Final Project Progress Report (05/30/17)

"Year 2: Assessment of the impact of watershed restoration on marine sediment dynamics in the USVI"

Submitted by:
Sarah Gray, Principle Investigator
Environmental and Ocean Sciences Department
University of San Diego (sgray@sandiego.edu)

Award Number: NA14NOS4820097
Recipient Name: University of San Diego
Award Period: 07/01/2014-6/30/2017
Program Office: NOS Office of Ocean and Coastal Resource Management (OCRM)
Program Officer: Liz Fairey, 301-427-8632, liz.fairey@noaa.gov

EXECUTIVE SUMMARY

Terrigenous sediment derived from unpaved roads is a significant stressor to coral reefs in the US Virgin Islands. The 10.7 km^2 Coral Bay, St. John, USVI watershed was the focus of a NOAA-ARRA watershed restoration program completed in 2011. A seven year terrestrial-marine monitoring program to assess the effectiveness of this restoration at multiple spatiotemporal scales measured: terrestrial erosion and runoff-sediment yields; time integrated (sediment traps) and high resolution (nephelometers) marine terrigenous sedimentation, sediment composition/grain size and turbidity at shoreline and coral reef sites.

This grant from the DCRC (Domestic Coral Reef Conservation) supplemented ongoing funding (non-competitive NOAA CRC) for this joint terrestrial-marine sediment monitoring project to support marine sedimentation monitoring from Aug.-Nov. of 2014 and—through cost savings--2015 (at two sites). The aim of this project was to a) gain a greater understanding of the linkages between watershed processes and marine sedimentation, b) compare marine sediment-monitoring protocols for coral reef areas, and c) to evaluate the effectiveness of ARRA watershed restoration activities on marine sedimentation and coral health (indirectly).

Our USD research team monitored sedimentation (at regular intervals ~26 days) using tube sediment traps, SedPods (at select reef sites) and benthic sediment in Coral Bay and Great and Little Lameshur Bays at 12 sites below 5 sub-watersheds on St. John. Our approach was to compare sedimentation below developed and restored watersheds to undeveloped "reference" sites. Nephelometers were deployed at three reef and five shoreline sites next to ephemeral stream outfalls equipped with a water level sensor (10-min resolution) and peak crest gauges (~13-day resolution). The water-level sensors and crest gauges were monitored by our collaborator (C. Ramos-Scharron). After collection, sediment samples were filtered (< 3 microns), dried and weighed to determine the mass of sediment accumulated per unit area over the time deployed. The % organic matter, carbonate and terrigenous sediment in each sample were determined by Loss on Ignition (LOI) and the grain size distribution measured on an LS 200 laser particle sorter.

Consistent with previous results, terrigenous sedimentation was greater below developed compared to minimally developed watersheds. The main factors that explained the spatial variability in the magnitude of the marine sedimentary response to runoff included the degree of watershed development, and possibly ARRA watershed restoration. Resuspension-induced turbidity and deposition were associated with hydrodynamic energy caused by waves during low tides, finer benthic sediment grain size, and also low macrophyte abundance.

Resuspension-induced spikes in turbidity and deposition were lower in magnitude but of longer duration (days-weeks), than were turbidity plumes generated by runoff, particularly at sites with finer-grained benthic sediments, and were associated with increased wave height during low tides. Resuspension contributed at least seven and three times more to turbidity and deposition, respectively than runoff over the monitoring period. Activities that increase resuspension, such as marina

construction related destruction of macrophyte beds and boat prop-wash, could potentially negate improvements from ARRA watershed restoration.

The high variability of marine terrigenous sedimentation rates due to sediment resuspension limited the statistical significance of mean pre- vs. post-restoration terrigenous sedimentation rate comparisons. However, significant decreases in the percentages of terrigenous sediment and % clay were found below the restored watersheds post-restoration. A reduction in % clay post-restoration is consistent with terrestrial monitoring, which demonstrated a post-restoration reduction in delivery of fine-grained sediment (clay) from unpaved roads to the marine environonment.

We found monthly mean sediment trap accumulation rates and nephelometer data were strongly correlated at the majority of sites. However, SedPod accumulation rates (net accumulation rates) did not correlate with sediment trap (gross accumulation rates) or time-averaged nephelometer deposition rates. We think the that most promising approach for marine monitoring of watershed restoration should combine high-resolution sediment deposition and turbidity data from nephelometers, with sediment-trap accumulation rates, sediment grain size, and the composition (% terrigenous vs. %carbonate) and geochemistry (particularly to track residence time) of the sediments. The Coral Bay watershed restoration and monitoring program may serve as a case study on how to develop effective management and monitoring strategies that may be applied to other areas with similar ephemeral hydrologic behavior.

INTRODUCTION AND PROJECT OBJECTIVES

We were awarded continued funding (for a 2nd year, 2014) from the DCRC (Domestic Coral Reef Conservation) Program to supplement ongoing funding (non-competitive NOAA CRC) to support a joint terrestrial-marine sediment monitoring project to study how marine sediment dynamics are affected by watershed erosion, runoff and restoration activities in Coral Bay, St. John, USVI. In July 2013, the P.I. and Dr. Carlos Ramos-Scharrón of UT Austin in partnership with NOAA and community environmental managers, initiated a joint terrestrial-marine monitoring program to build on previous work to determine how ARRA-funded watershed restoration projects completed in Coral Bay in 2011 have impacted watershed runoff and marine sedimentation. In addition, the program initiated new monitoring approaches to evaluate the specific linkages between watershed processes and marine sedimentation in near-shore and coral reef areas. This grant funded field work for an additional season from Aug.-Nov. of 2014 and the follow-up data synthesis and interpretation. However, through cost savings, this grant has supported continued sampling through 2015 at two of our shoreline sites.

Ultimately our aim was to a) understanding of the linkages between watershed processes and marine sedimentation, b) to evaluate the effectiveness of ARRA watershed restoration activities, b and c) evaluate marine sediment-monitoring protocols for coral reef areas. This report is divided into three parts, addressing each of these aims.

Location and Methods

Our ongoing research in St. John has focused on comparing sedimentation below developed watersheds in CB to undeveloped "reference" sites. These "reference" sites include: a) locations in Great and Little Lameshur Bays (LB) within the VI National Park (Figure 1), b) sites below watersheds with limited or no development in CB (Plantation) (Figure. 1). Through the end of the field season funded on this grant (Dec., 2014) our USD research team has monitored sedimentation (at regular intervals of approximately every 26 days) for seven rainy (Jun.-Dec.) seasons in Coral Bay and eight seasons in Great and Little Lameshur Bays at 12 sites below 5 sub-watersheds on St. John (Figure 1).

Laboratory methods followed previously published protocols (Gray et al., 2012). Sediments accumulated in the sediment-trap tubes were filtered (< 3 microns), dried and weighed to determine the mass of sediment accumulated per unit area over the time deployed. The % organic matter, carbonate and terrigenous sediment in each sample were determined by Loss on Ignition (LOI) (Gray et al., 2012). The proportion (%) of terrigenous sediment was then multiplied by the sediment trap accumulation rate to get the rate of terrigenous sediment accumulation (in $mg/cm^2/day$) in the trap tubes.

To more accurately measure short-term (minutes) marine sedimentation and the water quality impact of specific runoff events, the 26-day integrated marine sampling was complemented by inclusion of high-resolution *in situ* sampling of deposition, turbidity, currents and swells using instrumental packages (nephelometers) provided by the James Cook University Geophysical Laboratory at 3 near shore and 2 reef sites (Figure 2, Table 1). The downloaded data was sent to the James Cook University Marine Geophysical lab for processing after each deployment.

Data from runoff stage at one ephemeral drainage (Shipwreck Ghut; Figure 2) and a number of coastal crest gauges (Figure 2; Table 1) were provided by Dr. Carlos Ramos-Scharrón of UT Austin and were funded by a separate "watershed linkages" project.

