



Integrated Ridge-to-Reef Monitoring Framework: Tracking Reduction of Land-Based Pollutants and Their Impact on Caribbean Near-Shore Ecosystems in Culebra, Puerto Rico

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PROTECTORES DE CUENCAS (NGO)

ICRI WEBINAR SERIES: THE IMPACTS OF LAND-BASED SOURCES OF
POLLUTION ON CORAL REEFS

APRIL 4TH, 2024





Protectores de Cuencas

- Non-profit, non-governmental and community-based organization.
- Dedicated to establishing restoration and environmental management projects from a perspective of integrated watershed management.
- Headquarters located in Yauco
- Founded in January 2012



Projects Implemented by PDC



Tres Palmas Marine Reserve, Steps Beach

- Permeable parking
- Wooden boardwalk
- Green infrastructure



- Restoration
- Trail rehabilitation
- Erosion and sediment reduction



- Dirt road stabilization
- Coral nurseries and outplanting

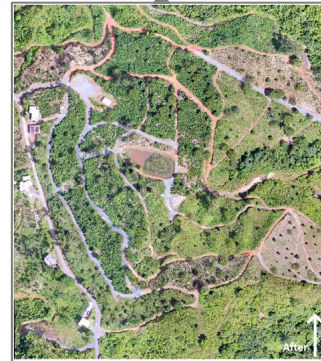
Northeastern Ecological Corridor



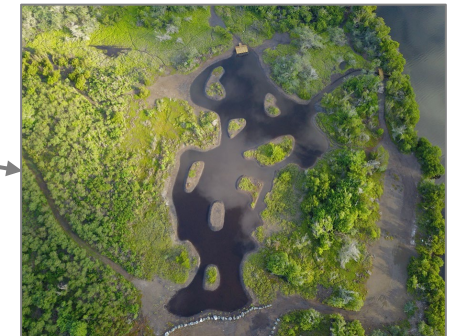
- Wetland restoration
- Shoreline stabilization



- Green infrastructure
- Dirt road stabilization
- Coastal reforestation



- Dirt road stabilization
- Sediment detention ponds
- Rainfall-runoff research



Culebra Island



Google Earth

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

- Culebra lies ~28 km east of mainland PR and consist of a 26.6 km² major land mass and 20 cays. Culebra has a maximum elevation of just shy of 200 m with slopes averaging 28%.
- The island's vegetation is sub-tropical dry, typical where annual rainfall rates, averaging 45 inches, are low relative to evapotranspiration potential (Ewel and Whitmore 1973).
- Watersheds within Culebra do not exceed 3 square kilometers in drainage area and mostly are drained by ephemeral streams.



FLAMENCO BEACH

CULEBRA ISLAND, PUERTO RICO

#26 IN THE WORLD

THE WORLD'S 50 BEST BE

Home of world-renowned beaches

- Culebra is one of the 78 municipalities of the island of Puerto Rico.
- Home of the third best beach in the world in 2014 according to Trip Advisor's Traveler's Choice Awards.
- Ranked 26th best beach in the world in 2023.

Coral Reefs in Culebra


- The island-municipality of Culebra supports coral reef ecosystems that are characteristic of the northeastern Caribbean marine biodiversity (Hernandez-Delgado et al. 2000) and represent valuable sources of fishing, tourism, and recreational activities (Montanez Acuna 2022).
- Culebra is a priority coral reef protection site for the Commonwealth of Puerto Rico (PR-Commonwealth and NOAA-CRCP 2010).
- Multiple organizations like Sociedad Ambiente Marino are invested in coral reef restoration.
 - www.sampr.org



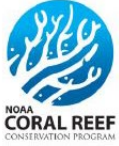
Image: www.coralesdelestep.com

Culebra Community Watershed Action Plan for water quality and coral reefs (2014)

- Mitigation of erosion from unpaved roads.
- Restoration efforts and development of green infrastructure to reduce sediment and sewage delivery to the coast.
- Need to assess effectiveness of implementations and restoration efforts.




CULEBRA
COMMUNITY WATERSHED ACTION PLAN FOR
WATER QUALITY AND CORAL REEFS




NOAA
CORAL REEF
CONSERVATION PROGRAM

PREPARED FOR
NOAA CORAL REEF CONSERVATION PROGRAM
PUERTO RICO DRNA
CULEBRA OFFICE OF THE MAYOR




DRNA




ridge to reefs

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Protectores de Cuencas




Protectores de Cuencas




CATEC

Coral Reef Summaries
Edwin A. Hernández-Delgado
Carmen González-Ramos
Alfredo Montañez-Acuña
Abimarie Otaño-Cruz




NSF



UNIVERSITY OF PUERTO RICO
DEPARTMENT OF COMMERCE

University of Puerto Rico, Center for Applied Tropical Ecology and Conservation
Sociedad Ambiente Marino



NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

March 2014

Table 2. Priority Areas for Implementation Identified by Stakeholders

Priority Areas	
Dirt Roads	Green Infrastructure(GI)/ GI Development
Boats and waste disposal	Solar energy
Residential connections to the sewer system	Education about contamination
Recycling / compost	Engage and involve students in activities
Nursery – Native Reforestation	



