Aloe), Fulladosa, and Almodova (Punta Del Viento) have been the focus of previous monitoring efforts to evaluate the success of unpaved road stabilization efforts. It is likely that additional watershed monitoring and modeling in these locations would provide the most cost-effective opportunity for advancing our understanding of watershed-scale effectiveness of unpaved road stabilization. However, a more thorough analysis of unpaved road stabilization watershed priorities should be conducted to determine whether other watersheds have more distinctive drainage points and offer better opportunities for watershed-scale monitoring. Lastly, the Cabra subwatershed is the target for nutrient management strategies (i.e., Floating Treatment Wetlands) implemented at the Culebra WWTP which drains into the only stream on the island with permanent baseflow. Subsequently, the Floating Treatment Wetlands (FTWs) and the corresponding stream will be nutrient monitoring priorities for Culebra.

Priority Nearshore fixed-site monitoring locations

Determining the results of watershed and site-level BMPs implementation on receiving nearshore habitats is complex, crossing multiple ecological boundaries, and once in the marine environment the signal from watershed restoration activities may be difficult to detect. However, monitoring priority indicators in the nearshore environment will be key to determining whether the scale of restoration is adequate to elicit nearshore environmental responses. To provide the greatest potential to detect change in the nearshore environment, as a result of LBSP management, over time, fixed monitoring locations should be identified. These fixed-sites should be located where the inputs from the watershed are most persistent so that any change in the nearshore resources can be attributed to runoff regimes that have been altered by restoration efforts on land. This requires an understanding of watershed hydrology and coastal hydrodynamics as well as the level of existing level LBSP exposure and anticipated changes to LBSP exposure due to management actions.

Remote analyses have been completed and site visits are pending to confirm and refine preferred nearshore fixed stations that are co-located with seagrass habitat. These fixed stations represent a range of LBSP threats and management levels to allow for data collection that supports the development of a baseline habitat risk assessment which can then be used to evaluate change in stressors, exposure, and seagrass response over time. Once the nearshore fixed stations are finalized results from the studies and field surveys will be summarized and appended to this document to provide background on the rationale for site selection.

Sample Timing

Because there is a general paucity of nearshore data collected in Culebra, for the purpose of evaluating the success of LBSP management actions, there is a need to understand the scope and scale of nearshore monitoring needed to detect change over time. Informational needs related to scope and scale include the number of sample locations and frequency and duration of monitoring needed for any of the priority indicators listed in this Framework. NOAA managers are working with local researchers to identify existing and ongoing studies that can provide nearshore water quality, sedimentation, seagrass, and coral reef data from Culebra for analyses. These data will be evaluated via a series of statistical analyses and a power analysis to determine the number of sample stations (and frequency and duration of sampling) needed to provide a statistically rigorous data set to answer the management questions provided in this Framework. This information will then be used to define the minimum nearshore monitoring requirements including: the number of fixed locations and monitoring frequency and duration for priority indicators identified in this Framework.

Long-Term Commitment to Monitoring

A cost effective M&E Framework will provide an integrated plan that coordinates implementation of LBSP management actions and monitoring across LBSP stressors, pollutant exposures, and seagrass and coral habitat responses. However, evaluations of existing data and research programs, highlight the general paucity of existing monitoring programs and/or datasets integrated across stressors, exposures, and responses to serve as baseline data for evaluating success of LBSP management. That being said, there has been some LBSP stressor data which has generally been coordinated with implementation of BMPs and serve as a starting point for building out baseline datasets for the M&E Framework. However, pollutant exposure and habitat response data integrated with stressor data is relatively limited suggesting the need to prioritize nearshore exposure and response data collection that aligns with the site/BMP and watershed-scales. Fortunately there are a multitude of existing programs and research in the nearshore waters of Culebra that provide opportunities for leverage. Yet there is no existing framework that outlines detailed monitoring priorities to allow these programs and researchers to understand how they can collaborate to support the evaluation of LBSP management success in the nearshore.

The M&E Framework, and associated data needs, has been outlined to support a range of monitoring and evaluation outcomes as well as funding levels, with the ultimate goal of enhancing our understanding and effectiveness of LBSP management on coral reef habitats. At a minimum, funding should be provided to monitor LBSP stressors over time. Ideally, this would be coupled with monitoring of pollutant exposures and habitat responses in the nearshore to understand whether LBSP management actions are eliciting a benefit to NOAA's target resources and habitats. These funding and monitoring levels are generally described below (and highlighted throughout the rest of the M&E Framework).

LBSP STRESSOR MONITORING: This level of monitoring is likely achievable through existing - or a modest increase to existing - funding and partnerships to evaluate and answer the following questions: (1) What area has been stabilized? (2) What percent of the BMPs are functioning as designed? (3) Has pollutant transport - from priority BMPs - been reduced? (4) Has pollutant transport - from priority subwatersheds - been reduced? This level of monitoring will allow the evaluation of BMP and watershed-level success for a subset of management actions (unpaved road stabilization and floating treatment wetlands at the WWTP). This empirical data will allow watershed managers the ability to evaluate performance at the BMP and watershed level; however, there will be no ability to determine whether these actions have resulted in a coastal ecosystem response. This level of monitoring will be capable of determining the need for BMP and watershed level corrective actions, but will have no ability to determine whether corrective actions are needed to elicit a coastal level response. Preliminary recommendations are provided in draft form in Appendix B.

POLLUTANT EXPOSURE MONITORING: This level of monitoring is inclusive of the 'stressor' monitoring and will require targeted increases in funding and/or partnerships to evaluate and answer the following questions: (1) Have nearshore water quality conditions improved? (2) Has nearshore terrigenous sedimentation decreased? In addition to the 'minimum monitoring', nearshore monitoring will allow researchers to establish water quality and sedimentation baselines and track changes in these indicators to determine whether they are trending toward reference conditions at priority locations. This will allow managers to determine whether nearshore water quality and sedimentation goals have been achieved at priority locations and/or whether additional management actions are needed in the corresponding watershed to elicit an improved nearshore coastal response. Preliminary considerations are provided in draft form in Appendix C.

HABITAT RESPONSE MONITORING: This level of monitoring is inclusive of the 'stressor' and 'exposure' monitoring recommendations and will leverage partnerships and existing programs to evaluate and answer the following questions: (1) Have seagrass habitat conditions improved? (2) Have coral reef habitat conditions improved? This level of monitoring will allow researchers to establish fixed-station seagrass and coral reef baselines and track changes in these indicators to determine whether they are trending toward reference conditions. This will allow managers to establish reference-based seagrass and coral reef goals and determine whether those goals have been achieved at priority locations and/or whether additional management actions are needed in the corresponding watershed to elicit an improved nearshore coastal response. Given the extent of data collection and coordination, this level of monitoring would require additional project oversight, management, and evaluation to establish coordination among partners and a feedback mechanism to support adaptive management needs for Culebra Island. Preliminary considerations are provided in draft form in Appendix D.

Evaluate Management Success using Multiple Lines of Evidence

The United States Coral Reef Task Force Watershed Working Group is implementing a Multiple Lines of Evidence (MLE) approach relevant for coral reef ecosystems, originally developed by the U.S. EPA, to evaluate watershed restoration success in coral reef jurisdictions and has been used to guide the development of an M&E Framework for Culebra (Figure 4). In short, the cumulative weight of progress toward site, watershed, water quality, and benthic habitat improvements can be used to assess whether benthic habitat improvement has likely occurred - even if no statistical significance is detected. This approach requires fulfillment of the lines of evidence outlined below, and should be vetted by a panel of subject matter experts. In using this approach, it decreases the emphasis of determining success based on a single, statistically significant indicator, by spreading the evidence across multiple indicators that, combined, shows the conservation needle moving in the right direction. Furthermore, these lines of evidence align themselves well to the evaluation questions and priority indicators established for an integrated M&E Framework for Culebra (Table 1).

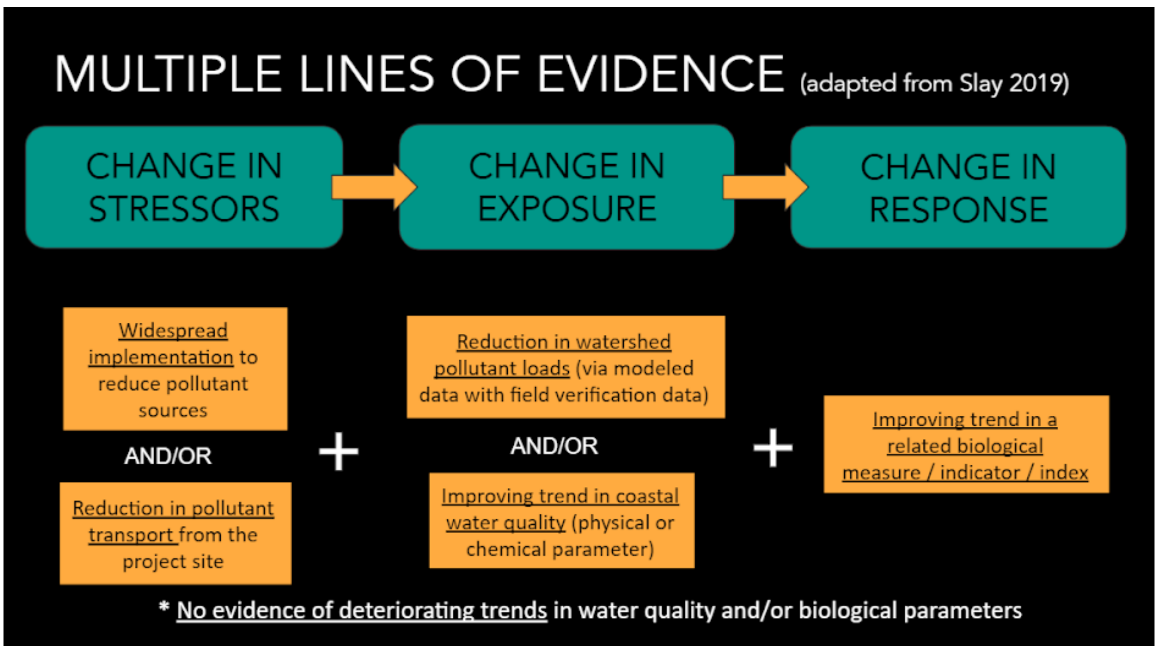


Figure 4: The Multiple Lines of Evidence (MLE) approach can be used to evaluate progress toward water quality, aquatic resource and/or watershed improvement. The cumulative weight of information can provide sufficient evidence to indicate improvement.