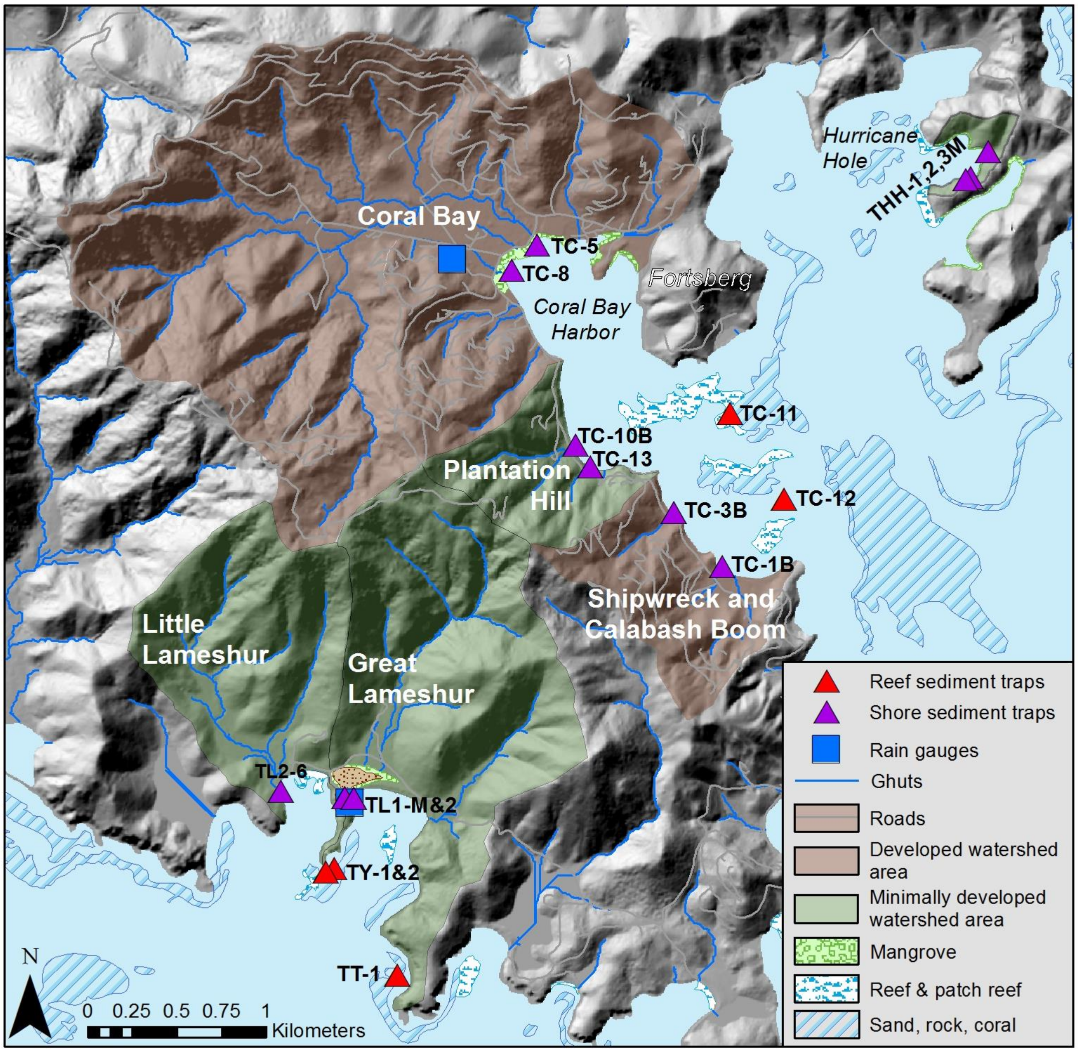

***Figure 1**. Study area in eastern St. John showing the Coral Bay and Lameshur Bay. Developed and minimally-developed watershed areas are shaded in brown and green, respectively. Marine monitoring sites in shore (purple triangles) and reef (red triangles) environments are shown. Sites in Hurricane Hole (THH-1, THH-2 and THH-3) were not monitored during this 2014 field season.*

Site Name	Site ID	Latitude	Longitude	Water Depth (m)	Environment	Watershed Classi-fication	Sed. trap deployment date	Nephelo-meter package?**	Gut-outfall crest gauge Site ID
GREAT AND LITTLE LAMESHUR BAYS									
G. Lameshur	TL1-2	18.31872	-64.72413	0.5	Shore	U	Aug-07		
E. Yawzi Reef	TY-1	18.31517	-64.72520	6.1	Reef	U	Aug-07	Yes***	
W. Yawzi Reef	TY-2	18.31502	-64.72567	7.6	Reef	U	Aug-07		
Tektite Reef	TT-1	18.30975	-64.72192	7	Reef	U	Aug-09		
Little Lameshur	TL2-6	18.31910	-64.72802	1.35	Shore	U	Aug-07		LL1
CORAL BAY									
Calabash Boom	TC-1B	18.33025	-64.70453	1	Shore	DR	Aug-08		CAL
Shipwreck	TC-3B	18.33300	-64.70707	1.6	Shore	DR	Aug-09	Yes	SWM3
Coral Harbor North	TC-5	18.34658	-64.71415	0.6	Shore	DR	Aug-08	Yes	CBM1
Coral Harbor South	TC-8	18.34533	-64.71552	0.6	Shore	DR	Aug-08		CBM2/CBM3
Plantation Hill North	TC-10B	18.33645	-64.71222	1.3	Shore	U	Aug-09	Yes	SGM6
Plantation Hill South	TC-13	18.33537	-64.71145	1	Shore	U	Aug-10		NN6
North Reef	TC-11	18.33797	-64.70402	7	Reef	DR	Aug-09	Yes	
South Reef	TC-12	18.33363	-64.70120	11	Reef	DR	Aug-09		

* Watershed draining to marine monitoring station is "U", undeveloped or minimally developed or "DR" developed with some ARRA restoration projects.

** Nephelometer instrument package includes one nephelometer, and one Marott current meter.

***If 5th instrument package available.

Table 1. *Location, characteristics, and deployment date at marine monitoring sites where sediment traps have been deployed in 2014. Nephelometer packages (1 nephelometer and 1 Marotte current meter) were deployed at 4-5 of the sites. The site ID for ghut outfall (shoreline) crest gauges which correspond to 3 of the shoreline marine monitoring stations are indicated.*

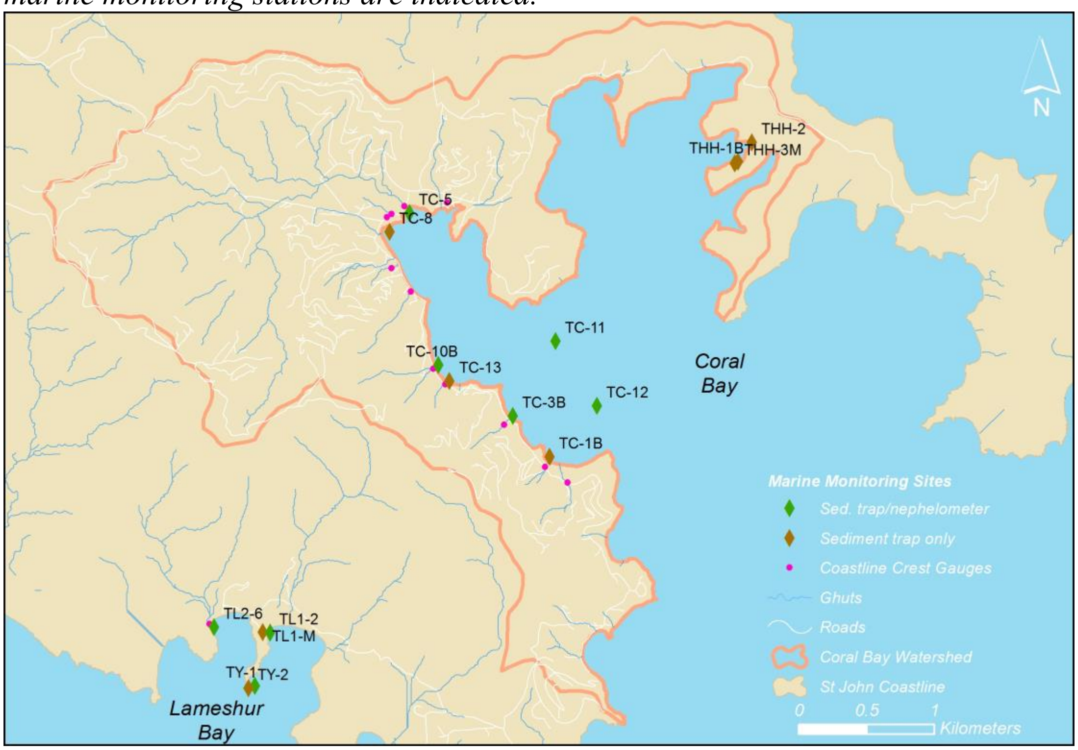

Figure 2. *Map showing the marine monitoring locations (diamonds) with sediment traps and corresponding coastal crest gauges (pink dots). Instrument packages (nephelometer and 1 Marotte current meters) are deployed adjacent to the sediment traps and are located at 5 of the 8 sites (marked by green diamonds).*

PART I: WATERSHED-MARINE LINKAGES

Objectives

This section of the project aimed constrain the relationship between watershed processes and marine sediment dynamics by addressing the following research questions:

1) What is the general spatial variability of turbidity and deposition in relation to watershed development?
2) How does runoff and resuspension affect marine sediment dynamics (turbidity and deposition), and how are the process connected from the shore to reef?
3) What factors affect resuspension?

Field Data collection & Laboratory Methods

Marine monitoring was conducted using Neph 1000 series *nephelometers* at two shore sites (1.7-1.9m depth) and one reef site (6.1m depth) in Lameshur Bays, and three shore sites (1.4-1.6m depth) and two reef sites (5.5-9.1m depth) in Coral Bay. (Figure 1 & 2). These nephelometers were developed by the James Cook University Marine Geophysics Lab, and tested in multiple studies (Ridd and Larcombe, 1994; Ridd et al, 2001; Thomas et al., 2002; Thomas and Ridd, 2005). The Neph 1000's measured turbidity (0-350 NTU ±2%), deposition (0-20 mg cm^{-2} ±5%), and pressure (0-5 ± 0.0005 atm., used to measure tidal fluctuations and as a proxy for wave energy) for 10 seconds every ten minutes, with wipers activating every 2 hours to prevent biofouling (JCU MGL, 2015). The Marine Geophysics Lab at James Cook University used benthic sediment samples from each respective site to calibrate the nephelometers and convert NTU values into suspended sediment concentration (SSC) values, and convert settled surface sediment density (SSSD) values to deposition values in mg/cm^2 (Thomas et al., 2002; Thomas and Ridd, 2004). While readings were taken every 10 minutes, instrument failure and biofouling (typically just one sensor), along with some delays between instrument recovery and re-deployment produced some gaps. Data processing protocols were employed to identify, correct, or discard the data affected by biofouling. Data that were affected by biofouling were not used for these analyses.