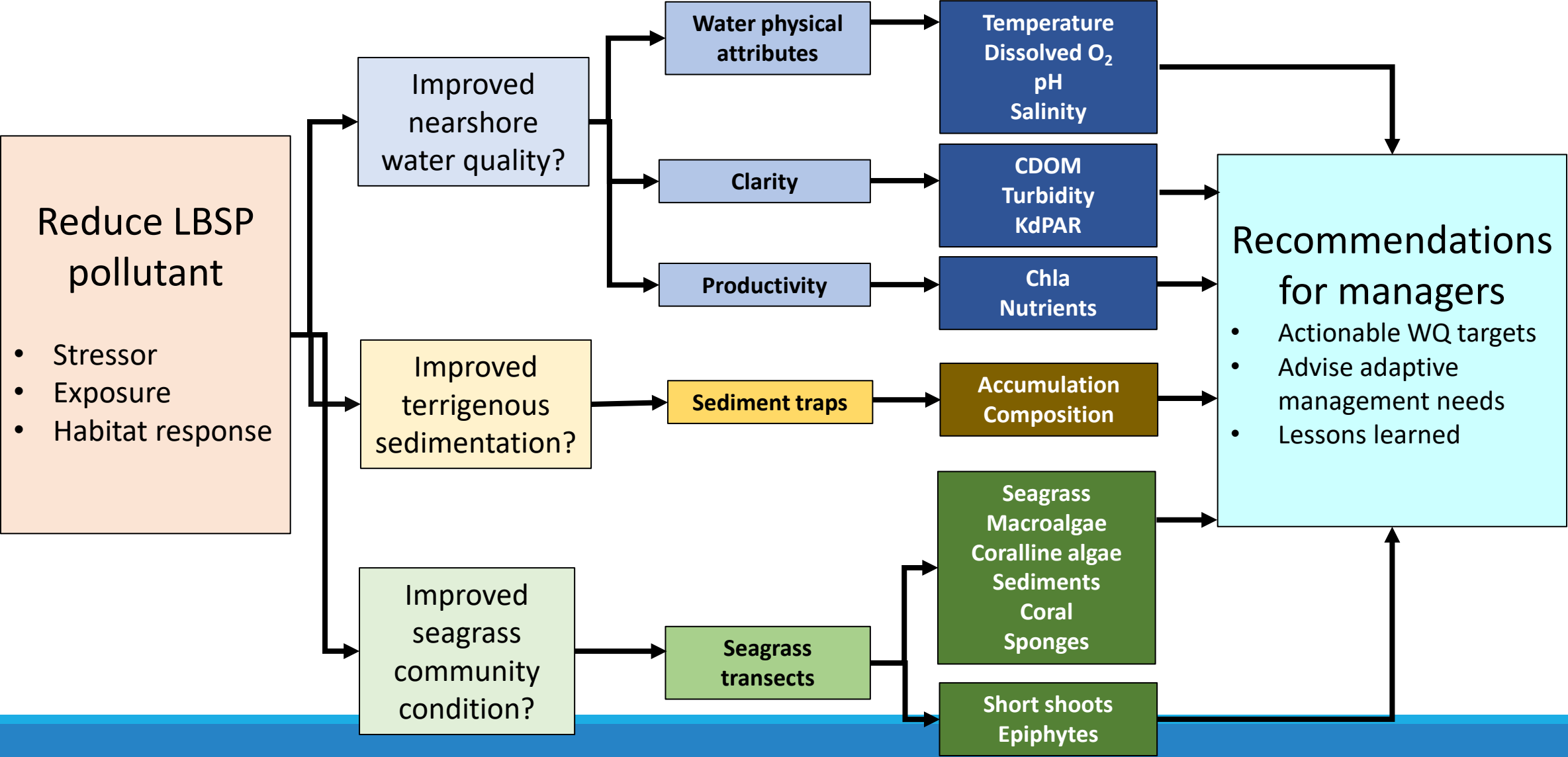
Shoreline stabilization

Unpaved road stabilization

Permeable parking

Implementation of green infrastructure

Monitoring & Evaluation Framework



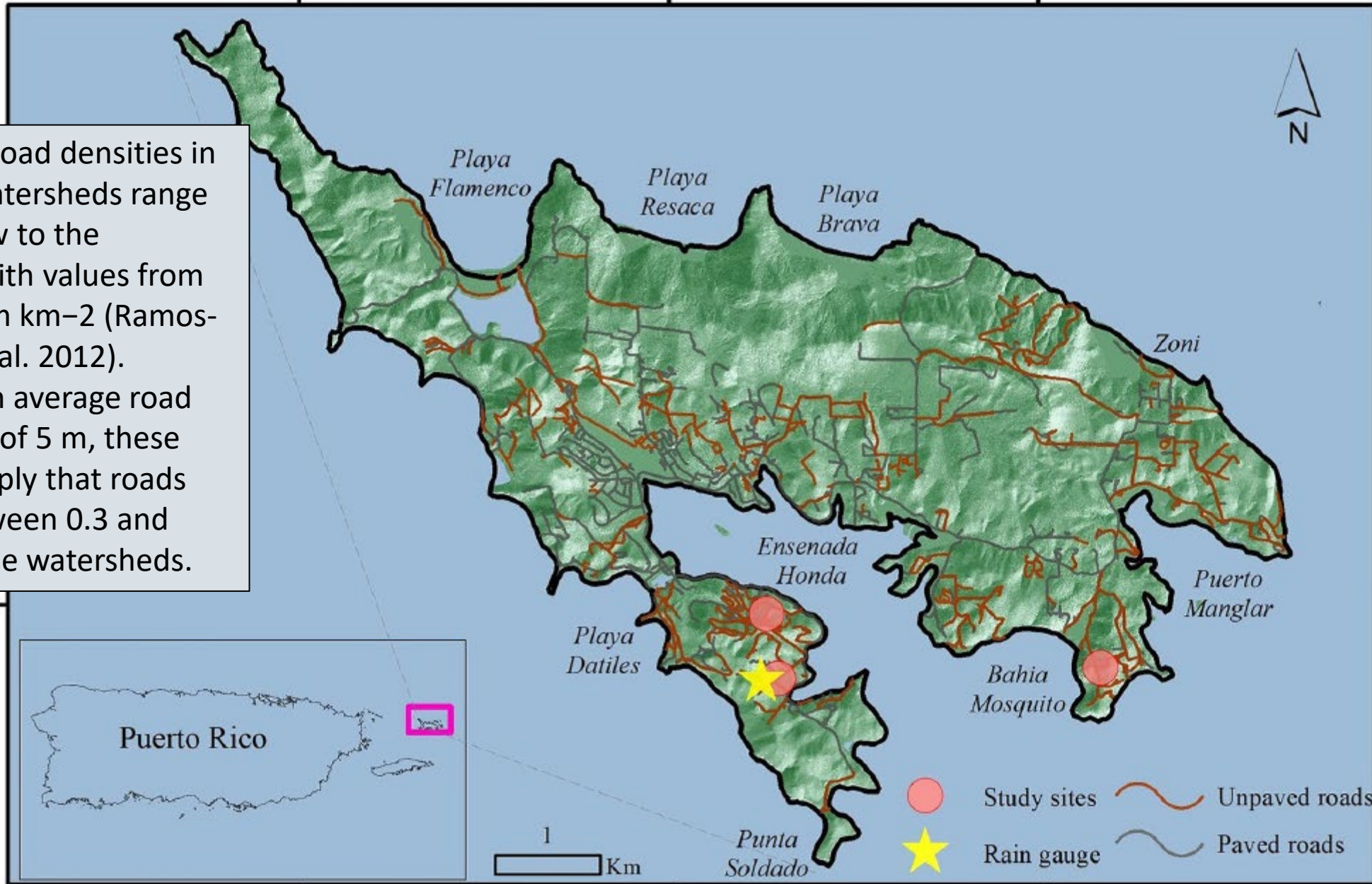
Monitoring of Stressors

a)

65°20'W

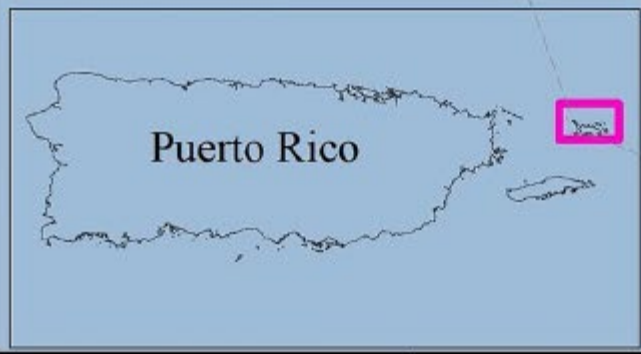
65°18'W

65°16'W



➤ Unpaved road densities in Culebra's watersheds range from the low to the moderate with values from 0.7 to 6.4 km km⁻² (Ramos-Scharrón et al. 2012). Assuming an average road tread width of 5 m, these densities imply that roads occupy between 0.3 and 3.2% of these watersheds.

- Study sites
- ★ Rain gauge
- Unpaved roads
- Paved roads



Rainfall Simulation Experiments

- Experiments were conducted using a standardized rainfall simulator design (Luk et al. 1986) and bounded plots delimited by ~ 2.5-cm thick iron plates vertically pounded into the soil.
- Rainfall was measured every 5 min.
- Experimental rainfall intensities were in the 30 to 70 mm/hr range (48 mm/hr average), which represent 1-h rain rates expected to occur in Culebra between once a year to once every 25 years, respectively (every 5 years for the average value) (Bonnin et al. 2006).
- Runoff was measured every minute.
- Sediment concentration samples were collected every 5 minutes.



Empirical documentation of the impact of unpaved roads on runoff and erosion

On average ~ 70 min and ~ 65 mm (2.5 inches) of rain at a rate of ~ 55 mm/hr (2.2 in/hr) were needed to generate any runoff from natural hillslopes.