In addition to the information above, an evaluation using this approach should document support for any improving trends with valid scientific information, and include parameters or other indicators associated with the initial water quality/ecosystem problem. Information compiled must specifically identify:

- A rationale that describes how a determination of improved water quality is supported – including the type, quality, and amount of environmental data, and decision criteria. The rationale must identify the specific parameters used to assess improvements, and describe the efforts made to locate and analyze any evidence of deteriorating trends in these or related parameters.
- Data used in the assessment, and

- The results which demonstrate improvement.

This information should be reviewed by a panel of credible experts spanning a range of relevant disciplines to identify consistency with the theory of change (Figure 3) and to identify and explain exceptions.

ADDITIONAL CONSIDERATIONS

The M&E Framework provided here is intended to serve as a 'living document' that provides high level physical, chemical, and biological data needs that will allow for implementation of pilot monitoring projects and adaptation of the M&E Framework over time. The M&E Framework intentionally did not include socioeconomic components since this requires a different monitoring approach. Future adaptations to this framework should incorporate this component as it is key to sustainability and long-term success of investments to reduce LBSP threats on Culebra. This Framework - and associated monitoring and evaluation - should ultimately be combined with a program management and evaluation process to establish a feedback mechanism to support adaptive management needs for Culebra Island. Although not explicitly covered in this version, future versions should provide recommendations on data management, evaluation, and reporting.

LITERATURE CITED

Hernández-Delgado EA, Sabat AM. 2000. Ecological status of essential fish habitats through an anthropogenic environmental stress gradient in Puerto Rican coral reefs. Proc Gulf Caribb Fish Inst; 51:457–70.

Hernández-Delgado et al. in preparation. Provided in a presentation entitled 'Culebra Benthic Habitat Monitoring – SAM'. Culebra Monitoring and Evaluation Framework Webinar: Existing Research and Programs. July 24, 2020.

Jr, Lenwood & Giddings, Jeffrey. (2000). The Need for Multiple Lines of Evidence for Predicting Site-Specific Ecological Effects. Human and Ecological Risk Assessment. 6. 679-710. Doi: 10.1080/10807030008951334.

Ramos-Scharrón CE, Amador-Gutierrez J, Hernández-Delgado E, 2012. An interdisciplinary erosion 648 mitigation approach for coral reef protection- A case study from the Eastern Caribbean (Chapter 6). 649 In: A Cruzado (Ed.), Marine Ecosystems- InTech Publications, pp. 127-160.

Table 1. Summary of LBSP management goals, outcomes, and evaluation questions aligned with components of the risk assessment model (stressor, exposure, response). Priority indicators will be used to evaluate change between pre- and post-restoration as well as progress toward reference conditions. Together, this information will provide the evidence needed (MLE requirements) to evaluate change over time as defined in the Multiple Lines of Evidence approach.

RISK COMPONENT	GOALS	OUTCOMES	EVALUATION QUESTIONS	PRIORITY INDICATORS
STRESSOR	By 2025, 100% implementation of NOAA priorities AND reduction in sediment and nutrient loads from the site (2)	Stabilize unpaved roads and bare soils in priority subwatersheds	What area has been stabilized?	Area stabilized
		Stabilize and protect the coastal zone in priority locations	What percent of the BMPs are functioning as designed?	Percent function
		Install tertiary treatment at the Culebra WWTP	Has pollutant transport - from priority BMPs - been reduced?	Nutrient (TN, TP) and/or sediment load
		Enhance stormwater treatment in priority locations		
	By 2025, reduction in sediment and nutrient loads from priority subwatersheds	Reduce sediment and nutrient delivery from priority subwatersheds	Has pollutant transport - from priority subwatersheds - been reduced?	Nutrient (TN, TP) and/or sediment load
EXPOSURE	By 2030, improvements to Culebra's nearshore water quality and sedimentation	Improve nearshore water quality	Has nearshore water quality conditions improved?	Water clarity (Light attenuation, turbidity, SSC, TSS, chl a, CDOM, PAR), Nutrient concentration (TN, TP, Ammonia, Nitrate+Nitrite, Orthophosphate)
		Reduce terrigenous sedimentation rates	Has nearshore terrigenous sedimentation decreased?	Sediment constituent accumulation (Percent terrigenous, Sediment accumulation rate)
RESPONSE	By 2035, improvements to Culebra's nearshore seagrass and coral reef condition	Improve nearshore seagrass and coral reef habitat condition	Have seagrass habitat conditions improved?	Benthic cover, Shoot density Epiphyte load, Deep edge of bed, Areal extent, Growth rates
			Have coral reef habitat conditions improved?	Benthic Cover, Coral Species Composition, Coral Recruitment, Recent Colony Mortality

APPENDIX A - CURRENT FUNDING FOR MONITORING AND EVALUATION

From 2015 to 2019 NOAA's CRCP and RC invested approximately 3% of Culebra LBSP project funds to monitor the unpaved road BMPs to better understand their performance (Appendix A - Table 1). Stabilizing unpaved roads requires a combination of BMPs (or treatment train) to divert flow off of erodible surfaces, slow flow down, promote infiltration, and - where possible - trap sediments on site. This treatment train limits the direct measurement of changes in sediment delivery, as there are no well-defined locations to measure pre- vs post-implementation sediment loads. Therefore, evaluations of effectiveness require a suite of indirect measurements through empirical experiments, hydrologic and sediment modeling, and field monitoring. To date, funding has been pooled across multiple sources to: (1) Quantify runoff and sediment production for both unpaved roads and undisturbed hillslopes at the plot-scale, (2) Develop runoff and sediment production models for both unpaved roads and undisturbed hillslopes based on the empirical data; (3) For some of the erosion mitigation strategies that have been implemented (i.e., check dams within road ditches and detention ponds) quantify the rate of sediment accumulation/retention; and (4) Provide watershed-scale assessments of the sediment delivery potential both prior and following the implementation of erosion control practices. Preliminary results can be found here.

These initial monitoring efforts highlight the need for increased investment in the development and implementation of a comprehensive monitoring approach to evaluate the performance of LBSP management investments on the island. As a result NOAA increased its commitment to monitoring and evaluation on Culebra to assist in the development of a Monitoring and Evaluation Framework and to seed initial monitoring efforts on the island. Subsequently, NOAA's CRCP and RC has maintained its commitment to LBSP management on the island through additional indications of future funding towards monitoring and evaluation. This includes the development of a monitoring and evaluation framework that outlines the data needed to evaluate LBSP management success on Culebra Island, Puerto Rico. To date, the framework has been used to identify and fund monitoring priorities that are integrated with management priorities to enhance the ability to evaluate management success over time and space. Past and current investments are highlighted in Table 1 and described further in the corresponding text below.

Appendix A - Table 1. Monitoring to evaluate LBSP management success that provide additional data that will contribute towards our ability to evaluate success over time. * Future fiscal year contributions are estimates at this point, which will require congressional budget approvals prior to formal commitment of funds.

Reference number	Descriptive Title	Funding source	Fiscal Year	Funding
1	Establish nearshore coastal ecosystem baseline for evaluating LBSP management performance on NOAA trust resources	NOAA RC and NCRMP internal funding	FY14	$62,800
2	Determine pollutant Best Management Practice (BMP) performance	CRCP Internal funding	FY15 - FY18	$24,100
3	Quantifying sediment production from unpaved roads	OHC Habitat Blueprint Cooperative Agreement	FY15- FY17	$64,307
4	Simulated rain events and modeling to estimate unpaved road sediment yields pre- and post-restoration	RC Community Based Restoration Program Cooperative Agreement	FY16 - FY18	$36,369
5	Continued monitoring to evaluate LBSP management success and establish baseline nearshore terrigenous sedimentation	RC Community Based Restoration Program Cooperative Agreement	FY19 - FY21	$174,180
6	Developing an integrated monitoring and evaluation framework and address priority data gaps	CRCP Internal Funding and OHC directorate	FY20 -FY23	$371,901*
7	Developing a road-map for a water quality monitoring program on nearshore habitats in Culebra	NFWF Coral Reef Conservation Fund Grant	FY21	$ 150,866

1: Establish nearshore coastal ecosystem baseline for evaluating LBSP management performance on NOAA trust resources

Timeframe: 2014 - 2016

Monitoring Location(s): Nearshore fixed stations representative of range of LBSP exposures (LBSP impaired / restoration sites, Reference – inside and outside of the bay)

Parameters / Metrics: Water quality (chlorophyll a, turbidity, ammonium, nitrate+nitrite, organic nitrogen, orthophosphate, and water clarity), seagrass habitat (percent cover, epiphyte load index, and deep edge of bed), and coral reef habitat (percent live cover, coral recruitment).

Summary description: Water quality and habitat metrics (seagrass and coral reef) were monitored across nearshore sites representative of a range of LBSP threats: LBSP impaired / restoration sites, Reference – inside and outside of the bay. Data collection was coordinated across space to ensure an integrated dataset of nearshore LBSP exposures and habitat responses. Methods included: (1) water quality monitoring: Ten fixed nearshore stations were established to monitor water quality parameters once a month for 14 months. Stations were selected based on their range of LBSP exposures. Parameters monitored at these sites included chlorophyll a, turbidity, ammonium, nitrate+nitrite, organic nitrogen, orthophosphate, and water clarity; (2) Seagrass monitoring: Three, 30 m long transects were established at each of the water quality monitoring stations (a total of 10 stations). Habitat measurements were made every meter within a 2.5 m^2 quadrat and included: percent cover of benthic habitat (seagrass, macroalgae, sediment), epiphyte load index, and depth. Within each 2.5 m^2 quadrat, seagrass shoot density was determined over a 100 cm^2 area. At each station, the depth of the deep edge of the seagrass bed was noted; (3) Coral reef monitoring: NOAA's National Coral Reef Monitoring Plan (NCRMP) collected standard coral reef cover data at up to 55 stations around Culebra, PR. NOAA's RC joined these monitoring efforts to also collect coral recruitment and percent live coral cover at each of these sites. This information was then evaluated to: (1) identify water quality and habitat metrics that are the best ecological descriptors of LBSP exposures, (2) determine baseline ecological responses to a range of LBSP exposures, and (3) test the potential of using the monitoring framework and associated data to establish interim nearshore water quality and habitat targets for LBSP management actions at the restoration sites.