Benthic sediment samples (~25mL) were collected from the upper 2 cm of the benthic substrate at each marine monitoring site approximately every 26 days. Watershed runoff data were collected using peak crest gauges and a stream gauge. Peak crest gauges, which were deployed in ephemeral stream beds adjacent to the three shore sites in Coral Bay, and the one shore site Little Lameshur Bay (Figure 2), provided (~13-day) data on the approximate maximum stage (maximum depth of flow) runoff events at relatively low temporal resolution (every 13 days or after each rain event exceeding 2 cm). The stream gauge, located near an ephemeral stream outfall adjacent to the Shipwreck marine sampling site (C-3B) (Figure 2), collected high-resolution (10-minute) stream-level data.

Analysis of Data

To compare the spatial variability of turbidity and deposition between sites below developed and minimally developed watersheds, and between shore and reef sites, nephelometer turbidity and deposition data during “matching periods”[1] were used to create box-and-whisker plots.

Runoff and resuspension periods were identified based on the peak crest gauge (~13-day resolution or less) data from each respective site. These periods will be referred to as “crest-gauge runoff periods” and “crest-gauge resuspension periods”. However, “crest gauge runoff periods” do include contributions to turbidity and deposition from resuspension in addition to runoff. Because the timing of runoff and resuspension periods varied between sites, to make inter-site comparisons, it was necessary to identify time periods when all sites were determined to have runoff, and other time periods when all sites were determined to have no runoff (resuspension periods

In order to compare turbidity to benthic sediment grain size, nephelometer turbidity data from each site were averaged to determine the mean turbidity during the time series for each respective site. The percent benthic sediment less than 63µm from the five collections at each site were averaged together to compare the mean percent benthic sediment less 63µm from each site with mean turbidity.

10-minute resolution runoff stage data from the stream gauge deployed at Shipwreck ephemeral stream (Figures 1, 2) was used to bin nephelometer turbidity and root mean square (RMS) water height (a proxy for wave energy) data from the Shipwreck marine sampling site (C-3B) into runoff and resuspension periods. These periods will be referred to as “stream-gauge runoff periods” and “stream-gauge resuspension periods”. This analysis differs from the crest-gauge runoff and resuspension periods discussed in the paragraph above, as those periods were binned based on the 13-day resolution crest gauges, not the 10-minute resolution stream-gauge. “Stream-gauge runoff periods” start at the first runoff signal from the stream gauge, and to end three hours following the last stream gauge runoff signal. Stream-gauge resuspension periods separated the stream-gauge runoff periods. The inclusion of a three-hour window after runoff stopped was to account for the lingering affect runoff has on turbidity and deposition, as sediment introduced during a runoff event is not immediately advected away from the site nor does it immediately deposit on the seafloor at the conclusion of the runoff event. To investigate how RMS water height (proxy for wave energy) may affect minimum turbidity measurements, RMS water height values, and their corresponding turbidity values, were binned into 0.01m increments (e.g. 0 - <0.01m, 0.01 - <0.02m, 0.02 - <0.03m, ect.). From each respective bin, the 5th percentile of turbidity data (proxy for minimum turbidity) were calculated. Bins with less than 25 data points were excluded from the minimum turbidity analysis.

To make an estimate of the relative contribution to turbidity and deposition from runoff vs. resuspension during the time series, nephelometer turbidity and deposition were binned into stream-gauge runoff and resuspension periods using the same protocol as the RMS water height analysis above. Turbidity and deposition measured during the stream gauged resuspension periods were summed and compared to turbidity and deposition measurements during stream gauge runoff periods.

Results

General spatial variability in turbidity and deposition. Turbidity and deposition were highly variable in St. John. Across all sites during the time series, turbidity ranged from 0mg/L to ~550mg/L, and deposition ranged from 0mg/cm^2 to 140mg/cm^2. While median turbidity and deposition were greatest below the developed Coral Bay watershed (6.4mg/L and 0.05mg/cm^2, respectively), the greatest max turbidity and deposition measurements were recorded below the developed Shipwreck watershed (553mg/L and 141mg/cm^2, respectively) (Figure 3). Among reefs sites (North Reef and South Reef), median turbidity and deposition were 2.9 and 6 times greater, respectively, at North Reef compared to South Reef (1.2mg/L vs. 0.4mg/L, and 0.012mg/cm^2 vs. 0.002mg/cm^2, respectively). However, maximum turbidity was 1.3 times greater at South Reef than at North Reef (Figure 3). Turbidity and deposition were compared between pairs of sites below geographically similar (area, slope) developed and minimally developed watersheds (Table 2). Median and max turbidity and deposition were greater below both developed watersheds, compared to the respective minimally developed watersheds (Table 2).

When data were available at Yawzi reef in Lameshur Bay (August through October), turbidity and deposition were on average 3 and 2 times greater, respectively, at the reef sites below the developed watersheds in Coral Bay (North Reef and South Reef) compared to the minimally developed reef site in Lameshur Bay (Yawzi).

Runoff induced sedimentation. Watershed runoff on St. John is characterized by ephemeral flow typically lasting only a few hours. To characterize the spatial and temporal variability of marine turbidity and deposition in response to the highest magnitude runoff events, 10-minute resolution runoff stage data from the stream gauge are presented with nephelometer turbidity and deposition data during the three greatest runoff event of the monitoring period (Figure 4). The marine sedimentary response to runoff was highly variable between sites and between runoff events. The greatest rainfall event of the monitoring period occurred on the morning 11/21/13, and resulted in 86mm of rainfall over 9 hours. The resulting runoff lasted ~21 hours. Excluding Hurricane Otto in 2010, which resulted in 175mm of rainfall in a single day, this storm event was comparable to maximum daily precipitation events over the previous 5 years. During the 11/21/13 runoff event at the Shipwreck site (C-3B), there were two distinct runoff flushes.

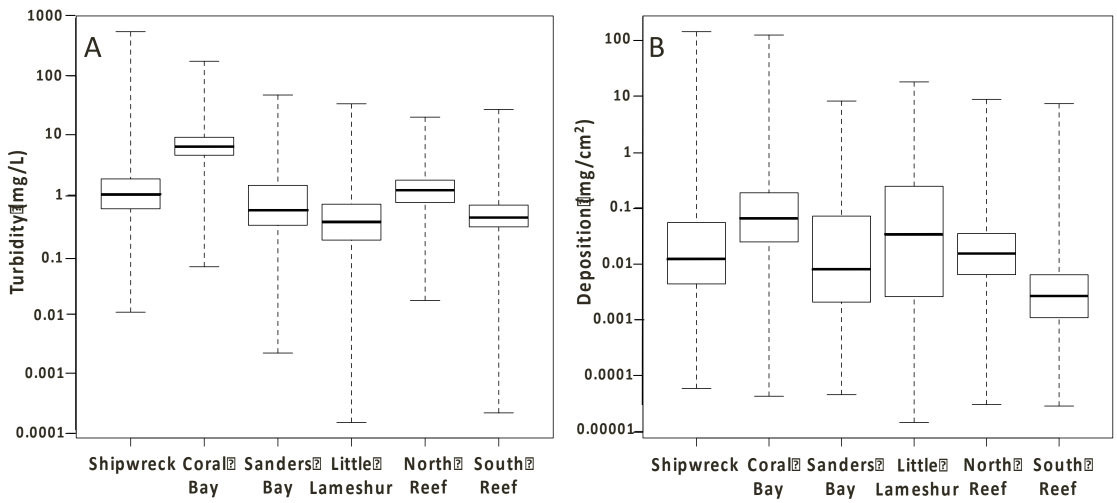

Figure 3. *Range of turbidity (**A. left**) and deposition (**B. right**) at developed (brown) and minimally developed (green) shore and reef sites. Boxes indicate 25th and 75th percentiles, whiskers indicate minimum and maximum values, bold lines indicate median values.*

	SHIPWRECK / SANDERS BAY		CORAL BAY / LAMESHUR BAY	
	Turbidity	**Deposition**	**Turbidity**	**Deposition**
MEDIAN	2	2	18	3
MAX	12	17	5	7

Table 2. *Ratio of median and max turbidity and deposition below pairs of comparable developed (brown) and minimally developed (green) watersheds. The large developed Coral Bay watershed was paired with the large minimally developed Lameshur watershed, and the small developed Shipwreck watershed was paired with the small minimally developed Sanders Bay watershed.*

Sedimentary response to runoff. The marine sedimentary response to runoff was highly variable between sites and between runoff events. For example, the greatest rainfall event of the monitoring period occurred on the morning 11/21/13, and resulted in 86mm of rainfall over 9 hours. Excluding Hurricane Otto in 2010, which resulted in 175mm of rainfall in a single day, this storm event was comparable to maximum daily precipitation events over the previous 5 years. During the 11/21/13 runoff event at the Shipwreck site (C-3B), there were two distinct runoff flushes. During the first flush, turbidity and deposition peaked at 553mg/L (the greatest magnitude turbidity peak of 2013) and 141mg/cm^2, respectively, below the small developed Shipwreck watershed, while turbidity and deposition below the much larger Coral Bay watershed, peaked at 99mg/L and 95mg/cm^2, respectively. Turbidity below the small minimally developed Sanders Bay watershed peaked at 6.4mg/L (98% lower magnitude than Shipwreck), and no deposition was measured (Figure 4).