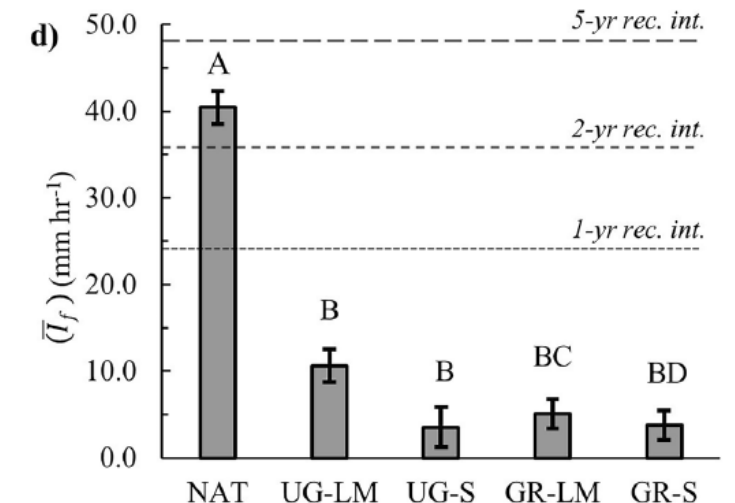
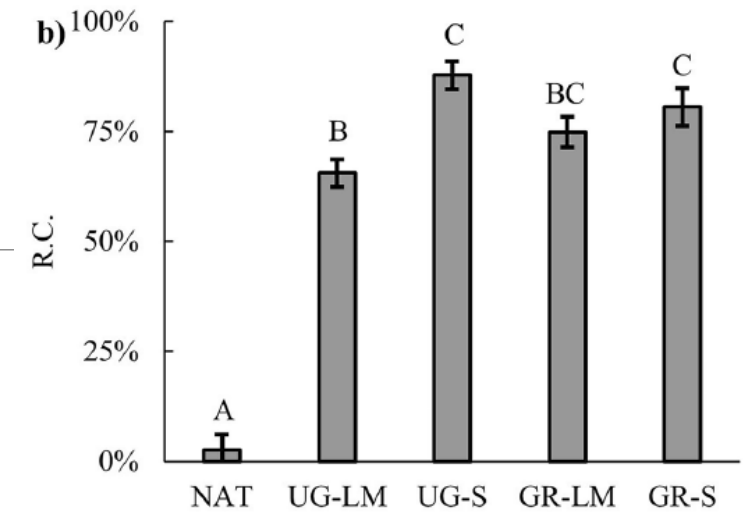
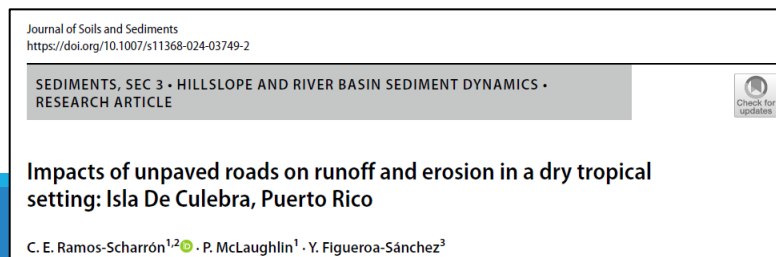
In contrast, road runoff began 2–4 min into the experiment and after only ~ 2 mm of rainfall at rain intensities of 35–50 mm/hr (1.4-1.9 mm/hr) range.

The modeled infiltration rate of natural hillslopes ranged from 55.8 mm/hr (2.2 in/hr) during the first 175 minutes of rainfall to 33.5 mm/hr after 225 minutes of rainfall.

In contrast to natural hillslopes, infiltration rates for roads were 35–54 mm/hr early during the rainfall simulations and dropped to 3.5–10.6 mm/hr during the last 15 min of the experiments.

Reference:

<https://link.springer.com/article/10.1007/s11368-024-03749-2>



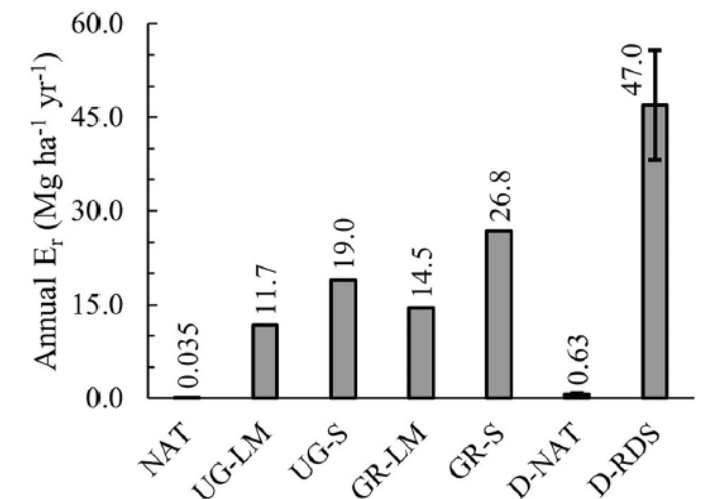
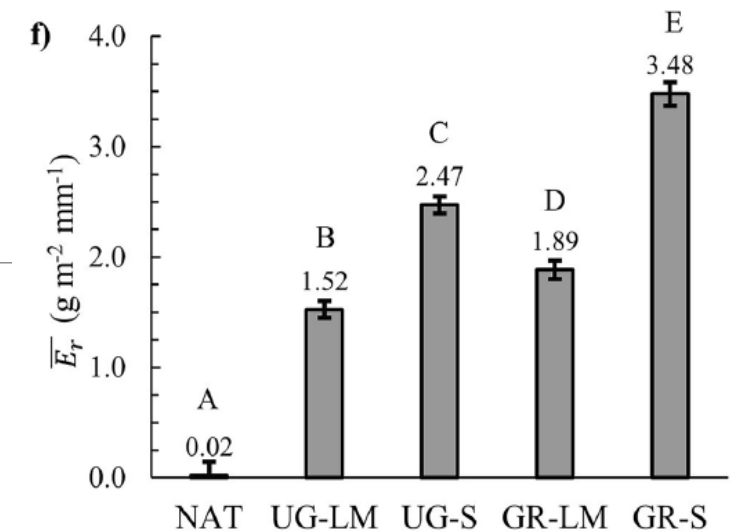
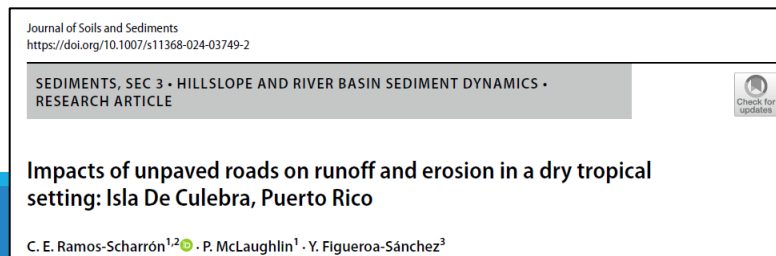
Empirical documentation of the impact of unpaved roads on runoff and erosion

➤ Annualized road erosion rates in Culebra are between 330 and 760 times greater than natural erosion ($\sim 0.035 \text{ Mg ha}^{-1} \text{ yr}^{-1}$).