Status: Data collection complete.

2: Determine pollutant Best Management Practice (BMP) performance

Timeframe: 2016 - 2021

Monitoring Location(s): At least 3 project-level BMPs

Parameters / Metrics: Sediment removal

Summary description: As a component of project implementation, funding was secured to monitor one of the BMPs implemented per year (3 total) to determine pollutant removal efficiencies. Depending on the practice, this could include comparisons of sediment inputs to the BMP versus sediment outputs or sediment accumulation within the BMP over time. Preliminary monitoring results determined the need for monitoring methods to provide a comprehensive analysis of management approach. For example, stabilizing unpaved roads requires a combination of BMPs (or treatment train) to divert flow off of erodible surfaces, slow flow down, promote infiltration, and - where possible - trap sediments on site. This treatment train limits the direct measurement of changes in sediment delivery, as there are no well-defined locations to measure pre- vs post-implementation sediment loads. Therefore, evaluations of effectiveness require a suite of indirect measurements through empirical experiments, hydrologic and sediment modeling, and field monitoring. Information gathered from this study were combined with future funding efforts to provide a more comprehensive analysis of management approaches.

Status: Complete. Data combined with studies #3 and #4 and results summarized here.

3: Quantifying sediment production from unpaved roads

Timeframe: 2016 - 2020

Monitoring Location(s): Project-level BMPs, Unpaved road segments

Parameters / Metrics: Sediment accumulation, rainfall

Summary description: This study, in combination with data from study #2, collected data to characterize independent variables (i.e., rainfall, slope) that influence erosion and sediment production from unpaved roads. Data recorders and tipping buckets were used to collect 15-min rainfall intensity time series. Sediment collecting BMPs were used to measure mass sediment production rates of each unpaved road segment. Observed rainfall and road segment slope were compared to sediment mass production to understand the relationship between the parameters and the amount of material eroded from roads. Results from this study informed the need for simulated rain events to establish the connection between independent variables, BMPs, and unpaved road sediment production.

Status: Complete. Data combined with studies #2 and #4 and results summarized here.

4: Experimental rainfall simulations and modeling to estimate unpaved road sediment yields pre- and post-restoration

Timeframe: 2016 -2022

Monitoring Location(s): Project-level BMPs, Unpaved road segment, Watershed

Parameters / Metrics: Rainfall, Runoff, Sediment, Nutrients

Summary description: Multiple monitoring approaches were utilized across space to integrate methodological advancements made through previous studies. Monitoring to evaluate performance unpaved road stabilization practices utilized: experimental rainfall simulations, measuring sediment accumulation in BMPs, rainfall measurements, other relevant measurements (i.e., peak runoff depth, infiltration rate). In particular, methods for the experiment rainfall simulations consisted of installing an experimental plot an unpaved road segment to confine and convey rainfall, erosion, runoff, and sediment delivery to the plot area which was outfitted with a trough to allow for sample collection. Rainfall was simulated over the experimental plot and measures of rainfall and runoff volume at standard time intervals. Runoff samples were also collected throughout the simulation and process for suspended sediment concentrations. This allowed for the quantification of total runoff and sediment mass generated before and after soil stabilization practices are implemented in each restoration site. This information was used to parameterize standard watershed modeling platforms to extrapolate across the entire unpaved road segment and provide estimates of the sediment yield reductions pre- versus post-unpaved road stabilization. Preliminary results indicate that these methods have been successful in developing locally-derived estimates of road runoff and net sediment retention in BMPs which are being used to calibrate and validate a watershed sediment production model. Separate from unpaved road monitoring, monitoring of a subset of stormwater BMPs in the Aeropuerto subwatershed was used to determine the likelihood of cost-effective estimates of stormwater BMP performance. Briefly, methods included collecting water samples at the inlet and outlet of a subset of BMPs and processed for sediment, nutrient, and fecal coliform.

Status: Ongoing. A portion of the data collected thus far has been combined with studies #2 and #2 and results summarized here.

5: Continued monitoring to evaluate LBSP management success and establish baseline nearshore terrigenous sedimentation

Timeframe: 2019 - 2022

Monitoring Location(s): Project-level BMPs, Watershed, Nearshore

Parameters / Metrics: Rainfall, Runoff, Sediment

Summary description: Funding was provided to continue implementing proven methodologies to collect data to evaluate the performance of management actions to stabilize unpaved roads. Additional monitoring will be focused on quantifying hydrologic connectivity within the watershed, which is a principle determinant of pollutant loadings into the nearshore. Methodologies include: rain gauge measurements, repeated topographical surveys of detention ponds (which have been found to be key watershed sinks / nearshore sources of runoff), peak-crest gauges and water level recorders. This project also seeks to expand monitoring into the nearshore through the installation of up to 10 sediment traps to characterize nearshore sedimentation patterns across a range of LBSP exposures. A portion of the sites will be located downstream of the ongoing BMP and watershed monitoring to enhance the ability to interpret the anticipated variance in the data. In addition, to the degree possible, sediment traps will be located near watershed discharge points to enhance connectivity between land-based stressors and nearshore exposure to those threats. Ideally sediment samples will be collected and processed every 3 – 4 months; however, the periodicity of sampling will be determined following the implementation of a pilot scale effort. Sediment samples will be sieved and ignited to quantify percent terrigenous and terrigenous accumulation rates in the traps.

Status: Ongoing

6: Developing an integrated monitoring and evaluation framework and addressing priority data gaps

Timeframe: 2020 - 2025

Monitoring Location(s): Task-specific

Parameters / Metrics: Task-specific

Summary description: This project provides NOAA contract support to provide technical support to develop an integrated monitoring and evaluation framework – which will provide an understanding of data gaps and associated monitoring priorities. In addition, funding is provided to implement studies to address data gaps. Monitoring priorities and protocols will determined in coordination with NOAA's RC and CRCP, but will likely include: (1) Identification of priority nearshore fixed stations. Through a series of studies select at least 10 priority nearshore fixed stations that are representative of a range of LBSP exposures and LBSP management levels which are priorities for long-term monitoring associated with the framework. (2) Development of an online GIS and data portal to enhance data management, sharing, and viewing. This portal should also be developed in coordination with anticipated future monitoring efforts in mind (i.e., Citizen Science Monitoring tools) to allow for seamless integration, access, and viewing of data collected through time. (3) Qualitative assessment of project function to inform status of BMP maintenance needs and qualitative ranking of pollutant reduction performance to be integrated into watershed modeling. This task would require knowledge of the location and design requirements of all BMPs implemented to date. It would also require site visits during- and/or post-rain events to evaluate the performance of the BMP related to its initial design. (4) Monitoring sediment mass accumulation at key accumulation points in the watershed (e.g., mangroves) or within BMPs (e.g., sediment ponds). (5) Comparison of watershed modeling platforms to identify preferred watershed modeling approach to support pollutant load estimates from Culebra subwatersheds. Regardless of the model, it is anticipated that refinements will be needed. This task could also support model refinement and/or parameterization needs which could be supported by this task. (6) Characterize baseline water quality conditions inside the artificial ponds at the Culebra Waste Water Treatment Plant (WWTP) and downstream. This dataset will provide pre-restoration conditions for evaluating the performance of Floating Treatment Wetlands (FTWs) that will be installed in the artificial ponds at the WWTP. This task would likely require monthly sampling along a longitudinal gradient from the discharge point at the Culebra WWTP, in the existing artificial ponds, within the receiving perennial stream, and into the nearshore waters. Water samples should be collected and processed for Chlorophyll A, Nutrient constituents, Turbidity, and Water Clarity. NOAA's Restoration Center is currently working with an intern from the University of South Florida to develop a monitoring plan to evaluate the performance of the FTM's at the site and watershed scale that could be applied here.

Status: Ongoing

7: Developing a road-map for a water quality monitoring program on nearshore habitats in Culebra

Timeframe: 2021-2023

Monitoring Location(s): Nearshore

Parameters / Metrics: Water quality (turbidity, chlorophyll-a, total suspended sediments, dissolved oxygen, salinity, water clarity via secchi disk), sediment constituent analysis

Summary description: This project will support the development and piloting of a nearshore water quality and sediment monitoring program to establish baseline conditions and evaluate in comparison to reference-based water quality and sedimentation targets. At least ten nearshore fixed monitoring sites will be selected to install sediment traps and to visit at least monthly through a citizen science program. This project will collect nearshore water quality and sedimentation data using a range of cost-effective approaches including: citizen science water quality monitoring program, sediment traps, and data sondes for validation. The data will provide a pollutant exposure baseline to measure future LBSP management success against. In addition, the data - relative to reference data – will inform also potential nearshore water quality and sedimentation targets for LBSP restoration actions.
Status: Not started

APPENDIX B: LBSP STRESSOR MONITORING

At a minimum, funding is needed to support monitoring and evaluation of LBSP management actions to: (1) track implementation progress of LBSP management actions and capture relevant external threats over time, (2) provide qualitative assessments of all LBSP management, (3) evaluate BMP and watershed scale performance of unpaved road stabilization and floating treatment wetlands at the Culebra WWTP, (4) identify BMP and/or watershed level corrective actions needed for unpaved road stabilization and floating treatment wetlands at the Culebra WWTP. The following information outlines the management questions that will be evaluated through the monitoring, indicators of success, and generalized approaches to monitoring of these indicators.

What area has been stabilized?

Indicator: Area stabilized

DEFINITION

Area stabilized is defined as the planar area of the project footprint. This footprint likely extends beyond the BMPs themselves to identify the impacted area that was 'stabilized' by the project as a whole. Area quantifications will also include land cover changes, such as road stabilization or bare soil creation, that occurred external to NOAA funded projects and should be designated as stabilized or unstabilized accordingly. This information will track the progress of project implementation over time as well as externalities that may impact project outcomes (i.e., unstabilized construction sites, stabilization that occurs external to the NOAA funded projects).

METRICS AND EVALUATION OF SUCCESS

Measurements should be provided in acres. Comparisons of pre- and post-implementation acres stabilized (or unstabilized) will provide a metric for tracking project implementation and external threats over time.