To characterize how short-term (hours) runoff events may affect turbidity and deposition over longer periods (weeks), nephelometer turbidity and deposition data were binned into crest-gauge runoff and resuspension periods. Maximum turbidity measurements were greater at every site during runoff periods compared to resuspension periods. However, compared to resuspension periods, median turbidity was only slightly greater during runoff periods at Coral Bay (1.2x), North Reef (1.1x), and South Reef (1.2x), while median deposition was less during runoff periods at Coral Bay (0.06x) and South Reef (0.8x) (Figure 5).

Factors affecting resuspension. While isolated runoff events directly affect turbidity for short periods (hours), resuspension of benthic sediment occurs over much longer periods (weeks-months), and is affected by increased hydrodynamic energy, and decreased benthic grain size. To characterize the spatial variability of turbidity in relation to benthic sediment grain size, mean turbidity at each site was compared to mean percent abundance of silt and clay in the benthic sediment at each respective site. Mean turbidity over the time series was generally greater at sites with finer benthic grain sizes. While the average percent of benthic silt and clay (<63µm) explained 80% (p-value= 0.004) of the variability in turbidity between sites, benthic grain size was variable between sites and sampling periods (Figure 6). On average, turbidity was greatest at the developed site Coral Bay (7mg/L), with silt+clay (fraction < 63µm) composing 36% of the benthic sediment, while at Yawzi Reef, turbidity was lowest (0.3mg/L), and the benthic sediment was composed of 4% silt+clay (Figure 6).

To characterize the effect of wave energy on turbidity, RMS water height (a proxy for wave energy) values were compared to their respective turbidity values during stream gauge runoff and resuspension periods (Figure 7). Maximum turbidity (550mg/L) during runoff periods were 5.3 times greater than during resuspension periods 104mg/L. Minimum turbidity measurements increased exponentially (a linear increase as seen on the log-scale in Figure 7) with increasing RMS water height during both runoff (R=0.97) periods and resuspension (R=0.99) periods.

To characterize the effect of tidal fluctuations on marine sediment dynamics, nephelometer turbidity and deposition measurements from the Shipwreck site were compared to water height (tides) values (Figure 8). During a week with no runoff, regional wave height was 50-100% greater than the time series mean, and turbidity and deposition peaked on a diurnal cycle during low tides. Tidal cycles were not associated with turbidity or deposition fluctuations during periods of average or below average wave height. Hydrodynamic energy generated by waves will directly resuspend benthic sediment if the water depth is shallow enough for wave orbitals to reach the benthic substrate. Relative to mean tide level, fluctuations in water depth caused by tides have the effect of reducing (at high tide) and increasing (at low tide) wave orbital energy contacting the benthic substrate and thus inducing resuspension.

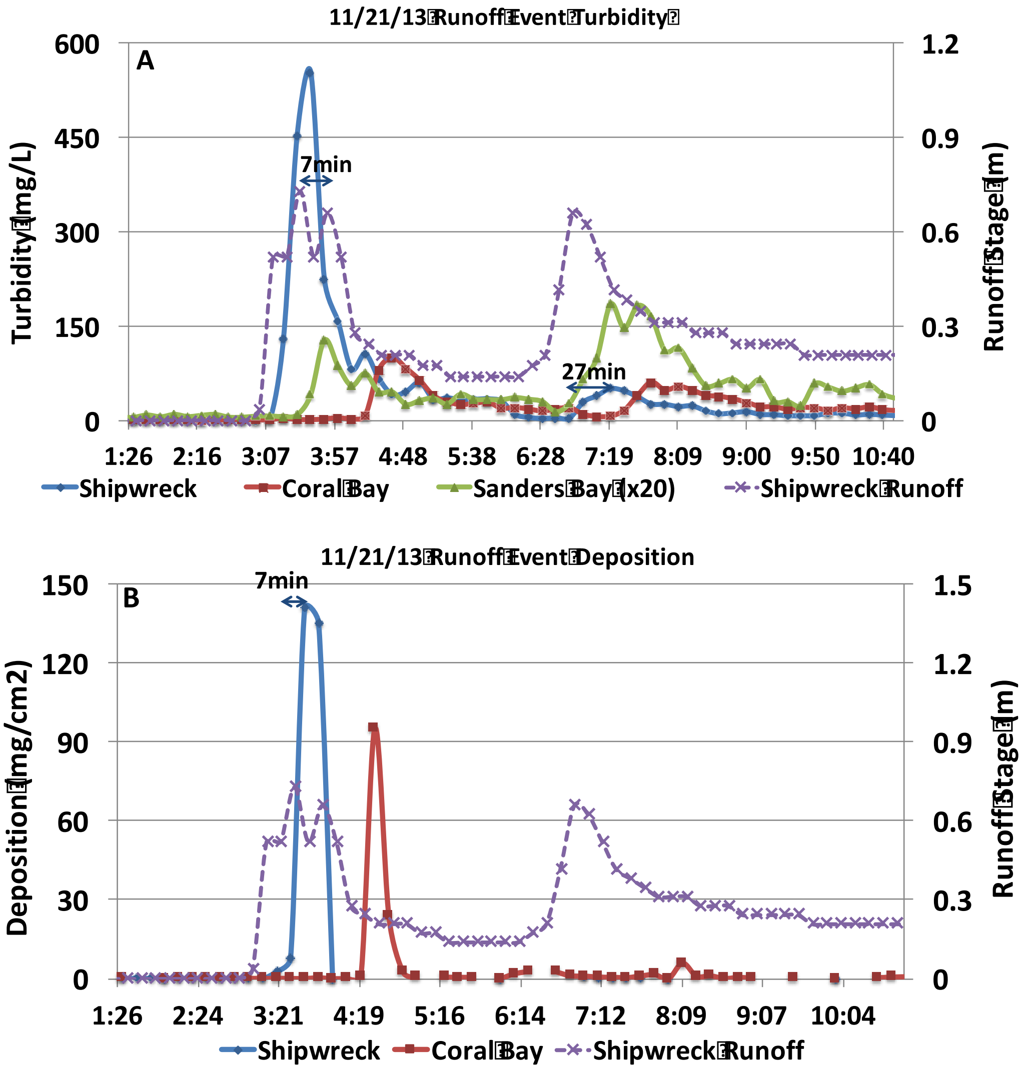

Figure 4. *Turbidity (**A. Top**) and deposition (**B. Bottom**) at shore sites, and Shipwreck runoff stage height vs. local time during the 11/21/13 runoff event.*