➤ These are on the midrange of values reported for similar dry tropical areas in the Caribbean (i.e., St. John-USVI and La Parguera and Cabo Rojo in Southwest PR) which average $\sim 47 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ (Ramos Scharrón et al. 2023), yet individually have reached up to $580 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ (Ramos Scharrón and MacDonald 2007)

Reference:

<https://link.springer.com/article/10.1007/s11368-024-03749-2>



Jardín Pluvial PR-250 Culebra

➤ Before Implementation

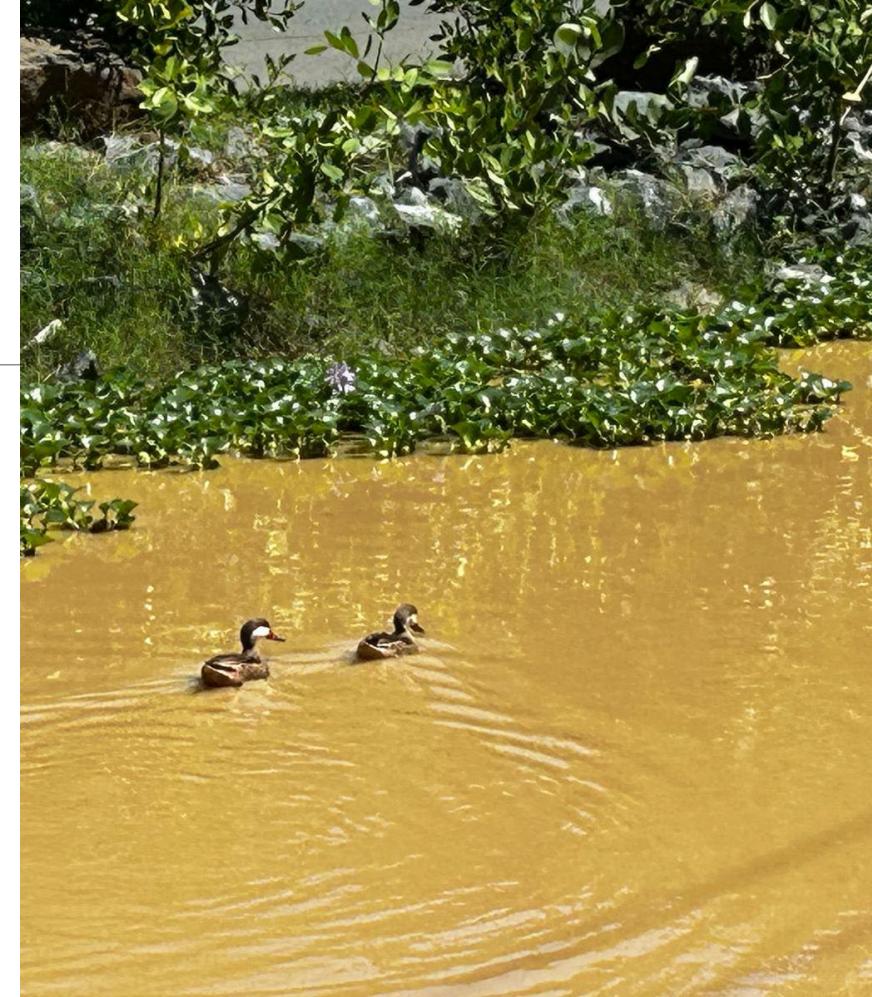
➤ Common drainage point of close to 1.3 miles of unpaved roads within the Coronel watershed.



Sep 14, 2023 at 10:40:33 AM
+18.312373, -65.291859 ±4.57m
Puerto Rico



Jardín Pluvial en PR-250 (Culebra, PR)



- Imágenes del 28 de febrero de 2024.
- Luego de 1.24 pulgadas de lluvia en 24 horas aprox.
- Estos eventos representan el 42% de la lluvia registrada en febrero.
- Previo a esto no hubo evento de lluvia significativo desde el 6-7 de febrero.

Evento	Cantidad de lluvia (Pulgadas)	Duración (horas)	Intensidad Max (pulg/hr)
Feb 26 (6:15 pm)	0.45	3.75	0.3
Feb 27 (7:00 am)	0.07	1.75	0.06
Feb 27 (1:30 pm)	0.53	1.75	0.41
Feb 27 (5:30 pm)	0.19	1.75	0.18
Total de lluvia	1.24 pulgadas		



PARADA
GUAGUA
ESCOLAR

Coronel Camino Cofresí

➤ Pre-Implementation
images

➤ Drains to main rain
garden in PR-250







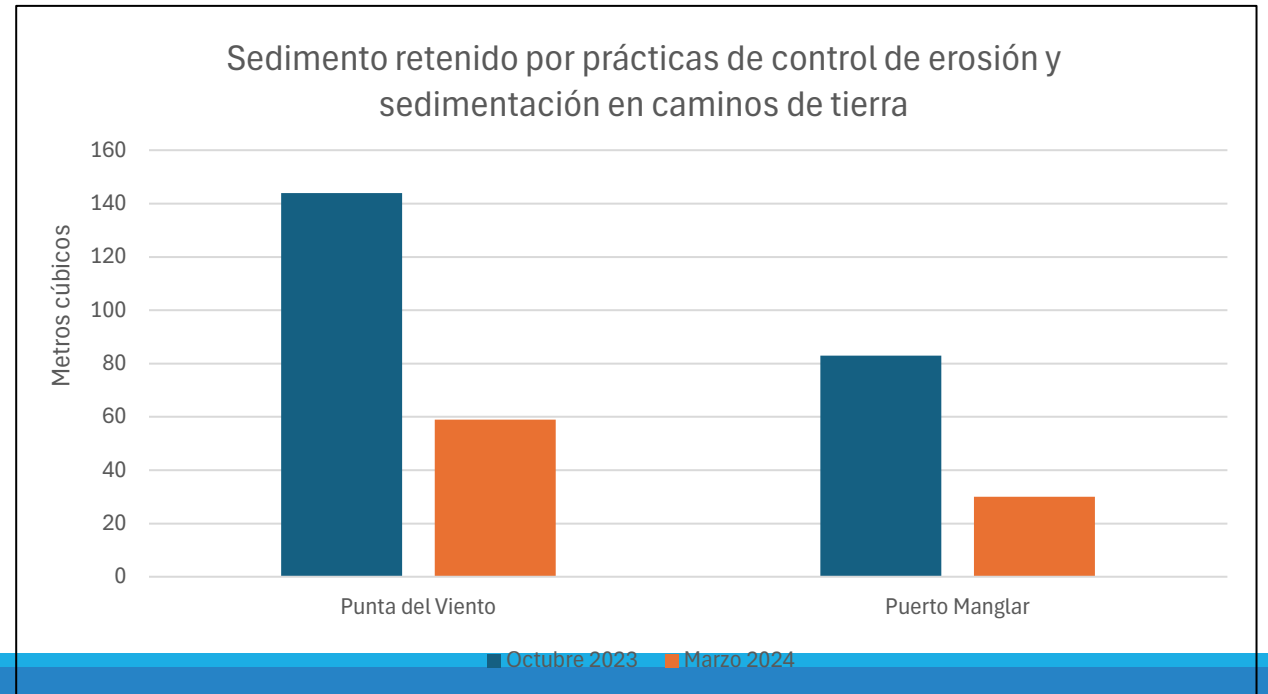




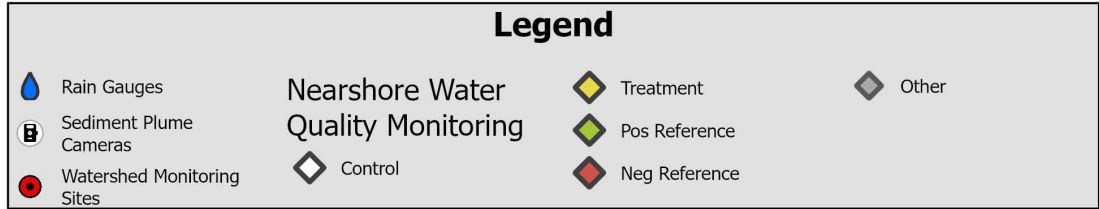
Mantenimiento y monitoreo de proyectos de estabilización de caminos de tierra



The delivery of nearly 400 cubic meters of sediment to the sea has been avoided in the last 2 years



Monitoring of Exposure



Sediment Traps



- A total of 26 sediment traps were installed in 13 monitoring fixed station.
 - Sediment traps were installed at ~10 feet depth.
 - Sediment traps are monitored every 3 months.
- Will provide data on sediment delivery rate and composition.