METHOD

The creation of **GIS data layers** will be key to tracking progress of project implementation and providing data input for watershed modeling efforts. These GIS layers include island-wide land use/land cover and an inventory of project foot-prints and BMP types and locations. In total, these GIS data layers will likely consist of up to 3 different data files: (1) A polygon shapefile to capture the planar footprint of NOAA funded LBSP management projects following project implementation. Potential external influences throughout the island should also be captured via imagery and digitization of the footprint (polygon) of the stabilized or unstabilized area. These external influences may include, but are not limited to, the creation of bare soil via new construction or road creation and the stabilization of unpaved roads external to the NOAA funded projects. (2) A point shapefile to capture the location of each BMP implemented following project implementation. An attribute table should be created to provide information about each BMP including: type of BMP, date of installation, date of maintenance / repairs, and information related to qualitative assessments of function over time. This information will also be relevant to evaluating BMP function over time. (3) A polygon shapefile to capture the contributing watershed area for relevant projects and/or BMPs. This information will provide necessary data inputs for modeling efforts to quantify watershed-scale pollutant loads pre- and post-restoration.

GIS data should be developed in coordination with project implementers, NOAA's Coastal Change and Analysis Program, and other BMP researchers to provide a repository and method for capturing and tracking BMP and/or project specific data including: location and timing of BMP and/or project implementation, evaluations of BMP and/or project function, timing of maintenance and/or need for repairs.

LOCATION

The GIS data should cover the entire island of Culebra; however, project specific information will be limited to the priority watersheds for LBSP management (see Figure 2).

FREQUENCY / DURATION

The GIS data should be developed and compared across at least 3 time frames that are indicative of 'baseline', 'during restoration', 'post-restoration'. Project area should be updated following implementation, which can also serve as a means for project tracking. While, external influences should be captured for the pre-selected timeframes mentioned above.

COST ESTIMATE

TBD

What percent of the BMPs are functioning as designed?

Indicator: Percent function

DEFINITION

Percent function is defined as the combined evaluation of individual BMPs - within a project's footprint - to determine the functionality of the project as a whole. For example, unpaved road stabilization projects are designed as a treatment train. Subsequently the function of one individual BMP within the system of treatment BMPs is not particularly valuable information; however, assessments of the system of BMPs within a project footprint will allow semi-quantitative assessments about the percent function of the project as a whole.

METRICS AND EVALUATION OF SUCCESS

Function will be quantified as a percent of full function (0 to 100%) defined in the assessment method. Comparisons of BMP and project percent function (post-implementation) over time will provide a metric for level of success across all projects. It will also provide data to assist in developing a maintenance schedule for BMPs to enhance project function over time.

METHOD

Percent function will be estimated using two general methods: semi-quantitative assessments and, where feasible, field-based assessments of BMP performance.

A method should be developed to facilitate **semi-quantitative assessments** of BMP and/or project function. The method will require the development of surveys and/or checklists that can be used to guide in-field assessments of BMPs to provide an understanding of the function of the project as a whole. Subsequently, the checklist or survey employed will need to clearly define degrees of function for individual BMPs to provide an assessment method that is easily discernible and repeatable over space and time. Ideally, this method would be combined with an online data portal which would be linked to the GIS data (noted previously) to allow for real-time data (e.g., survey results, photos) intake and a repository of data over time. Prior to assessments, in-field training will be required to ensure consistency of data collection.

In addition to the qualitative assessments, there are several **field-based assessments** that could be used to evaluate unpaved road BMP performance to determine appropriate maintenance frequency, identify potential corrective actions needed, and - ultimately - enhance the cost-effectiveness of BMPs. These assessments alone may not result in estimates of 'percent function' of the BMPs, but this information will be essential to enhancing the performance of the BMPs over time. These studies may include, but are not limited to:

- Evaluation of sediment ponds trapping efficiency to identify preferred maintenance schedules to maximum BMP performance. These studies may include simulated rain events to quantify and compare runoff volume, rate, and sediment load at the inlet and outlet of the ponds. Or pressure transducers could be deployed in the ponds to monitor water levels in the pond during rain events. This information, combined with modeling, will help refine our understanding of event-based performance of these ponds in terms of runoff volume and rate into pond and capacity of pond.
- Experimental evaluations of BMPs that disperse stormwater throughout the landscape to evaluate the performance of these BMPs. Some methods may include the use of experimental rainfall / runoff simulations combined with flumes, pressure transducers, and samples to quantify rainfall volume, runoff volumes and rates and total suspended solids over the course of a simulated rain / runoff event. These methods may be applicable to BMPs like cross-swales, underdrains, or vegetated buffers to better understand performance of the BMPs during rain events.
- Utilize USGS methods to evaluate change in road surface over time

LOCATION

Assessments of BMP and/or project function should generally cover all priority watersheds that include management. However, it is anticipated that only a subset of the BMPs / projects in these watersheds will be assessed to provide a broader understanding about function across all BMPs / projects.

FREQUENCY / DURATION

Frequency will likely fluctuate over time to account for the learning curve associated with the newly adopted assessment techniques. In general, higher frequency of monitoring will occur initially as we are learning more about the BMPs. It is anticipated that monitoring will likely dissipate over the life of the BMP. Although not a requirement, during- or post-rain event assessments will be particularly helpful during the course of data collection. Regardless, it is anticipated that only a portion of the BMPs / projects will need to be assessed to understand the likely range of function of all BMPs / projects employed.

COST ESTIMATE

TBD

Has pollutant transport - from stabilized unpaved roads - been reduced?

Indicator: Sediment Mass Accumulation

DEFINITION

Opportunities for direct measurements of site- or BMP-level performance of unpaved road stabilization projects are limited due to the treatment train approach utilized for unpaved roads. Subsequently, estimates of the pollutant reduction benefits of stabilizing unpaved roads is best quantified using a range of monitoring techniques (empirical experiments, hydrologic and sediment modeling, field monitoring) conducted at the watershed scale. However, sediment ponds - one of the BMPs used in the unpaved road stabilization treatment train - provide the greatest logistical opportunity to estimate sediment mass reductions via sediment accumulation.

Sediment mass accumulation is defined as the volume of sediment that accumulates within a discrete location (i.e., BMP) over time. This value is then adjusted by dry bulk density to calculate sediment mass. Although this measurement cannot quantify reductions in sediment transport from unpaved road projects as a whole, this data combined with watershed modeling approaches can provide validated estimates of project level reductions in sediment transport.

METRICS AND EVALUATION OF SUCCESS

Sediment mass accumulated between sample events will be measured in metric tons. Summation of these values over a year can provide low-level estimates of annual BMP sediment mass removal. Comparisons of mass accumulation with total rainfall between sample events can also provide valuable data for watershed model validation.

METHOD

This method is best utilized on sediment ponds where topographic surveys of the pond are taken immediately post-construction and then some logistically feasible frequency thereafter. Rainfall data should also be collected over the timeframe of sample events and used as a covariate to evaluations of variance in sediment mass accumulation.

Topographic surveys can be conducted by standard surveying techniques or by Unmanned Aircraft Systems (UAS) outfitted with LiDAR capacity. The lip of the outlet for the sediment pond can be used as a reference elevation to quantify the volume of the pond for each sample event. The volume of sediment accumulated between sample events is equal to the difference in pond volume between sample events. AutoCAD, ArcGIS, or similar spatial analysis tools can process topographic data and quantify pond volumes for sampling events. The precision of the volume of sediment accumulated will depend on both accuracy of the topographic survey and volume determination with each method (Verstraeten and Poesen, 2002). Finally, dry bulk density of the accumulated sediment should be measured to translate the volume of trapped sediment to a mass (Verstraeten and Poesen, 2001). This approach is considered as a type of detailed method to measure sediment yield from accumulated sediment (Ramos-Diez et al., 2017), that can be expected to provide sediment yields with a percent error of 20 – 30% (Verstraeten and Poesen, 2002).

LOCATION

This method has been applied to select sediment ponds in the Fulldosa, Punta Aloe, and Almodovar watersheds on Culebra and should be replicated over space and time to increase accuracy of estimates of sediment mass accumulation. Efforts to continue and/or scale up monitoring of sediment ponds on Culebra should target monitoring that encompasses the variability in sediment pond designs, watershed drainage characteristics, rainfall intensities / volume, etc. that is representative of the restoration and environmental conditions of the island. It is also possible that similar methods could be applied to other locations known to receive and trap sediment (i.e., mangroves)

FREQUENCY / DURATION

Frequency is largely dictated by logistical constraints, but at a minimum should include immediate post-implementation surveys followed by a survey every 6 months. Ideally, monitoring should occur for the life of the pond (5 to 10 years) to understand the full life cycle of the BMP.

COST ESTIMATE

TBD

Has pollutant transport - from the Culebra WWTP - been reduced?

Indicator: Nutrient load (and/or yield)

Event based nutrient loads and/or annual yields should be monitored at the inlet and outlet of the Culebra WWTP ponds to evaluate the performance of Floating Treatment Wetlands (FTMs) over time. NOAA’s Restoration Center is currently working with an intern from the University of South Florida to develop a monitoring plan to evaluate the performance of the FTM’s at the site and watershed scale. Details will be incorporated into corresponding components of the M&E Framework when available.

Has pollutant transport - from priority subwatersheds - been reduced?

Given the ephemeral nature of runoff and pollutant loads on Culebra, watershed modeling will be a key component of watershed-scale efforts to estimate event- and/or annual- discharge and pollutant (nutrient, sediment) loads. In particular, a regionally based model (RoadConnect) provides a useful GIS-based platform for predicting sediment contributions from unpaved roads pre- and post-restoration (citation). However, relatively significant uncertainty remains regarding the utility of other modeling platforms in predicting runoff and pollutant loads from other land uses within Culebra.

Subsequently, NOAA is funding a comparison of modeling approaches in one to two subwatersheds on Culebra to better understand the pros / cons of each potential modeling platform and the capabilities of easily calibrating the model to our needs on Culebra as well as the broader Caribbean region. Following this analysis, we intend on utilizing RoadConnect and an island-wide modeling platform to make predictions about pollutant loads from each watershed across the island.

Where possible, in situ monitoring should also be utilized to calibrate and/or validate model inputs and outputs. This may include, but is not limited to:

- Site-specific measurements of rainfall coupled with in-situ measurements of flow to enhance model inputs and outputs via parameterization, calibration, and/or validation. Punta Aloe has a defined ephemeral stream and has been the focus of previous monitoring and modeling efforts. Therefore, Punta Aloe likely presents a good opportunity for additional rainfall and flow measurements to enhance watershed models.
- Experimental rain simulations to provide additional model inputs for land cover categories not previously studied. In particular, there is a need to collect data to determine hydrologic and sediment / erosion properties associated with bare soils from construction sites. As restoration implementation continues it is also likely that additional land cover categories may need to be monitored to provide similar model inputs.