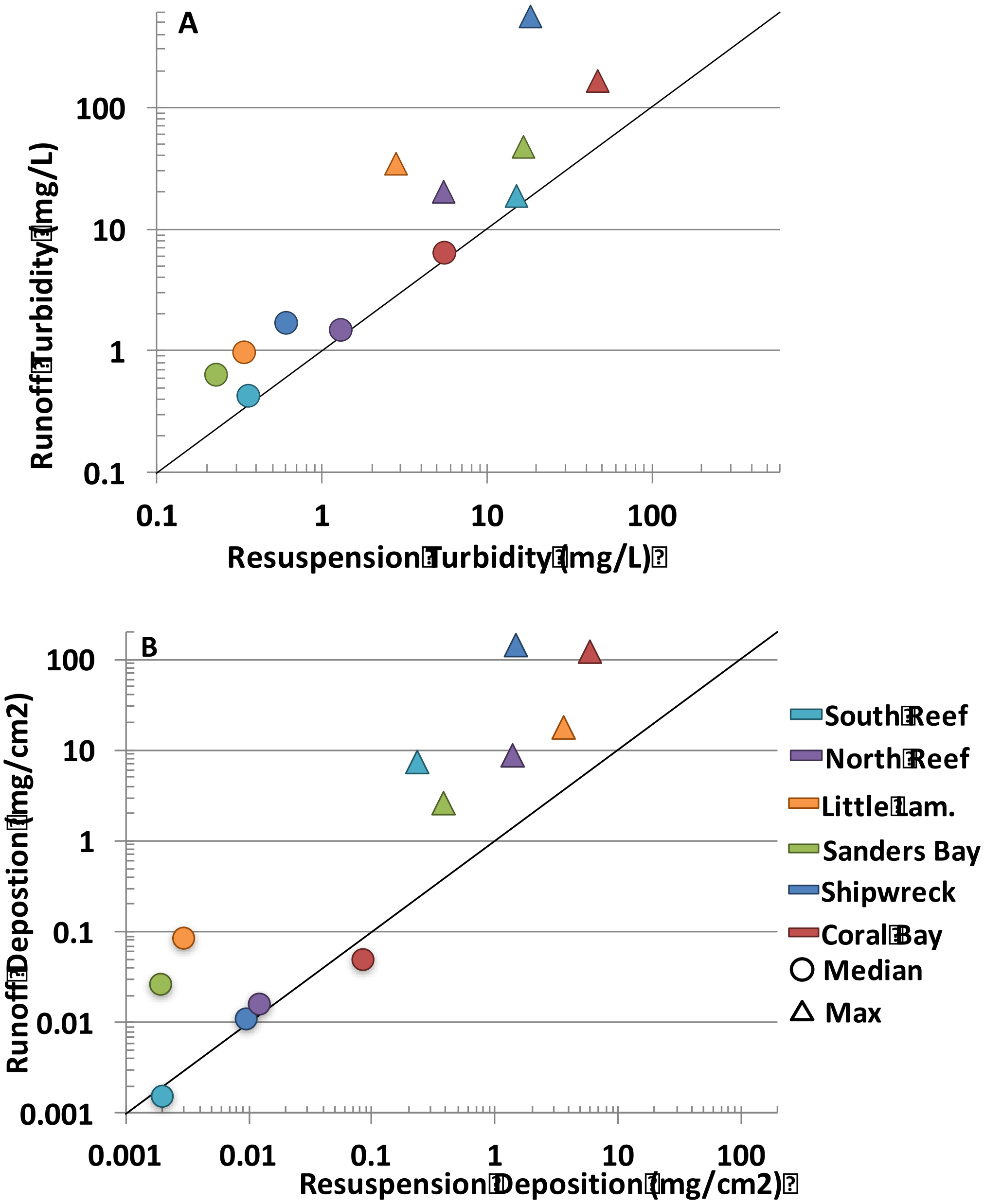

Figure 5. *Median and max turbidity (**A. Top**), and deposition (**B. Bottom**) during crest gauge runoff and resuspension periods at shore and reef sites, and an x=y line.*

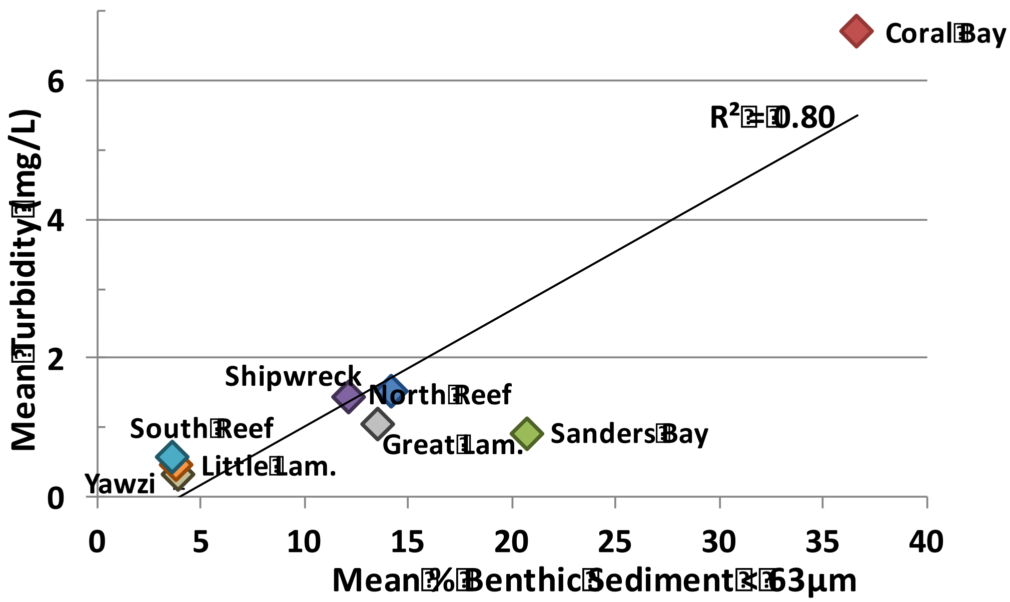

Figure 6. *Mean turbidity vs. mean % fine grained (< 63µm) benthic sediment during the fall of 2013, at 5 shore and 3 reef sites.*

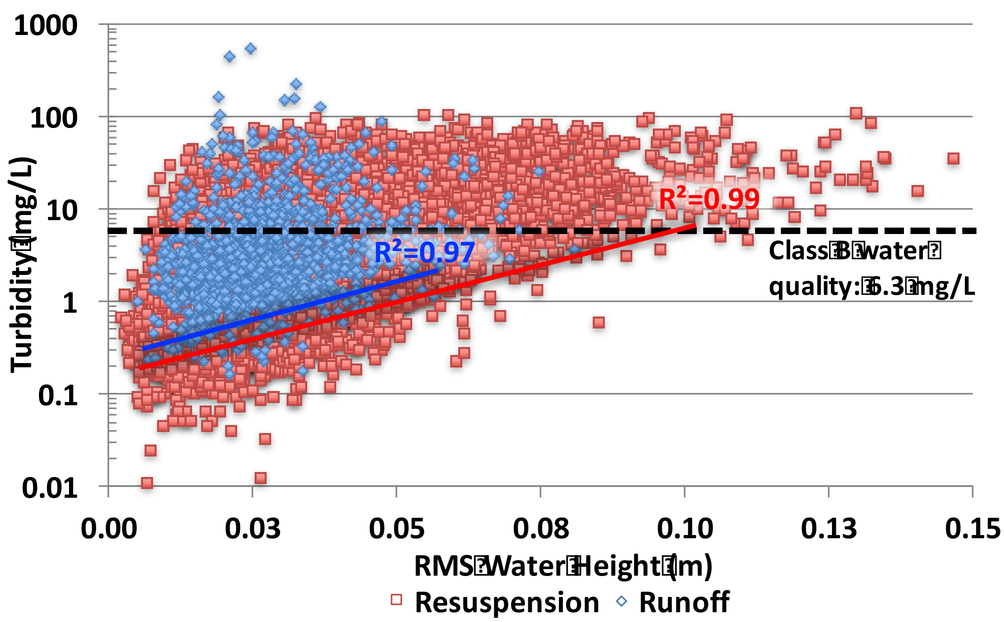

Figure 7. *RMS water height (proxy for wave energy) vs. turbidity during stream-gauge runoff periods (blue) and stream gauge resuspension periods (red) at Shipwreck. Minimum turbidity (5*th *percentile) trend-lines during runoff periods (blue line) and resuspension periods (red line), with corresponding* R^2 *values.*

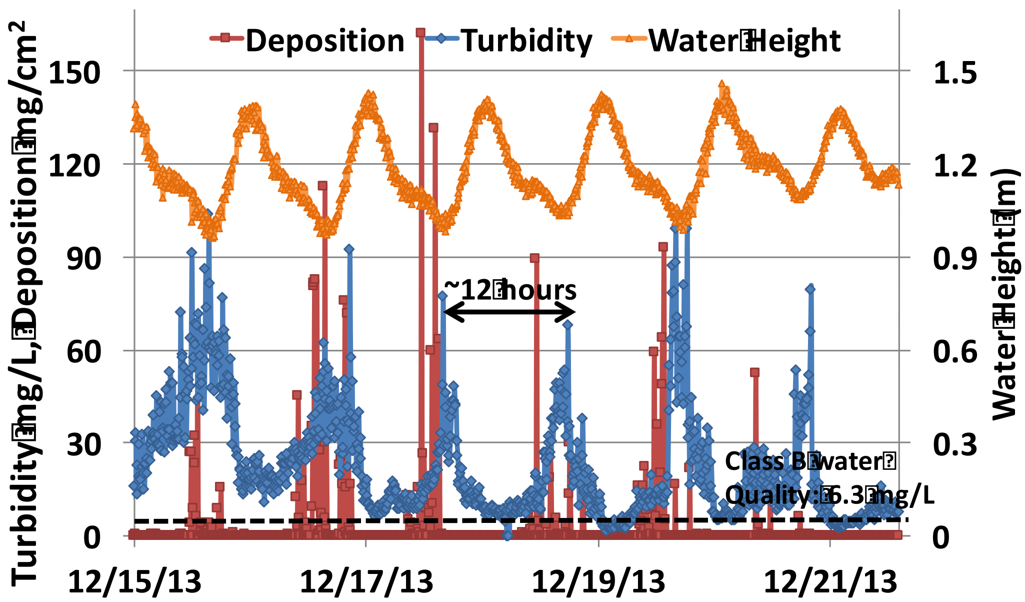

Figure 8. *Turbidity, deposition, and water height (tides) at Shipwreck, during period of elevated regional wave height in December of 2013.*