Nearshore Water Quality Monitoring

- Measurements are done with a Eureka Manta+35 multi-sonde probe sonde at 1-m and 2-m depth.
- Photosynthetically available radiation is measured using an Apogee PAR sensor.
- Water samples are collected to measure enterococci levels, nutrients and tracers (i.e. caffeine and sucralose).
- Nutrient and tracers analyses is being carried out by NOAA's NCCOS.

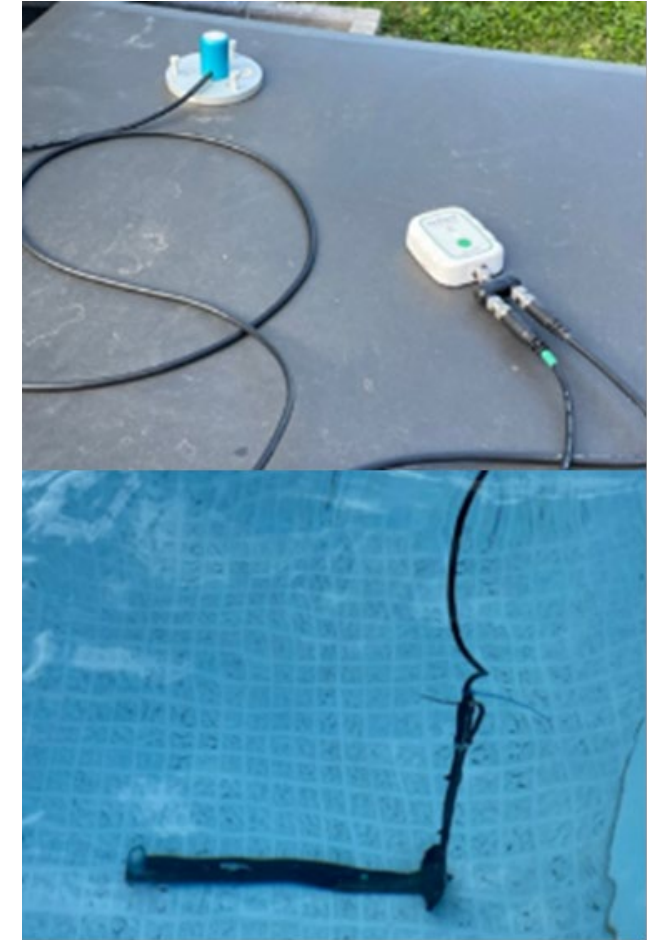
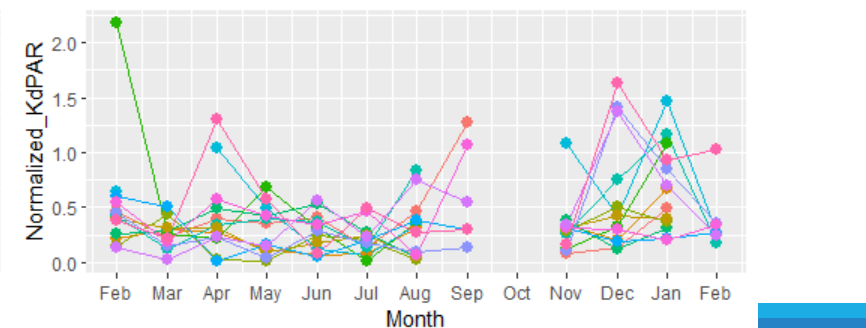
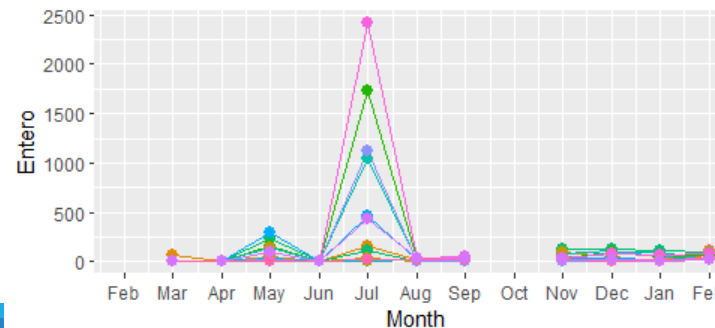
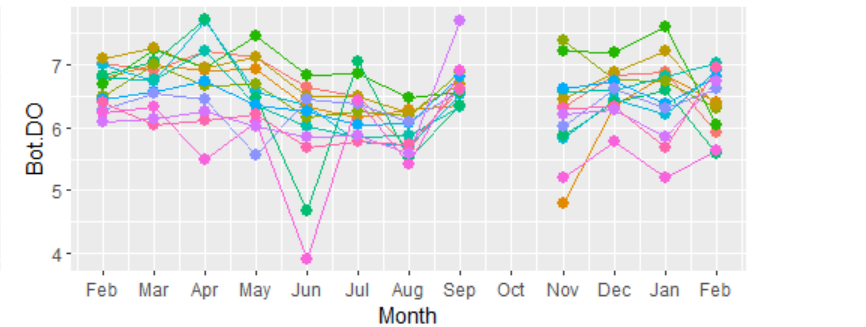
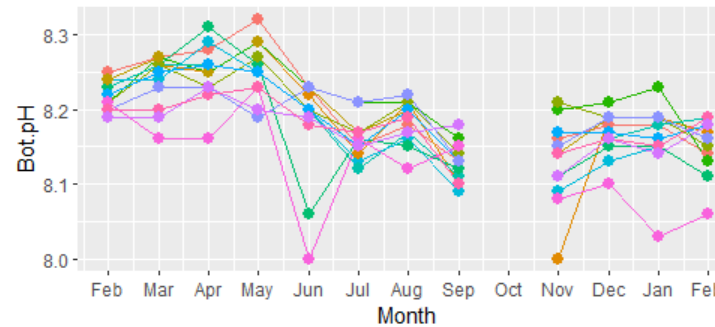
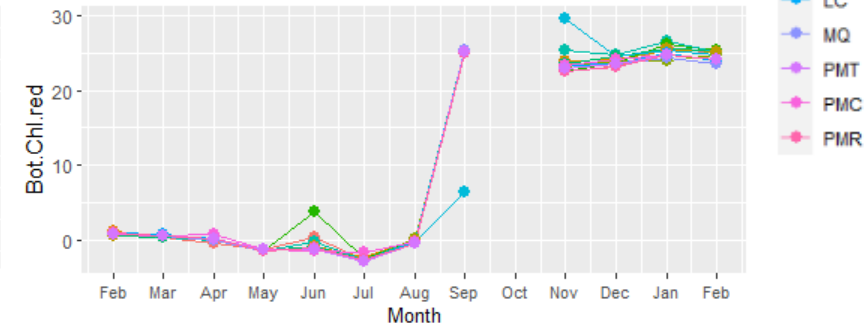
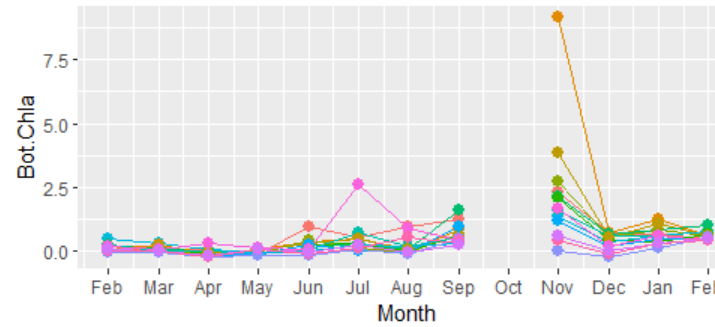
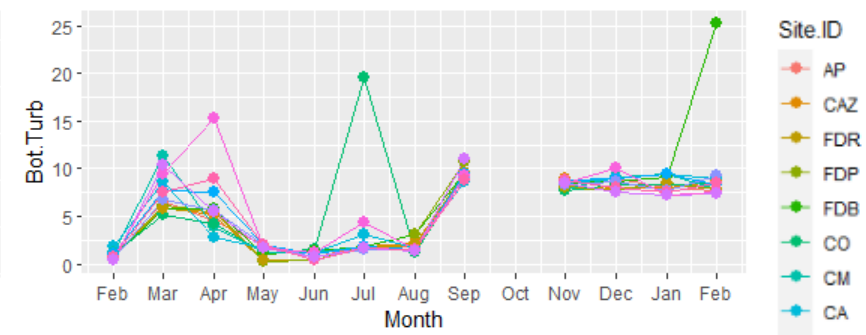
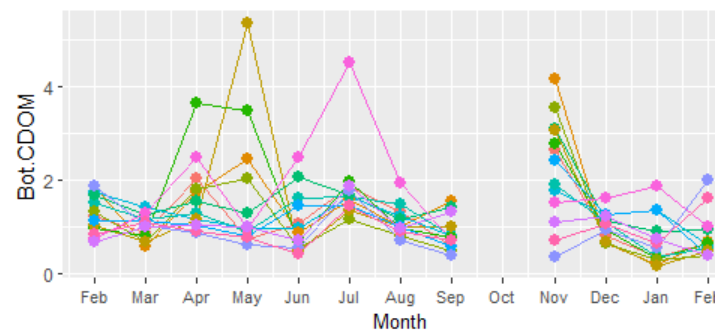
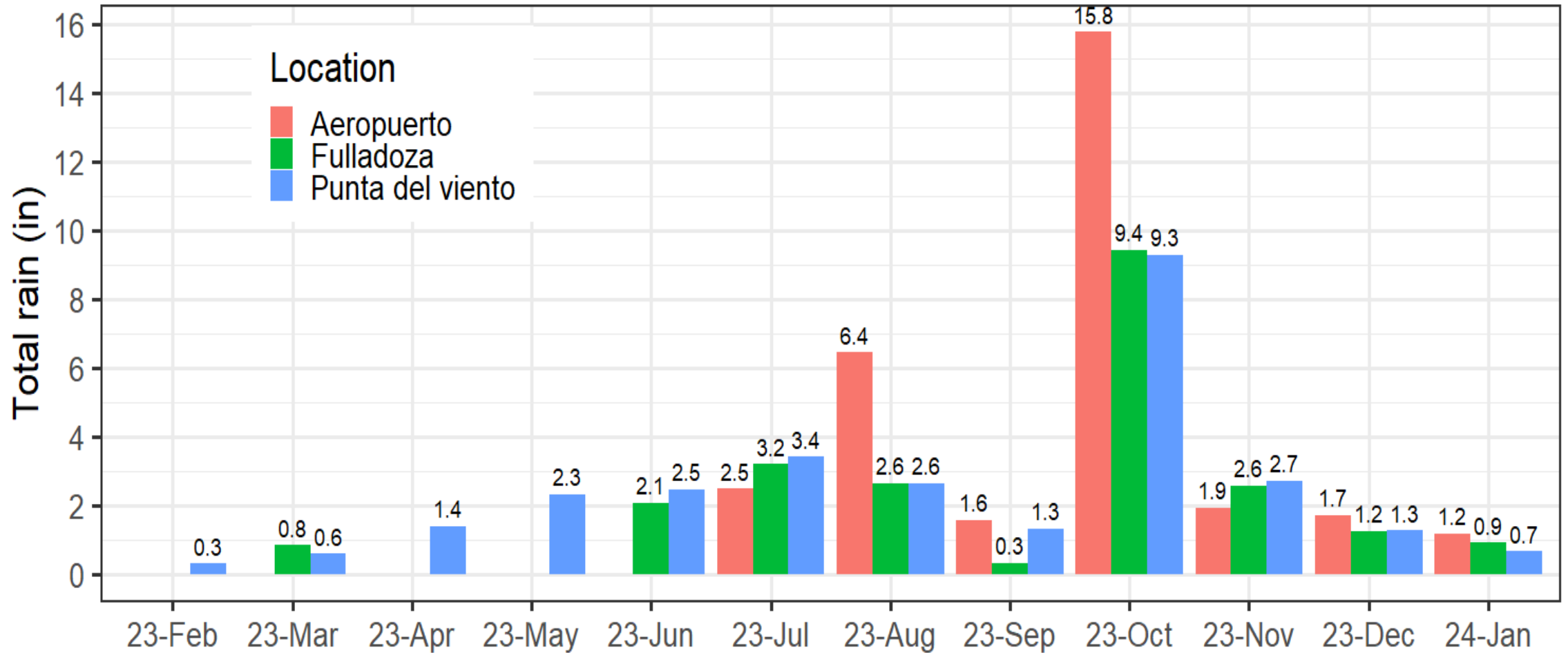