More details about these opportunities and/or key considerations have been provided for each indicator below.

Indicator: Sediment load / yield (from unpaved roads)

DEFINITION - Parameterization and Modeling

> Sediment load is defined as the total mass of sediment transport across a surface during a simulated rain event. Typically, this measurement occurs over the course of a full hydrograph and is summed to provide a total over the event. Measurements of sediment load can also be correlated to covariates such as rainfall intensity, rainfall volume, slope, and land cover / land use characteristics to provide a means of modeling island-wide estimates of sediment load from unpaved roads across space and time.

METRIC AND EVALUATION OF SUCCESS

METHOD

Rainfall simulation designs and operation should follow standard protocols proven successful in the region (Luk et al., 1986; Ramos-Scharron and Figueroa, 2017). Rainfall experiments should also occur across a range of unpaved road characteristics representative of Culebra Island with replicates to account for potential variance across unpaved roads and rainfall responses. Method designs generally consist of experimental plots of thick iron plates and a collection trough that are installed on the road surface. Sixty-minute rainfall simulations are produced across the plots using a single-nozzle. Average rainfall intensity is measured every five minutes with six manual gauges placed along the perimeter of each plot. Surface runoff is collected as it exits the collection trough and volumes are measured every minute. Every five minutes, a sample of the runoff is collected in 0.5-L bottles and processed for suspended sediment concentration (evaporation method - ASTM, 2000). The per unit area total sediment mass production is calculated as time-dependent, runoff multiplied by the time-dependent, average suspended sediment concentration and summed across the simulated event. Data from the experimental events can also be analyzed to provide valuable information for each unpaved road surface including: time to runoff, rainfall-runoff threshold, total runoff, runoff coefficients, erosion rate, infiltration rate, infiltration capacity equations, per unit area precipitation excess runoff generated for individual rainstorms over a full year of rainfall (see Ramos-Scharron and Figueroa, 2017). Finally, plot-scale data can be extrapolated over space and time to provide watershed-scale estimates of annual sediment loads for similar land use / land cover.

Additional methods should be used to measure data associated with relevant independent variables. Surface area and slope should be quantified for each experimental plot. A soil sample should be taken from a non-wetted surface in the immediate vicinity of each plot to quantify pre-simulation moisture content. Post-simulation a soil sample should be taken within the plot via a galvanized cylinder to evaluate moisture gains after the simulation (Gardner, 1986), as well as to establish dry bulk density (Blake and Hartge, 1986), and texture by dry sieving (Bowles, 1992).

LOCATION

This method has been applied across pre-restoration unpaved roads and vegetated surfaces that represent a range of slopes, traffic use, and grading found across Culebra. Efforts to continue the use of experimental plots should be applied to those landscape scale characteristics not previously evaluated. For example, unpaved road stabilization often consists of retiring roads to allow them to revegetate. However, revegetated surfaces have not yet been monitored. Subsequently, it is possible that experimental plots established on these revegetated surfaces could provide meaningful information to expand our knowledge of the sediment reduction efficiencies of this component of unpaved road stabilization efforts. Otherwise, previous monitoring efforts have generally captured the range in unpaved road characteristics needed to provide relevant data inputs for estimating sediment loads from unpaved road across the island via modeling.

FREQUENCY / DURATION

Since these are simulated rain events, the researcher can dictate the timing and frequency according to their data needs. Ideally each land cover / land use monitored would have 3 replicates to ensure scientifically robust data outcomes.

COST ESTIMATE

TBD

Indicator: Nutrient load / yield (from Culebra WWTP)

Event based nitrogen and phosphorus loads and/or annual yields should be monitored in the receiving stream pre- and post- implementation of the FTWs to evaluate their performance at the watershed scale over time. NOAA's Restoration Center is currently working with an intern from the University of South Florida to develop a monitoring plan to evaluate the performance of the FTM's at the site and watershed scale. The Cabra sub-watershed is the only location with a stream with baseflow. As such, it is likely that stream gaging and water quality sampling will be a priority to enhance model outputs for this work. Details will be incorporated into corresponding components of the M&E Framework when available.

Table 2. Summary of Minimum Monitoring Recommendations for evaluating best management practices (BMP) and watershed performance of LBSP management actions. This table outlines management evaluation questions, recommended indicator for monitoring and answering the management question, the type of indicator (project tracking or effectiveness), priority locations for monitoring - if known, frequency and duration of monitoring, estimated annual costs of monitoring, and funding source - if available. At a minimum, monitoring of these indicators before, during, and after LBSP implementation will provide the ability to track implementation of projects and evaluate their effectiveness over time.

Evaluation Question	Indicator	Indicator Type	Priority Location(s)	Frequency	Duration	Funding	Annual Cost
What area has been stabilized?	Area stabilized	Project tracking	Island wide	Annual post-restoration measurements	Until completion of restoration (5+ years)	NOAA CRCP / OHC FY20 and future project funds	TBD
What percent of the BMPs are functioning as designed?	Percent function	Project tracking	Priority watersheds (see Figure 2)	Annual post-restoration measurements	For life cycle of restoration (5+ years)	NOAA CRCP / OHC FY20 and future project funds	TBD
Has pollutant transport - from priority BMPs - been reduced?	Sediment mass accumulation	BMP effectiveness	Unpaved road stabilization (sediment traps)	3-4 measurements per year	For life cycle of restoration (5+ years)	NOAA CRCP / OHC FY20	TBD
	Nutrient load	BMP effectiveness	Floating treatment wetlands	3-4 measurements per year	For life cycle of restoration (5 to 10 years)	NOAA CRCP FY21-FY23	TBD
Has pollutant transport - from priority subwatersheds - been reduced?	Sediment load / yield	Watershed effectiveness (unpaved road stabilization)	Priority unpaved road stabilization subwatersheds	3-4 measurements per year	For life cycle of restoration (5 to 10 years)	NOAA CRCP / OHC FY20	TBD
	Nutrient load / yield	Watershed effectiveness (floating treatment	Cabra subwatershed	3-4 measurements per year	For life cycle of restoration (5 to 10 years)	NOAA CRCP / OHC FY20	

		wetlands)					

APPENDIX C: POLLUTANT EXPOSURE MONITORING

This level of monitoring is inclusive of the 'LBSP stressor monitoring' with the addition of integrated monitoring of nearshore physical parameters (sedimentation, water quality) at priority fixed nearshore locations. Through careful selection of nearshore physical indicators, siting of nearshore fixed stations, and establishing the minimum number of samples needed to detect change[1], researchers will be able to establish water quality and sedimentation baselines along a spectrum of LBSP impairments and future LBSP management levels. Collectively this information will provide an integrated dataset of BMP, watershed, and nearshore physical data to determine whether nearshore water quality and sedimentation goals have been achieved at priority locations and/or whether additional management actions are needed in corresponding watersheds to elicit an improved nearshore coastal response.

At this time, there is little existing nearshore Culebra water quality or sedimentation data to inform decisions about the best metrics (and methods) for detecting and measuring changes to LBSP threats over time. A study seeking to characterize Culebra's nearshore water quality and sedimentation conditions across a range of LBSP threats (including reference sites) could be particularly beneficial in selecting the most appropriate metrics and methods for this component of the monitoring recommendations. Once priority metrics and methods are identified, a long-term monitoring program could be established to provide the most cost-effective and sustainable approach for monitoring water quality and sedimentation in Culebra's nearshore environment.

Ultimately, the monitoring methods provided within this section will be appropriate for detecting and defining long-term trends in nearshore physical parameters along a spectrum of LBSP impairment (inclusive of reference sites) and future LBSP management levels. These sites should also be co-located with seagrass and coral reef fixed-stations to enhance site-specific knowledge of the linkages between physical and biological parameters in the nearshore ecosystem. Although these methods are not necessarily appropriate for event-based monitoring, timing of monitoring can be targeted to capture a range of dry and wet events to understand the variance in water quality parameters across sites.

Have nearshore water quality conditions improved?

Indicator: Light attenuation

DEFINITION

Light attenuation, or reduction in the intensity of a light beam as it propagates through the water column, is a major factor in the health of seagrass and coral reef habitats (citation). In the water column, concentrations of phytoplankton, total suspended solids, and colored dissolved organic matter (CDOM) are primary factors in determining light attenuation at any

[1] These studies are currently underway and are generally described in the section entitled 'Addressing Key Data Gaps'

depth. Measurements of these parameters or proxies (i.e., secchi depth, PAR) can provide useful data for evaluating the level of light attenuation across time and space.

METRIC AND EVALUATION OF SUCCESS

At this time, there is little existing nearshore water quality data to provide an ability to understand the best metric for evaluating whether water quality conditions have improved following LBSP management actions. Subsequently, there is a need for nearshore water quality monitoring to characterize optical properties in nearshore Culebra waters across a range of LBSP threats over time. This monitoring should include measures of water column transparency (i.e., secchi depth, percent surface irradiance), phytoplankton biomass (i.e., chlorophyll a concentration), and sediment loading and resuspension (i.e., turbidity, total suspended solid concentration). This data will provide foundational information needed to understand optical limitations (and primary stressors) in the Culebra nearshore environment as it relates to LBSP threats.

Once priority metrics and priority nearshore fixed stations are known, monitoring of indicators at nearshore fixed stations that represent before restoration, after restoration, control / reference condition, and LBSP impact conditions (BACI) will be needed to adequately characterize variance of indicators over time and space. LBSP management performance in the nearshore will be evaluated by comparing measures of indicators at control/reference sites against LBSP impacted and restored sites. In general, measures of indicators from impacted / restored sites that show progress toward control / reference conditions will be indicative of 'improvements'.

METHOD(S)

Depending on the method selected, measurements of parameters that influence light attenuation can be costly. In addition, fieldwork in Culebra can be logistically challenging - requiring long travel times to access the island (if personnel don't live on the island) and additional boat travel to access sample sites. Where possible, water quality monitoring should utilize local support - via Citizen Science Program and/or hire local researchers - to address logistical challenges while supporting consistent data collection throughout the year.