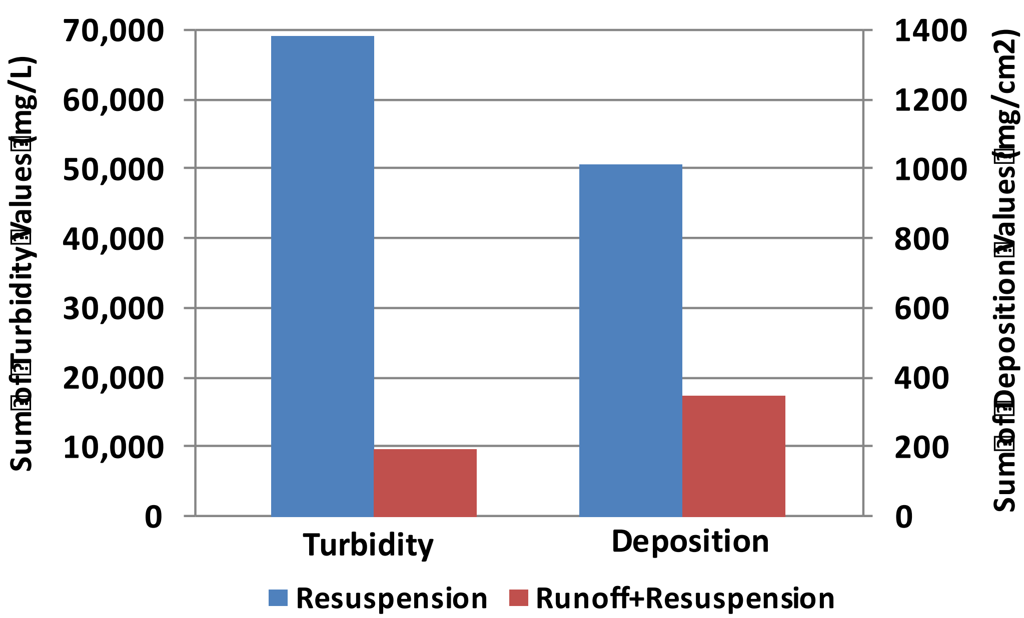

Figure 9. *Contributions to turbidity and deposition from only resuspension (blue) and from runoff+resuspension (red) during the fall of 2013.*

Contributions to turbidity and deposition from runoff vs. resuspension. At the Shipwreck site resuspension contributed at least 7 times more to turbidity and 3 times more to deposition than runoff at the Shipwreck marine monitoring site (Figure 9).

Processes affecting sediment dynamics at the shore and reef

Runoff to the marine environment was relatively infrequent because of St. John's temperate climate and small watersheds. Runoff consisted of short (median runoff duration: 2.5 hours) flushes separated by up to two weeks with no runoff. During runoff events, turbidity and deposition at shore sites adjacent to ephemeral stream outfalls increased by up to three orders of magnitude above background, but only remained elevated for short (minutes to hours) periods. In contrast, elevated turbidity and deposition were not observed at reef sites (~0.6 km from ephemeral stream outfalls) during and immediately following (within hours) runoff events. However, benthic sediment composition at the reef sites were up to 30% terrigenous, so land-based sediment is eventually transported and deposited on the reefs, even if not immediately (minutes-hours-days) following runoff events. It is possible that terrigenous sediment carried by runoff is either a) deposited in an area near the ephemeral stream outfall before reaching the reefs, or b) transported seaward of the reef monitoring sites prior to deposition. The latter scenario is unlikely because a temporary turbidity signal resulting from sediment transport across the reef monitoring sites was not observed following runoff. It is therefore more plausible that sediment introduced during runoff initially accumulates near the ephemeral stream outfall before some of this terrigenous sediment is resuspended, then transported and deposited at the reef sites.

Though the nephelometers did not record elevated turbidity measurements immediately following (within hours) runoff events at the reefs, greater median turbidity at the developed shore sites during runoff periods could be caused by 1) increased resuspension due to greater wave energy, 2) the high-magnitude but short-duration runoff induced sediment plumes, and/or 3) increased resuspension due to increased availability of recently introduced fine-terrigenous sediment. Our observations suggest that after a runoff-induced sediment plume dissipates (within hours) turbidity may be elevated for weeks due to resuspension of fine terrigenous sediment introduced by runoff.

Our data suggests that during runoff periods, contributions to turbidity are a result of both resuspension and runoff. Resuspension is affected by currents, benthic grain size, and tides. On St. John during low tides, wave orbitals contact the shallow seafloor and resuspend sediment because there are no physical structures to attenuate wave energy. In addition to hydrodynamic energy, our study associated finer benthic sediments with increased turbidity. Finer grains are more easily resuspended than coarser grains and stay in suspension longer. While finer benthic sediments were associated with greater turbidity, confounding factors including macrophyte abundance and exposure to hydrodynamic energy also affected variability in turbidity between sites. The relative contributions of resuspension and runoff to turbidity and deposition varied spatially. While median turbidity and deposition were greatest at

Coral Bay, max turbidity and deposition were greatest at Shipwreck. As the marine sedimentary response to runoff is very short-lived (minutes-hours), the greater median turbidity and deposition measured at Coral Bay indicate that resuspension contributes relatively more to turbidity and deposition than at Shipwreck. Our data suggest that runoff contributes less to turbidity and deposition over longer periods (weeks to months) in Coral Bay, possibly because of effective watershed restoration, and/or the presence of mangroves along the shoreline of Coral Bay Harbor.

Our study is the first to use high-resolution (10-minute) instruments to monitor marine turbidity and deposition below geographically similar developed and minimally developed watersheds. We found median turbidity and deposition were up to 18 and 3 times greater, respectively, and max turbidity and deposition were up to 12 and 17 times greater, respectively, below developed watersheds compared to sites below geographically similar minimally developed watersheds. Numerous studies corroborate the link between watershed development on St. John and increases in watershed erosion and marine sedimentation by up to an order of magnitude above background (Macdonald et al., 1997; Brooks et al., 2007; Gray et al., 2008; Gray et al., 2012; Gray et al., 2016; Ramos-Scharrón and Macdonald, 2007a; Ramos-Scharrón and Macdonald, 2007b; Ramos-Scharron et al., 2012). Turbidity and deposition were also greater at reef sites in a bay adjacent to developed watersheds (Coral Bay) compared to a bay below minimally developed watersheds (Lameshur Bay). Over short time periods (minutes) during runoff events, turbidity was up to ~90 times greater below the developed Shipwreck watershed compared to the geographically similar minimally developed Sanders Bay watershed. Marine areas below developed watersheds receive greater sediment loads during runoff events than areas below minimally developed watersheds. Therefor there is more fine sediment available for resuspension below developed watersheds, which leads to persistently elevated turbidity and deposition relative to areas below minimally developed watersheds.

With the goal of reducing marine turbidity and sedimentation by decreasing sediment laden watershed runoff, watershed restoration in the developed Coral Bay and Shipwreck watersheds were completed in 2011. Watershed modeling suggested that the installation of retention ponds, such as those in Coral Bay, accounted for 90% of the reduction in sediment yield. Restoration efforts in the Shipwreck watershed consisted of constructing water-bars on unpaved roads to divert runoff into an ephemeral stream channel, rather than letting the unpaved roads serve as a conduit for runoff. Restoration structures in the Shipwreck watershed likely reduced watershed-scale sediment yields to coastal waters. However, the restoration channeled sediment rich runoff water from an unpaved road segment into the ephemeral stream channel with an outlet adjacent to our Shipwreck marine monitoring site which may have caused localized increases in marine turbidity and deposition at our Shipwreck marine sampling site, while watershed scale sediment yield was reduced. The apparent success of watershed restoration in Coral Bay, relative to the Shipwreck watershed, may have also been enhanced by the presence of mangroves along the shoreline of Coral Bay Harbor, the gentle sloping central valley of the Coral Bay watershed, and the effect of water-bar placement on unpaved road segments in the Shipwreck watershed.

Although we would generally expect to see more rapid improvements in water quality at sites with greater hydrodynamic energy due to high sediment removal rates, the residence time of terrigenous sediment at any particular site on St. John is unknown. This highlights the need for long time series monitoring to separate natural variability of marine sediment dynamics from the effects of watershed development and restoration, and to evaluate the potential effectiveness of restoration.

Anthropogenic activity associated with marine construction and marina use, such as dredging, and boat/ship traffic, would also increase turbidity and deposition (Bak, 1978, Brown et al., 1990; Jones, 2011). While watershed restoration appears to have reduced sediment transport to the marine environment, the proposed Summer's End Group Mega Yacht Marina and The Sirius Resort and Marina would likely negate these improvements in water quality by indefinitely increasing resuspension and temporally (6-17 months) increasing sediment laden watershed. Construction of the proposed mega yacht marina would temporarily increase turbidity and deposition during both the land and marine phases of construction. When these fine particles are resuspended during construction, natural currents speeds in Coral Bay are sufficient to keep the finer particles in suspension indefinitely. From the proposed marina construction, we would expect higher magnitude spikes in turbidity and deposition following runoff events, and persistently elevated turbidity year round from prop-wash induced resuspension. Of the eight sites in eastern St. John in which benthic sediment samples were collected, the samples collected from Coral Bay contained the greatest fraction of silt and clay, due to low hydrodynamic energy in the bay and thus low removal rates. After construction is complete and the marina is in use, increased boat traffic (including mega-yachts) would also result in increased turbidity and deposition due to greater resuspension from prop-wash (the disturbed mass of water pushed by the propeller of a watercraft) induced scouring of fine benthic sediment. Due to the relatively low (lowest mean RMS water height of shore sites in St. John) hydrodynamic energy in Coral Bay Harbor, benthic sediments resuspended by prop-wash scouring are unlikely to be advected to another area outside of the bay, and instead would either stay in suspension or deposit back on the seafloor. With regular traffic of large boats such as mega-yachts, this would result in repeated cycles of resuspension and deposition. At 6.4 mg/L, median turbidity in Coral Bay is above the Class B water quality threshold of 5.8 mg/L. An increase in boat traffic and thus resuspension, would push turbidity levels in Coral Bay further above the Class B water quality threshold for turbidity.