Figure 4: APOGEE PAR sensors

Preliminary Nearshore Water Quality Data

- Strong correlation between 1-m and 2-m depth measurements.
- Time series show variability along time for most parameters.
- This trend maybe related to changes in rainfall.



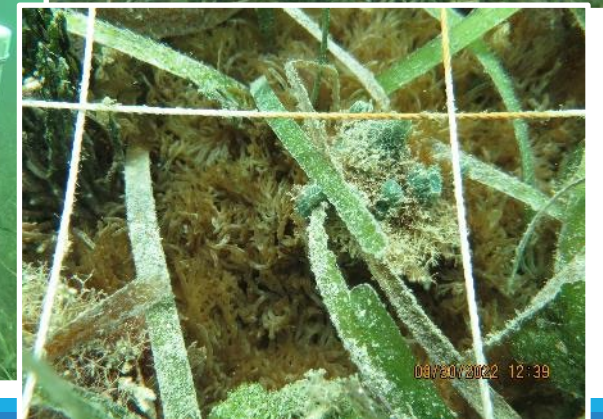
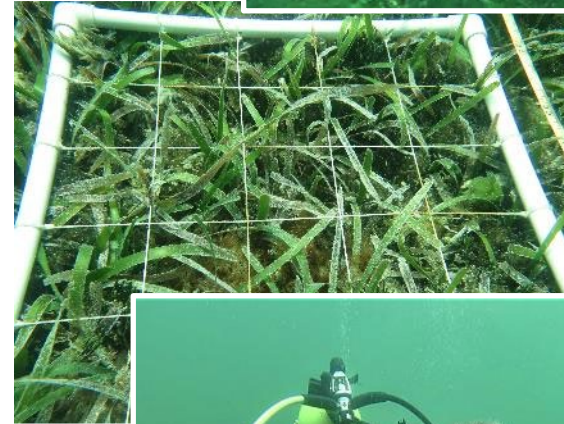