Since there is limited water quality data for Culebra, it is recommended that initial water quality monitoring efforts support the following objectives: (1) characterize the variance of optical properties in nearshore Culebra waters across a range of LBSP threats over time and (2) evaluate a range of techniques to support the development of the most cost-effective, long-term water quality monitoring program for the island. As such, initial water quality monitoring should combine more expensive, scientifically robust techniques with low-tech, low-cost techniques to support the development of the most cost-effective, long-term water quality monitoring program. For example, a citizen science program may provide monthly measures of secchi depth, while a series of PAR sensors may be deployed in the same location to provide more accurate measurements of percent surface irradiance. Comparisons of these types of measures over time will allow researchers to quickly understand the relative cost / benefit of techniques locally to enhance monitoring outcomes at the least cost. Regardless, collecting consistent measures of water column transparency, phytoplankton biomass, and/or sediment loading and resuspension at priority nearshore locations will provide valuable information for linking LBSP threats (and restoration) to measures of habitat health.

LOCATION

Ultimately this should be located at priority nearshore fixed-stations which are co-located with seagrass and coral reef monitoring sites.

FREQUENCY / DURATION

The frequency of measurements depends on the technique employed. Discrete measurements should be collected at least monthly, while remote techniques like deployment of data sondes and/or remote imagery may be collected at a greater frequency. Although these methods are not necessarily appropriate for event-based monitoring, timing of monitoring can be targeted to capture a range of dry and wet events to understand the variance in water quality parameters across sites.

COST

TBD

Indicator: Nutrient concentrations

DEFINITION

Nutrient (nitrogen and phosphorus) discharge into naturally nutrient poor ecosystems, like the Caribbean, can fuel excessive plant and algal growth (i.e., eutrophication) which can significantly affect the health of benthic habitats. Nitrogen and phosphorus consist of many different forms depending on their place within the nutrient cycle as well as the source of the pollutant (i.e., fertilize, sewage). Since nutrient management techniques will be employed as a component of LBSP management on Culebra, nutrient concentrations should be monitored to establish baseline conditions and evaluate change over time.

METRIC AND EVALUATION OF SUCCESS

At this time, there is little existing nearshore nutrient data to inform the selection of a nutrient metric (or suite of metrics) to characterize LBSP threats and management actions in the nearshore. A study should be utilized to characterize the variance in nutrient concentrations from the LBSP source (i.e., Culebra WWTP) to the nearshore waters surrounding Culebra. This will provide valuable information for evaluating and selecting the most appropriate metric and methods for tracking LBSP management over space and time.

Once priority metrics and priority nearshore fixed stations are known, monitoring of indicators at nearshore fixed stations that represent before restoration, after restoration, control / reference condition, and LBSP impact conditions (BACI) will be needed to adequately characterize variance of indicators over time and space. LBSP management performance in the nearshore will be evaluated by comparing measures of indicators at control/reference sites against LBSP impacted and restored sites. In general, measures of indicators from impacted / restored sites that show progress toward control / reference conditions will be indicative of 'improvements'.

METHODS

Additional evaluations are needed here but, in general, EPA approved methods are preferred (EPA, 2010A).

LOCATION

The Cabra subwatershed is the primary focus area for implementation of nutrient management techniques. Subsequently, monitoring of nutrients in the nearshore should target fixed locations which represent stratified levels of nutrient delivery from Cabra subwatershed. An intern from University of South Florida will be helping build out an appropriate monitoring plan for this component of the M&E Framework.

FREQUENCY / DURATION

TBD

COST ESTIMATE

TBD

Has nearshore terrigenous sedimentation decreased?

Indicator: Sediment constituent analysis

DEFINITION

Sediment constituent accumulation is an important indicator used to measure water quality and assess ecological aspects of a coral reef community. Sediment can originate from carbonate from coral reefs and from terrigenous environments. In order to calculate the composition of sediment from each source, sediment is collected from the seabed by hand or dedicated devices, and data is presented as a percentage by mass for a sample or a specific grain size fraction of a sample (% mass by grain size, % weight of organic carbon, carbonate, and terrigenous sediment of a sediment sample [Barber, 2002]).

METRIC AND EVALUATION OF SUCCESS

METHODS

Sediment traps can be used as a semi-quantitative measure of sediment being transported through the reef (Rice et al. 2016, Barber 2002). Processing of the sediment generally falls into three parts: (1) Measuring weights, (2) Determining grain sizes, and (3) Constituent analysis. When measuring the weight of a sediment sample, this is usually done as a dry weight; drying can be done in an oven at a temperature of 30°C for 48 hours. Grain size can be determined, usually as a percentage of the total dry sample weight, via a range of methods, from running the sediment through simple mesh sieves (either wet or dry) up to x-ray or laser diffraction particle size analyzers. Constituent analyses are usually done on some size fractions of the sediment sample; a typical example is conducting analyses on the sand-sized (2.000-0.063 mm), silt-sized (0.063-0.004 mm), and clay-sized (<0.004 mm) fractions.

Sediment is sieved into these fractions and each fraction is weighed. The carbonate portion of each grain-size fraction is then removed, either by bathing them in an acid (e.g., perchloric) or burning them off in an oven at high (950°C) temperature through use of Loss On Ignition. See standard operating procedure here: http://lrc.geo.umn.edu/laccore/assets/pdf/sops/loi.pdf. By removing all of the carbonate, one is just left with the non-carbonate or terrigenous material, which is then re-weighed to determine percentage of terrigenous material by mass. The percentage carbonate is simply the difference between the overall fraction mass and the mass of the terrigenous material remaining in the fraction after removing the carbonate material. Ratios of terrigenous to carbonate material by mass for the different size fractions then can be computed.

LOCATION

Ultimately this should be located at priority nearshore fixed-stations which are co-located with seagrass and coral reef monitoring sites.

FREQUENCY / DURATION

Preferably samples would be collected from sediment traps every 3-6 months to support long-term, cost-effective methods. However, exploratory analyses are required to determine whether this periodicity is supported by Culebra field conditions.

COST ESTIMATE

TBD

Table 3. Summary of Pollutant Exposure Monitoring Recommendations. At a minimum, monitoring of these indicators before, during, and after LBSP implementation will provide the ability to track implementation of projects and evaluate their effectiveness over time. This table outlines management evaluation questions, recommended indicator for monitoring and answering the management question, the type of indicator (project tracking or effectiveness), priority locations for monitoring - if known, frequency and duration of monitoring, estimated annual costs of monitoring, and funding source - if available. At a minimum, monitoring of these indicators before, during, and after LBSP implementation will provide the ability to track implementation of projects and evaluate their effectiveness over time.

Evaluation Question	Indicator	Indicator type	Priority Location(s)	Frequency	Duration	Funding	Annual Cost
Have nearshore water quality conditions improved?	Light attenuation	Nearshore water quality effectiveness	Nearshore fixed station (n=TBD)	TBD	5+ years	TBD	TBD
		Index of nearshore water quality effectiveness	Island-wide	TBD	5+ years	TBD	TBD
	Nutrient concentrations						
Has nearshore terrigenous sedimentation decreased?	Sediment constituent accumulation	Nearshore sedimentation effectiveness	Nearshore fixed station (n=TBD)	Every 3-6 months	5+ years	TBD	TBD

APPENDIX D: HABITAT RESPONSE MONITORING

This level of monitoring is inclusive of the 'stressor' and 'exposure' monitoring recommendations and will leverage partnerships and existing programs to evaluate and answer the following questions: (1) Have seagrass habitat conditions improved? (2) Have coral reef habitat conditions improved? This level of monitoring will allow researchers to establish fixed-station seagrass and coral reef baselines and track changes in these indicators to determine whether they are trending toward reference conditions. This will allow managers to establish reference-based seagrass and coral reef goals and determine whether those goals have been achieved at priority locations and/or whether additional management actions are needed in the corresponding watershed to elicit an improved nearshore coastal response. Given the extent of data collection and coordination, this level of monitoring would require additional project oversight, management, and evaluation to establish coordination among partners and a feedback mechanism to support adaptive management needs for Culebra Island.

Habitat response monitoring recommendations focus on addressing nearshore biological management questions and the greater goal of "improved biological condition by 2035." Determining the results of watershed and site-level BMPs implementation on receiving nearshore habitats is complex, crossing multiple ecological boundaries, and once in the marine environment the signal from watershed restoration activities may be difficult to detect. The purpose of monitoring nearshore habitats is to determine whether restoration activities done on land result in measurable change over time as pollutant loads decrease. To quantify changes in the receiving habitats, first it is important to understand the hydrodynamic characteristics of the nearshore environment and use that data to inform selection of fixed sites to monitor. It is anticipated that fixed sites will be located where inputs from the watershed are most persistent or influential so that any change in the nearshore resources can be attributable or correlated to runoff regimes that have been altered by restoration efforts on land. For each habitat type of interest the idea is to monitor along a range or gradient of LBSP threat or influence of management actions.

NOAA convened local resource managers and nearshore habitat subject matter experts in 2020 and asked them to help identify indicators that represent the aspects of the nearshore biological community that may respond to the ongoing restoration activities occurring on Culebra.

Have seagrass habitat conditions improved?

Seagrass responses to natural and anthropogenic disturbances are observable as changes in habitat areal extent, cover, and density. In addition, natural and anthropogenic disturbances can result in declines in water quality or water clarity parameters as well changes or overgrowths of algae that can in turn affect seagrass productivity and survival. **Based on input from subject matter experts, top response indicators for nearshore seagrass habitats were benthic cover, shoot density, epiphyte load, and deep edge of seagrass bed.** These indicators along with abiotic indicators for water quality and sediment should be colocated to document biological changes commensurate with these abiotic factors.

Indicator: Benthic cover

DEFINITION

The term benthic refers to anything associated with or occurring on the bottom of a body of water. The organisms associated with the seafloor environment (benthos) include both plants and animals. To address the question regarding seagrass habitat conditions, the benthic covers of interest will be macrophytes, seagrass and algae. Benthic cover is a calculated measure of the relative abundance of ecologically important types of sessile organisms (live coral, crustose coralline algae, sponges, etc.) and plants (seagrass, macroalgae, and turf algae) and abiotic features (sand, sediment, pavement, etc.).

UNIT OF MEASURE AND EVALUATION OF SUCCESS

Area and percentage of biotic elements occupying the benthos.