PART II: COMPARISONS BETWEEN MONITORING METHODS

Objectives

Here were examine the efficacy of different monitoring methods by comparing various sedimentation metrices measured simultaneously using three different approaches: a) nephelometers (10-minute resolution), b) tube sediment traps (~ monthly resolution) and c) SedPods (~monthly resolution) to address the following research questions:

a. Is there a significant correlation between the turbidity and deposition measured by the nephelometers and the total sediment accumulation rate (ΣAR) measured by the sediment traps?
b. Is there a significant correlation between the ΣAR, terrigenous accumulation rate (TAR), silt accumulation rate (SAR), and clay accumulation rate (CAR) measured by SedPods to that measured by sediment traps?

Time integrated (nephelometers) vs. tube sediment traps

To compare time-integrated sediment trap accumulation data to high-resolution nephelometer data, turbidity and deposition data from each nephelometer were grouped and the data were averaged according to the deployment interval of the corresponding sediment trap, to determine the average turbidity in mg/L and average deposition in mg/cm^2 over the course of the sediment trap deployment. To quantify the strength of the relationship between the data collected by the two monitoring approaches, a Pearson r Correlation test was used to compare the average accumulation rate (mg/cm^2/day) from sediment traps with the average turbidity (mg/L) and deposition (mg/cm^2) from nephelometers at each site. Nephelometer turbidity and deposition data averaged over the course of ~26-day sediment trap deployment periods were significantly correlated with sediment trap accumulation rates at the majority of the sites. Pearson r values comparing averaged nephelometer turbidity and deposition to sediment trap accumulation ranged from 0.721 to 0.999. P-values ranged from 0.0001 to 0.14.

Until this study, we do not know of direct comparisons of data collected from field deployed time-integrated sediment traps and high-resolution nephelometers monitoring turbidity and deposition. While our study showed that sediment traps and nephelometers record similar relative changes in marine sedimentation and turbidity, there are still considerations regarding the interpretation of sediment trap data. Strong and significant correlations between sediment trap accumulation and nephelometer turbidity and deposition values at the majority of sites indicate that sediment traps are effectively recording relative changes in some measure of sediment dynamics over longer periods. Though sediment traps were conventionally interpreted to measure “gross” sedimentation (Field et al., 2012), at four of the five sites included in the analysis, there were stronger correlations between sediment trap accumulation and nephelometer turbidity rather than sediment trap accumulation to nephelometer deposition. Due to the hydrodynamic disturbance around the trap mouth and the quiescent zone with in the trap walls (Butman et al., 1986; Storlazzi et al., 2011), sediment traps can siphon in suspended sediment, and collect sediment even in net erosional environments (areas where sediment is removed rather from than deposited on the benthic substrate). For this reason, Storlazzi et al. (2011) has suggested that sediment trap accumulation rates may be more appropriately interpreted as a measure of suspended-sediment dynamics rather than sedimentation/deposition. Essentially, sediment traps in energetic coastal environments collect sediment that would not have deposited on the seafloor near the trap. This may explain the stronger correlation between sediment trap accumulation and turbidity, rather than deposition.

While nephelometers and sediment traps record similar relative changes in sediment deposition and turbidity over longer periods, there is an important distinction between the two approaches. Sediment traps collect a sample that can be used for further sedimentological and geochemical analyses. The sediment can be analyzed to determine grain size distributions, which provide insight into the propensity for resuspension at a particular site.

We examined whether there were significant correlations between total sediment accumulation rates (ΣAR), terrigenous accumulation rates (TAR), silt accumulation rates (SAR), and clay accumulation rate (CAR) measured by SedPods and tube sediment traps. We found no significant correlations between the parameters over the sampling periods and resolution of our study (~monthly resolution).

PART III: SEDIMENTATION STRESS ON CORALS

Another objective of our study was to evaluate whether corals at our study sites were under stress from sedimentation and whether the degree of sedimentation stress differed between developed and minimally developed sites and pre- vs post- ARRA restoration. Using data from the literature to define thresholds of sedimentation stress from sedimentation and turbidity, we addressed the following research questions:

a. During what percentage of sampling periods were reefs under stress from terrigenous sediment (TAR >10 mg/cm^2/day) or from siltation (SAR >4 mg/cm^2/day)? Does this percentage differ between developed and minimally developed locations? Pre- and post-restoration?
b. During what percentage of sampling periods were reefs under turbidity stress according to the following turbidity thresholds: SSC > 10 mg/L, SSC > 20 mg/L, SSC > 40 mg/L, and SSC > 100 mg/L?

Patch reefs near shore were under stress from terrigenous sediment about 65% of the time at the developed Coral South Shore, compared to only 20% of the time at the minimally developed Plantation Hill (Figure 10). Reefs at both developed Coral Reef and minimally developed Lamershur Reef were only under stress from terrigenous sediment for 2-3% of all fall sampling periods. Corals appeared to be under stress from terrigenous sediment more often post-restoration at the developed Coral South Shore. There were no apparent differences post-restoration at developed Coral Reef nor minimally developed Plantation Hill and Lameshur Reef. Corals at developed reef locations were under siltation stress (SAR >4 mg/cm^2/day) for about half of all July-December sampling periods, whereas those in minimally developed reefs were under siltation stress about 12% of the time (Figure 10). This suggests that reefs below the developed watershed are under greater siltation stress than those below minimally developed watersheds.

Patch reefs near shore below developed watersheds were under siltation stress during 85% of July-December sampling periods compared to 46% of sampling periods below the minimally developed watersheds (Figure 10). Siltation stress increased slightly post-restoration at developed Coral South Shore patch reefs. However, there was no observed change at the developed Coral Reef post-restoration. Siltation stress appeared to decrease post-restoration at both the minimally developed Plantation Hill and Lameshur Reef.

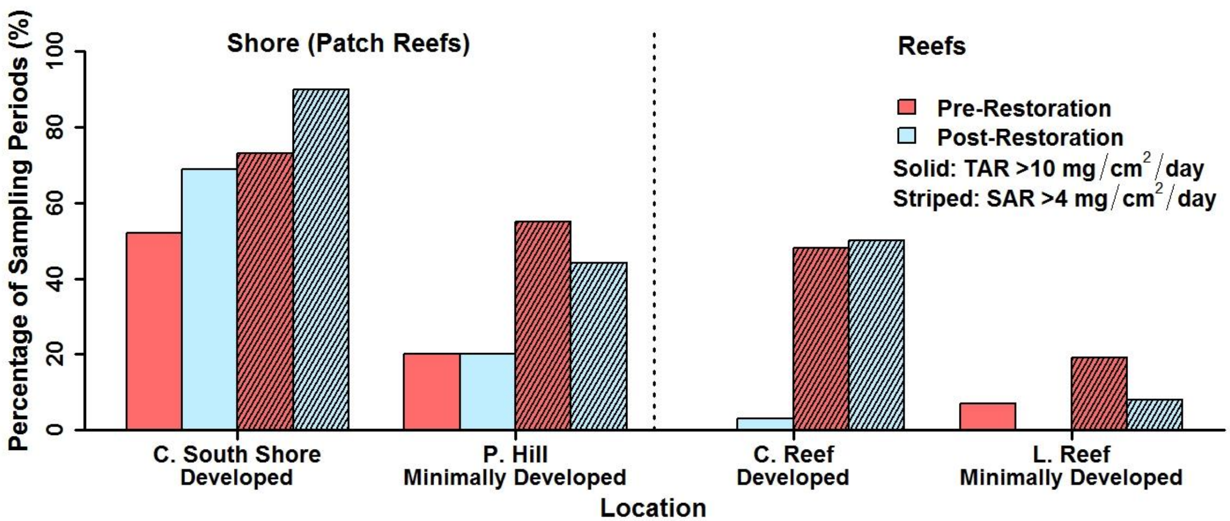

Figure 10. *Percentage of sampling periods in which corals are under stress from terrigenous sediment or siltation stress according to proposed stress "thresholds" (Smith, T., personal communication; Gray et al., 2016).*

Prior to analysis, all turbidity data were converted from NTU to suspended sediment concentration (SSC) and pooled by site for areas with coral reefs that had nephelometers deployed (TC-3B, TC-10B, TC-11, TC-12, and TY-1). Due to instrument failure and biofouling, there were gaps in the datasets from each site, and some sites had more nephelometer readings than others. For these reasons, in order to assess coral stress due to turbidity, the percentage of all 10-minute turbidity readings at each site that were >10, 20, 40, and 100 mg/L were calculated. These SSCs were chosen to represent the wide range of published critical thresholds of corals for turbidity found in the literature (reviewed in Erftemeijer et al., 2012). After calculating the percentage of time that the thresholds were exceeded at each site, it was possible to roughly compare coral stress between developed and minimally developed sites, as well as between shore and reef sites.