Monthly rainfall for monitoring period

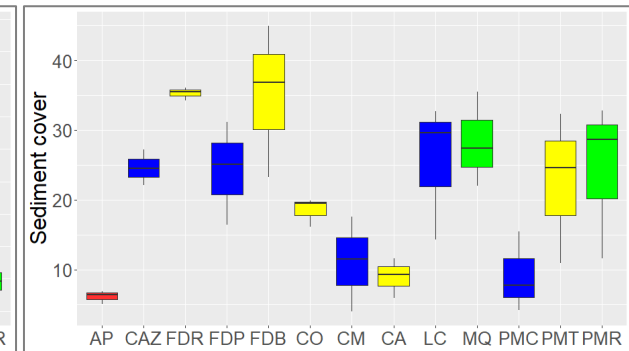
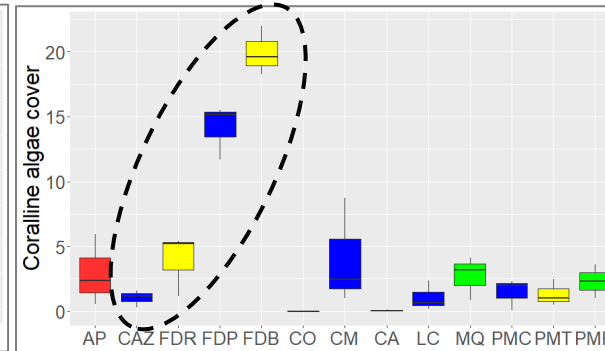
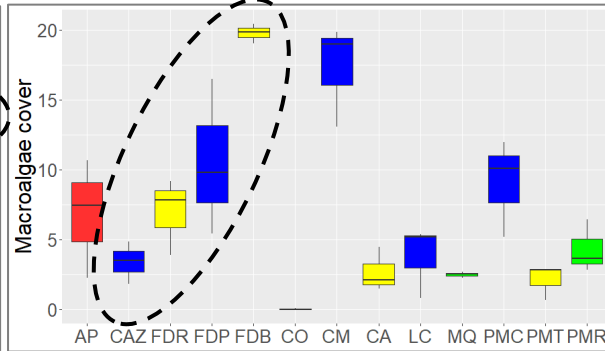
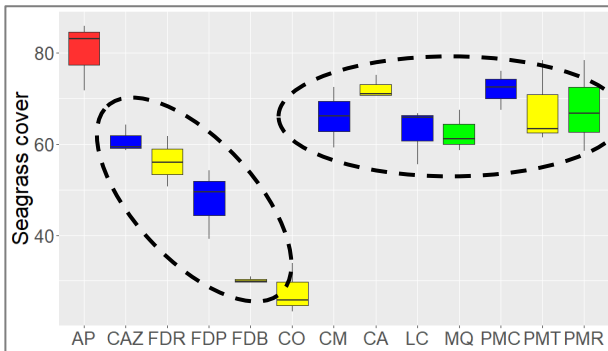
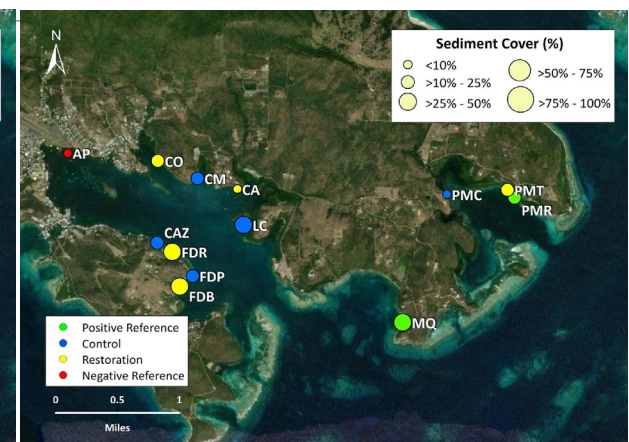
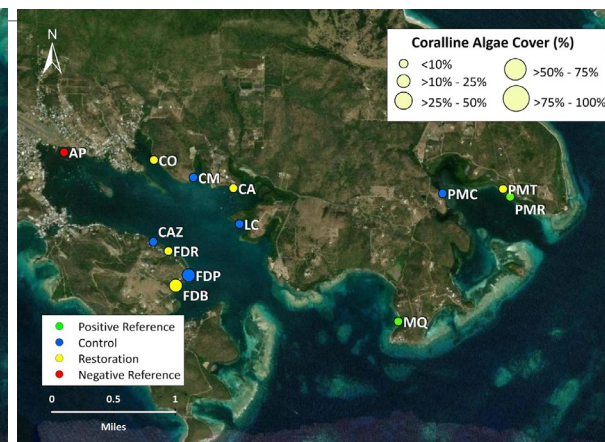
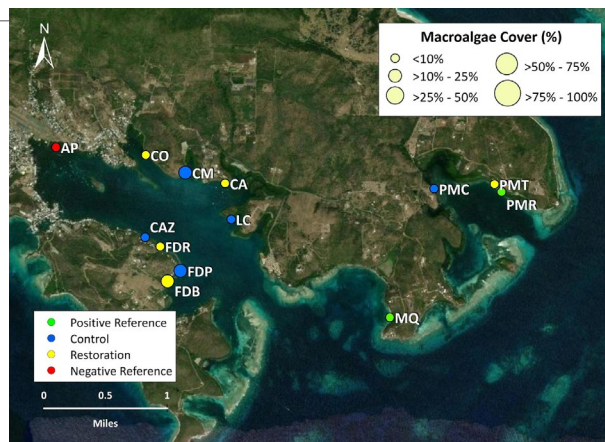
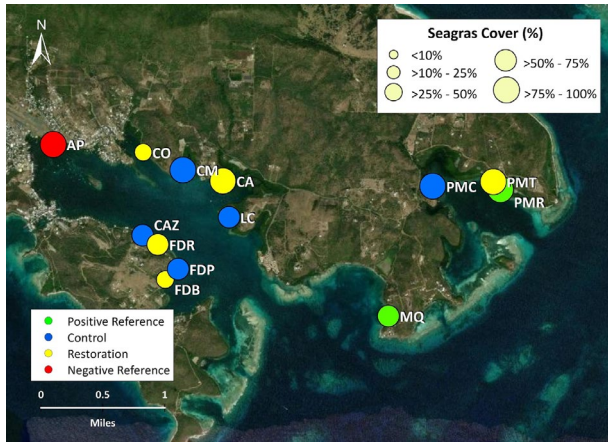
Habitat Response Monitoring