METHOD

Benthic cover data can be collected at several different spatial scales via remote sensing to create benthic habitat maps where areal cover estimates are derived or in-situ direct measure of cover using transect or quadrat data collection methods. A 50 x 50 cm quadrat is often the recommended quadrat size used to measure cover. In-situ cover data is recorded by species present or total cover using the categorized Braun-Blanquet method or percentage estimates.

LOCATION

TBD -- fixed sites will be determined based on hydrodynamic characteristics and locations of known points of discharge of land-based runoff that impact nearshore areas. Once identified, these sites should be colocated with water quality sampling.

FREQUENCY / DURATION

The frequency of data collection will be contingent upon the methods selected for data collection and the size of the area of interest.

COST

TBD

Indicator: Shoot density

DEFINITION

Shoot density is the number of seagrass shoots per unit area (m^2). Seagrass structural responses to disturbances can occur as small (fine) scale changes at the shoot-level, within the larger seagrass habitat complex. The density at which seagrass occupies bottom sediment areas is a measure of abundance and can be used as an ecological indicator.

UNIT OF MEASURE AND EVALUATION OF SUCCESS

Unit of area, m^2.

METHOD

Shoot density is calculated by counting the number of shoots contained within the specified area of a quadrat. For example, one recommended quadrat size used to measure density is 25 x 25 cm.

LOCATION

TBD -- fixed sites will be determined based on hydrodynamic characteristics and locations of known points of discharge of land-based runoff that impact nearshore areas. Once identified, these sites should be colocated with water quality sampling.

FREQUENCY / DURATION

Shoot density can be collected as a parameter during planned transect or fix station seagrass sampling. Regular, seasonal sampling is preferred in order to analyze trends.

Indicator: Epiphyte load

DEFINITION

Epiphytes are the plants and animals growing on the surfaces of seagrass leaves. Epiphyte load is the mean epiphyte biomass per unit seagrass leaf surface area (Nelson 2018). Epiphyte "load" is usually expressed as biomass of epiphyte per unit biomass of plant substrate. Comparability requires a standardized definition particularly for the denominator, where units have included "per leaf" or "per shoot".

UNIT OF MEASURE AND EVALUATION OF SUCCESS

Epiphyte load has been measured (wet weight vs. dry weight) and reported using several different methods and units of substrate surface area (surface area of a leaf vs. shoot). The measure is frequently expressed as mg DW per cm^2. If measuring values for several species or for comparison purposes, it is important to note that due to morphological differences, biomass expressed as weight per shoot may not be comparable among seagrass species. Conversion to a standard measure such as weight per cm−2 of macrophyte from weight per shoot requires data on surface area (Nelson 2018). Review of literature by Nelson (2018) classified levels of epiphyte loading into four categories: low (<0.4 g g-1 DW), moderate (0.4 - 0.7 g g-1 DW), high (0.8 - 1.5 g g-1 DW), and very high (<1.5 g g-1 DW).

METHOD

At a sampling site, a set number of intact short shoots for the species of interest are randomly collected from within a specified area. In a laboratory setting, leaves are cut from the short shoot and cleaned of the attached epiphytes. The biomass collected is then measured as wet or dry weight using the appropriate techniques. Leaf length and width data are collected in order to calculate leaf area. See Kendrick and Lavery (2001) for a detailed guide on measurement of epiphyte biomass.

LOCATION

TBD -- fixed sites will be determined based on hydrodynamic characteristics and locations of known points of discharge of land-based runoff that impact nearshore areas. Once identified, these sites should be colocated with water quality sampling.

FREQUENCY / DURATION

Collection conducted seasonally.

COST

TBD

Indicator: Deep edge of bed

DEFINITION

Seagrass grows in meadows or beds and the boundaries within the marine landscape are visible from the water as well as remotely sensed imagery. The deep edge of a seagrass bed is the furthest extension of vegetative growth into a measured depth of water and provides the bounds for calculating area of the habitat. Two definitions of "edge of bed" have been proposed for operational use by monitoring programs: 1) edge of bed as >10 percent visual cover, that includes enough seagrass to provide reasonable ecological value and is mappable, and; 2) edge of seagrass zone or occurrence where some seagrass as sparse as one shoot per m^2 for a given length of 10 or so meters creates a "fuzzy" less quantifiable edge (Virstein and Johansson 2000).

UNIT OF MEASURE AND EVALUATION OF SUCCESS

Unit of measure is depth of water in meters. Change detection of repeated measures can be used as a means for evaluating the deep edge of seagrass. Seagrass requires light to photosynthesize and therefore the deeper depths to which light is available for seagrass to persist as beds can be an indicator of water quality and seagrass health.

METHOD

A repeatable measure using in-situ transect methods or mapping seagrass boundaries from aerial or remote imagery.

LOCATION

TBD -- fixed sites will be determined based on hydrodynamic characteristics and locations of known points of discharge of land-based runoff that impact nearshore areas. Once identified, these sites should be colocated with water quality sampling.

FREQUENCY / DURATION

The measure should be collected at a regular interval, occurring during the same season or month every time. Repeat measures could be collected biennially, or every three to five years.

COST

TBD

Have coral reef habitat conditions improved?

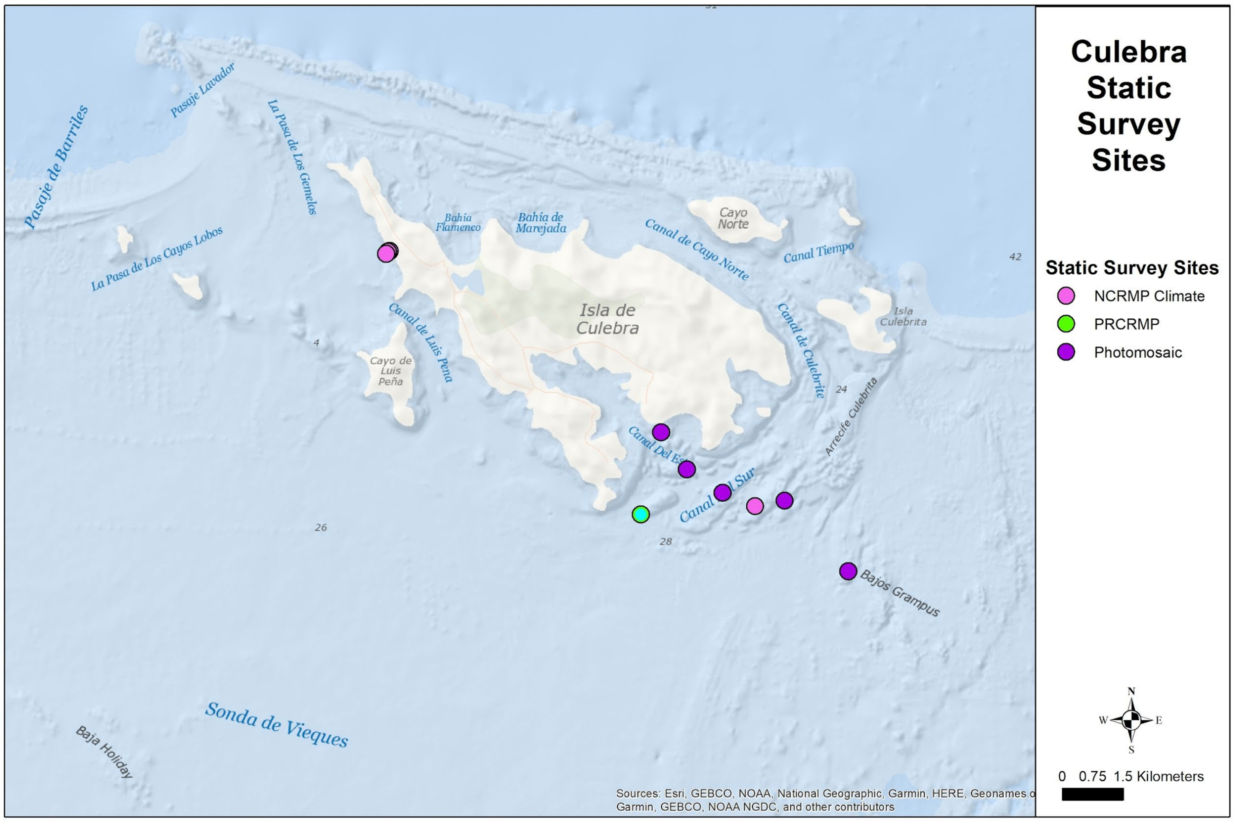
Determining the results of watershed and site-level BMP implementation on receiving nearshore habitats is complex, and the signal from watershed restoration activities may be difficult to detect in the marine environment. The purpose of monitoring nearshore habitats is to determine whether mitigation activities done on land result in measurable change in marine habitats over time as pollutant loads decrease. Establishing potential relationships between terrestrial runoff and change in nearshore marine resources requires monitoring sites where the inputs from the watershed are most persistent and control sites with comparable habitats located away from terrestrial runoff. Therefore, establishing appropriate fixed-sites to monitor for the quantification of potential changes in benthic habitats from watershed runoff relies on an accurate hydrodynamic assessment of the nearshore habitats.

NOAA convened local resource managers and nearshore habitat subject matter experts in 2020 and asked them to help identify indicators that represent the aspects of the nearshore biological community that may respond to the ongoing mitigation activities occurring on Culebra. **For nearshore coral reef habitats the top indicators were benthic cover, coral species composition, coral recruitment, and recent colony mortality.** Survey sites for these indicators along with abiotic indicators for water quality and sediment should be colocated to document biological changes commensurate with these abiotic factors.

Documenting baselines for these indicators is very important since watershed restoration activities have been underway and funding has been secured for the planned activities that have not yet been implemented. Funding aside, the limiting factor with collecting baseline information is that fixed sites for monitoring have not been chosen. Currently, a hydrodynamic study is underway to identify prevailing water circulation and run-off patterns to inform site selection for future monitoring stations. Once the sites have been identified, monitoring can then commence to provide long-term data on these indicators to document change and determine the results of watershed restoration to nearshore coral habitats.

OVERARCHING OPPORTUNITIES

NOAA's National Coral Reef Monitoring Program (NCRMP) is a long-term monitoring program that provides status and trend information for shallow coral reef ecosystems at the jurisdictional (e.g., Puerto Rico) and sub-jurisdictional scale (e.g., by habitat strata). Sampling in Puerto Rico is conducted approximately every 2 years (2014, 2016, 2019, expected 2021). NCRMP uses a stratified random sampling survey design to sample coral reef habitats to 99 feet depth; it is important to note that this survey design incorporates replication at the strata level, not at the site level. NCRMP provides benthic data on benthic cover (%), coral demographics, including species composition, abundance, and size structure, coral mortality (recent and old), and bleaching and disease presence or absence. NCRMP also provides fish data on species composition, abundance, and size structure, and additional data on the presence of conch and lobster, and abundance of Diadema urchins. NCRMP has conducted a total of 75 surveys of the shallow coral reef ecosystems surrounding Culebra. Combined, these surveys represent 2014 (22 surveys), 2016 (27 surveys), and 2019 (26 surveys) sample years. In addition, in 2014, NOAA's Restoration Center provided staff support to collect additional data on coral recruitment at NCRMP 2014 at the sites around Culebra. This information still needs to be compiled and analyzed. NCRMP data may be used as baselines for representative coral reef habitats and contextual information for the status of shallow coral reefs around Culebra.



Puerto Rico's Department of Environmental and Natural Resources (DNER) has a long-term [Coral Reef Monitoring Program (PRCRMP)]() with three fixed stations that include 5 replicate transects per station surrounding Culebra. PRCRMP collects data on benthic cover, coral species composition, disease prevalence, size and abundance of reef fish, and size and abundance of conch and lobster species every 2 years, which began in 2016 for sites located around Culebra. PRCRMP has conducted 2 surveys of the coral reef ecosystems surrounding Culebra in 2016 and 2018. Of the fixed-stations monitored, Dakiti is potentially representative of an LBSP impacted site, while Carlos Rosario and Luis Canal Pena are potentially reasonable reference sites. If there is interest in using these sites to support data needs for this framework, it would be worth conducting a power analysis of the existing data and protocols to determine if more sample sites and/or replicates are needed to detect change that is statistically significant. There may be an opportunity to build off of PRCRMP by adding new sites around Culebra that are informed by local hydrodynamics and knowledge of locations where LBSP runoff is persistent. If resources are available but limited there is an option to establish new fixed sites at optimal locations for long-term monitoring using Structure from Motion photomosaics. Photos may be taken to establish a baseline but analysis could be delayed until more funding is available.

In 2018, NOAA's National Center for Coastal and Ocean Science (NCCOS) established a series of 18 fixed photomosaic sites off the southeast coast of Culebra. These photomosaic sites were collected utilizing the Structure from Motion approach within a 10x10m area, creating a single mosaic at each site from the series of overlapping photos. These mosaics have not yet been analyzed for biological metrics. This presents an opportunity to establish a 2018 baseline for benthic cover, coral species composition, and potentially recent colony mortality.

Lastly, Sociedad Ambiente Marino (SAM) has been collecting coral habitat data at x sites around Culebra since the 1980s. These datasets include x, x, and coral recruitment. DNER is currently discussing a data sharing agreement with SAM to access, collaborate, and build off the existing data. An agreement would offer the opportunity to review available coral recruitment data and determine if sites that they monitor could serve as impacted and reference sites for this larger M&E Framework.

Currently, more information is needed from the pending hydrodynamic studies prior to making recommendations to pursue opportunities. All opportunities to use existing data need to be reviewed in conjunction with forthcoming hydrodynamic analysis and known LBSP discharge points to determine if they represent impacted nearshore habitats.

Additionally, if methods are compatible with NCRMP, the information from surveys to collect data for benthic cover and coral species composition may also be used to calculate numerous other coral indicators (USCRTF Priority Ecosystem Indicators (2016), Appendix G) which may be helpful in demonstrating changes in the coral community.

After conducting an initial review of existing coral reef ecosystem monitoring programs, we suggest that it would not be effective to meet the goals of detecting change from LBSP to simply leverage or combine the available information. None of the existing monitoring programs include all of the indicators selected during the 2020 workshop series. Without standing up a specific monitoring project, it will not be possible to acquire all of the information on the indicators that the working group initially identified. The fixed sites that are currently established may not be in locations suited for measuring change associated with LBSP inputs at the nearshore coral reefs off Culebra. The group may want to consider proposing a specific monitoring plan or potentially work with DNER to add sites to the PRCRMP monitoring program that would cover the preferred indicators. Additionally, consideration should be given to focusing on a subset of the four coral habitat indicators and using those in conjunction with the other data streams to be included in the multiple lines of evidence approach to determine whether resources are improving in nearshore habitats due to reductions in LBSP.

Indicator: Benthic cover

DEFINITION

A calculated measure of relative abundance of benthic cover of ecologically important types of sessile organisms and plants (live coral, macroalgae, turf algae, crustose coralline algae, sponges, etc.) and abiotic features (sand, sediment, pavement, etc.). For Culebra specifically, this can be categorized into important subsets of the cover types mentioned above to include *Dictyota* spp., *Lobophora variegata*, cyanobacteria, *Ramicrusta textilis* and *Peyssonnelia* algal crusts.

UNIT OF MEASURE AND EVALUATION OF SUCCESS

Percentage of biotic and abiotic elements occupying the benthos in a defined area. Data for this indicator will be analyzed to determine the mean values and variability for the benthic components of interest and trends of these mean values will be compared over time. These data will be included in the Multiple Lines of Evidence approach to be reviewed by subject matter experts to determine if the trends over time, statistically significant or not, suggest improvements in the resource.

METHOD

Benthic cover surveys should be conducted using protocols that are compatible with the NOAA National Coral Reef Monitoring Program (NCRMP) and/or PRCRMP's methods.

LOCATION

TBD -- fixed sites will be determined based on hydrodynamic characteristics and locations of known points of discharge of land-based runoff that impact nearshore areas. Once identified, these sites should be colocated with water quality sampling.

FREQUENCY / DURATION

Baselines should be established ASAP and regular, periodic monitoring should be conducted every 2-5 years.

COST ESTIMATE

TBD

Indicator: Coral Species Composition

DEFINITION

Relative abundance of coral species with discretionary biological, physical or regulatory attributes (e.g., tolerance, branching, protected status).

UNIT OF MEASURE AND EVALUATION OF SUCCESS

A compiled list of coral species present and the number of colonies of each species in a defined area. These data will be included in the Multiple Lines of Evidence approach to be reviewed by subject matter experts to determine if the trends over time, statistically significant or not, suggest improvements in the resource.

METHOD

Surveys to collect information about coral species composition should be conducted using protocols that are compatible with the NCRMP and/or PRCRMP's methods.

LOCATION

TBD -- fixed sites will be determined based on hydrodynamic characteristics and locations of known points of discharge of land-based runoff that impact nearshore areas. Once identified, these sites should be colocated with water quality sampling.

FREQUENCY / DURATION

Baselines should be established ASAP and regular, periodic monitoring should be conducted every 2-5 years.

COST ESTIMATE

TBD

Indicator: Coral Recruitment

DEFINITION

Coral recruitment is the process by which coral larvae undergo larval settlement and survive to become part of the adult population. [Additionally, a viable proxy for recruitment data may be CCA cover using NCRMP data but this would not give us site specific information.]

UNIT OF MEASURE AND EVALUATION OF SUCCESS

The abundance of juvenile corals less than 4cm in diameter observed per unit area. These data will be included in the Multiple Lines of Evidence approach to be reviewed by subject matter experts to determine if the trends over time, statistically significant or not, suggest improvements in the resource.

METHOD

TBD -- would like any additional coral recruitment monitoring to be complementary to the methods used by SAM.

LOCATION

TBD -- fixed sites will be determined based on hydrodynamic characteristics and locations of known points of discharge of land-based runoff that impact nearshore areas. Once identified, these sites should be colocated with water quality sampling.

FREQUENCY / DURATION

Baselines should be established ASAP and regular, periodic monitoring should be conducted every 2-5 years.

COST ESTIMATE

TBD

Indicator: Recent Colony Mortality

CONSIDERATIONS

This indicator has limitations, as shown in recent analysis of NCRMP coral condition measurements. Recent mortality is heavily influenced by the timing of sampling (e.g., during a coral mortality event), and is highly temporally variable. Old mortality has limitations including 1) that it cannot be definitively linked to a source of mortality, and 2) as coral colonies with a high proportion of mortality continue to degrade over time, it can be difficult to differentiate between remnant fragments of what had been a large coral colony and small colonies that are growing on dead coral.

DEFINITION

Recent mortality is defined as the exposed white bare skeleton on a coral colony that does not have bleached tissue present and is not colonized by algae or other organisms. These data will be included in the Multiple Lines of Evidence approach to be reviewed by subject matter experts to determine if the trends over time, statistically significant or not, suggest improvements in the resource.

UNIT OF MEASURE AND EVALUATION OF SUCCESS

Estimate of the recent mortality as a percentage of the total colony size.

METHOD

Surveys to collect information about recent colony mortality should be conducted using protocols that are compatible with the NCRMP coral demographic protocols.

LOCATION

TBD -- fixed sites will be determined based on hydrodynamic characteristics and locations of known points of discharge of land-based runoff that impact nearshore areas. Once identified, these sites should be colocated with water quality sampling.

FREQUENCY / DURATION

Baselines should be established ASAP and regular, periodic monitoring should be conducted every 2-5 years.

COST ESTIMATE

TBD

Table 4. Summary of Aspirational Monitoring Recommendations. At a minimum, monitoring of these indicators before, during, and after LBSP implementation will provide the ability to track implementation of projects and evaluate their effectiveness over time. This table outlines management evaluation questions, recommended indicators for monitoring and answering each management question, the type of indicator (project tracking or effectiveness), priority locations for monitoring - if known, frequency and duration of monitoring, estimated annual costs of monitoring, and funding source - if available. At a minimum, monitoring of these indicators before, during, and after LBSP implementation will provide the ability to track implementation of projects and evaluate their effectiveness over time.

Evaluation Question	Indicator	Indicator type	Priority Location(s)	Frequency	Duration	Funding	Annual Cost
Has seagrass habitat conditions improved?	Benthic cover	Seagrass habitat effectiveness	Nearshore fixed station (n=TBD)	Every 3 to 5 years	10+ years	TBD	TBD
	Shoot density						
	Epiphyte load						
	Deep edge of bed						
Has coral reef habitat condition improved?	Benthic cover	Coral reef habitat effectiveness	Nearshore fixed station (n=TBD)	Every 2 to 5 years	10+ years	TBD	TBD
	Coral Species Composition						
	Coral Recruitment						
	Recent Colony Mortality						