Sea grass monitoring

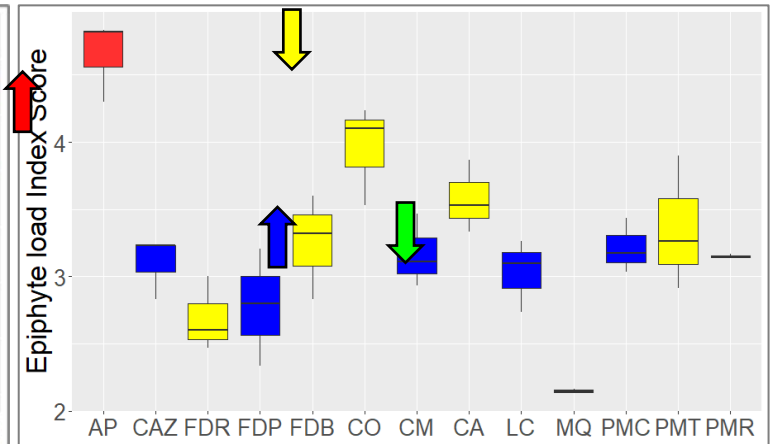
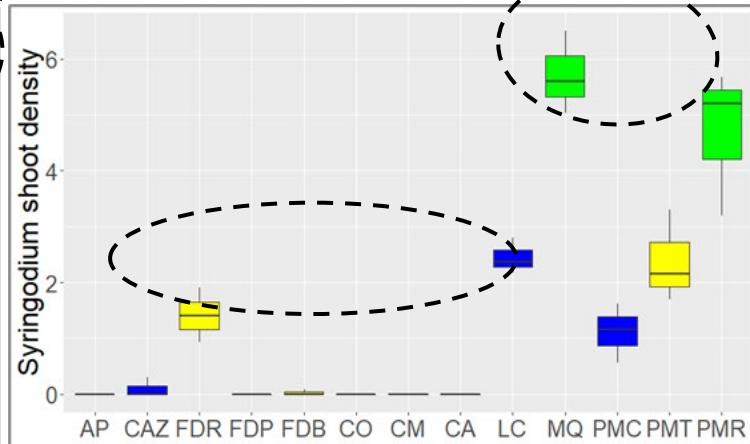
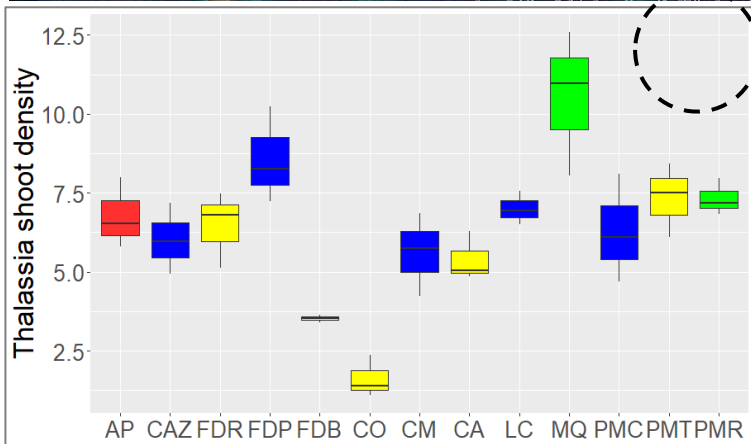
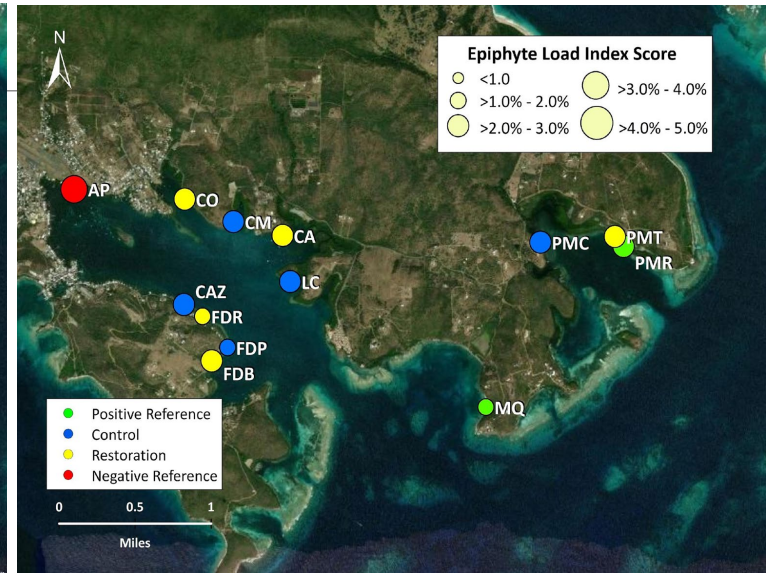
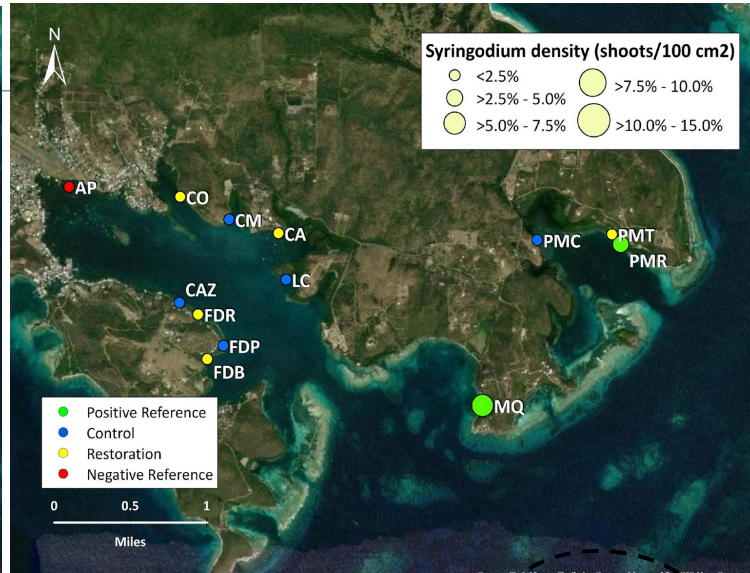
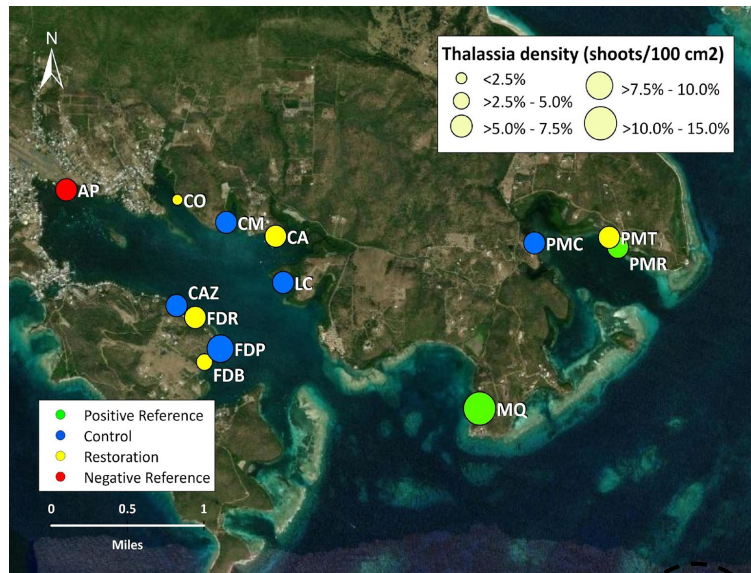
- Data from 2014 and 2022.
- Benthic cover and demographics.
- Epiphytometers at fixed monitoring stations.



2022 Culebra Seagrass Benthic Cover



2022 Culebra Seagrass Demographics



Next Steps



COMPLETE DATA ANALYSIS.
ESTABLISH WATER QUALITY
TARGETS



SECURE FUNDING FOR LONG-
TERM MONITORING.
CONTINUE IMPLEMENTATIONS



UPDATE WATERSHED
MANAGEMENT
RECOMMENDATIONS BASED ON
DATA ANALYSIS OF
PERFORMANCE AND
EFFECTIVENESS OF GREEN
INFRASTRUCTURE AND BEST
MANAGEMENT PRACTICES.



IMPROVE DESIGN OF BMPS AND
GREEN INFRASTRUCTURE BASED
ON ANALYSIS OUTCOMES.

Relevant Literature and Websites

- Culebra community watershed action plan for water quality and coral reefs
 - <https://repository.library.noaa.gov/view/noaa/829>
- Impacts of unpaved roads on runoff and erosion in a dry tropical setting: Isla De Culebra, Puerto Rico
 - <https://link.springer.com/article/10.1007/s11368-024-03749-2>
- Three Decades of Road and Trail Runoff and Erosion Work in the Northeastern Caribbean – A Research Program Perspective
 - <https://elibrary.asabe.org/abstract.asp?aid=53790>
- Corales del Este (Website of Culebra's Marine Protected Area)
 - <https://www.coralesdelestepur.com/>
- Sociedad Ambiente Marino (Partner Organization focused on coral reef restoration)
 - <https://www.sampr.org/>
- Monitoring and Evaluation Framework Portal
 - <https://the-culebra-project-horsleywitten.opendata.arcgis.com/>



Thank you for your attention

FOR MORE INFORMATION

PROTECTORES DE CUENCAS :
WWW.PROTECTORESDECUENCAS.ORG

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