In general, patch reefs found at shore sites were exposed to elevated turbidity levels for greater percentages of time compared to reef sites for all evaluated turbidity levels (Table 3). In addition, maximum turbidity levels were greater at shore sites compared to reef sites. For both shore and, to a lesser degree, reef sites, corals were exposed to elevated turbidity levels at the developed sites for a greater percentage of time and exposed to higher maximum turbidity levels relative to the corals at comparable minimally developed sites; maximum SSC at developed TC-3B was approximately 4 times greater than that at minimally developed TC-10B, while maximum SSCs at developed TC-11 and TC-12 were 1.5 and 5 times greater, respectively, than minimally developed TY-1. At all reef sites, SSC exceeded the lowest critical threshold value of 10 mg/L less than 1.5% of the time (Table 3).

Table 3. *Percentage of 10-minute turbidity readings at each site exceeding published critical thresholds for SSC and maximum SSC at sites with reefs (Erftemeijer et al., 2012).*

	Shore Sites		**Reef Sites**		
	Developed	**Min. Developed**	**Developed**		**Min. Developed**
Site	**TC-3B**	**TC-10B**	**TC-11**	**TC-12**	**TY-1**
% SSC > 10 mg/L	8.62	4.33	0.66	1.43	0.14
% SSC > 20 mg/L	3.73	1.78	0.05	0.00	0.00
% SSC > 40 mg/L	1.01	0.44	0.00	0.01	0.00
% SSC > 100 mg/L	0.05	0.02	0.00	0.01	0.00
Max SSC (mg/L)	553.20	135.5	29.54	108.60	21.03

PART IV: CHANGES IN SEDIMENTATION POST-RESTORATION

We completed the compositional and textural analyses of sediments collected during fall of 2016 (with funding from a subsequent grant from UPR Sea Grant). These data provide additional critical data points to make comparisons between sediment trap compositional and textural sedimentary parameters pre- (2009-11) vs. post- (2011-16) restoration including at both the restored and minimally developed, unrestored sites. Rain normalized and non rain normalized compositional sedimentary parameters compared include: Total Sediment Accumulation Rate (□AR), Terrigenous Accumulation Rate (TAR), Percent Terrigenous Sediment of the inorganic component (%Ti), Percent Organic Matter (%O), and the ratio of Carbonate over Terrigenous of the inorganic sediment (Ci/Ti). Textural sedimentary parameters we are comparing include mean, median and modal grains size, % clay, % silt, and Silt Accumulation Rate (SAR). Generally, the variability in the data make it challenging to detect statistically significant pre- vs. post-restoration differences in several parameters. Thus we used rainfall as a criteria to select key sampling periods for comparisons. However, some general trends are evident from our initial comparisons, which are summarized in Table 4. Our research questions for this section of the project included the following:

a. Is there a significant difference between the following sedimentary parameters pre- and post-restoration: median grain size, % clay, % terrigenous$_{inorganic}$ (%T_i), terrigenous accumulation rate (TAR), rain-normalized terrigenous accumulation rate (TAR_{rn}), silt accumulation rate (SAR), and total accumulation rate (ΣAR)?

b. Is there a difference (% change) in % clay, % T_i, and TAR pre- vs. post-restoration during "small" and "large" equivalent storm periods?

To address these questions, all fall (July-December) sedimentation matrices measured pre-restoration (9/2/2008 to 7/27/2011) and post-restoration (8/20/2011-11/11/2016) were pooled and compared by site. After testing for normality, all data was reciprocal-transformed, all percentage data were arcsine-square root transformed, and all sediment accumulation rate data were log-transformed to bring the data closer to normality. A Mann-Whitney U test in R was used to test for differences in the medians of the transformed data.

Pre- vs. Post Restoration differences

Texture. Though there were not consistent differences in median grains size, there were significant decreases (17-41% decrease) in trap and benthic % clay post-restoration at all developed shore sites except TC-5 (Figures 11A, 12A). No significant differences were observed in % clay pre- and post-restoration at minimally developed sites in either the trap or the benthic samples (Figures 11A, 12A). In contrast, there were no significant decreases in trap or benthic % clay post-restoration at the developed reef sites, with the exception of a BC-11 (43% decrease) (Figures 11B). Sediment trap % clay at minimally developed reef sites TY-1 and TY-2 significantly increased, while there were no significant changes in % clay in trap nor benthic samples at TT-1 (Figure 12B).

% T_i. Significant decreases post-restoration in trap %T_i were measured at Coral South Shore trap sites (~21% decrease; Figure 13A) and for benthic samples at all developed shore sites (7-20% decrease in median; Figure 13B). There were no significant differences in pre- vs. post-restoration % T_i at minimally developed shore sites (Fig. 5A) and no consistent pattern at the reef sites.

TAR, TAR_{rn}, ΣAR, and SAR. Due to the high variability in the data there was not a consistent pattern of pre- vs. post- restoration significant differences found in TAR, TAR_{rn}, ΣAR or SAR.

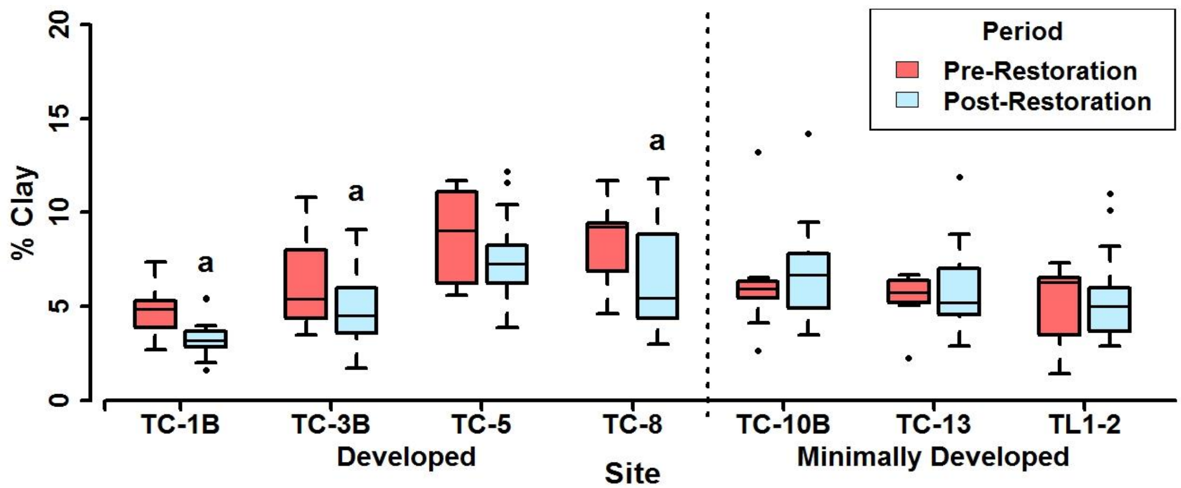

Figure 11A. % Clay in sediment traps pre- vs. post-restoration at shore sites during fall sampling periods. "a" indicates significant difference between pre- and post-restoration.

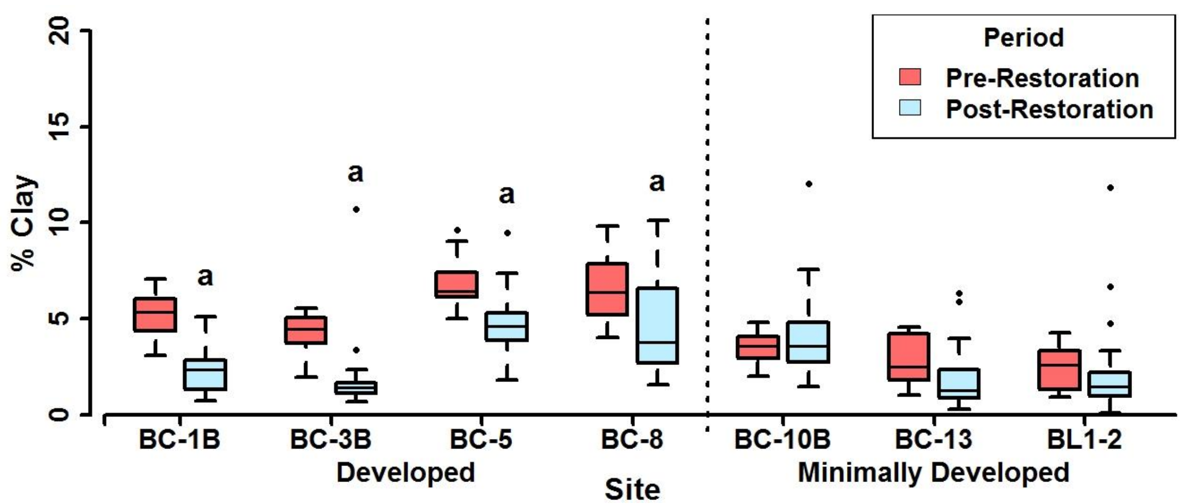

Figure 11B. % Clay in benthic samples pre- vs. post-restoration at shore sites during fall sampling periods. "a" indicates significant difference between pre- and post-restoration.

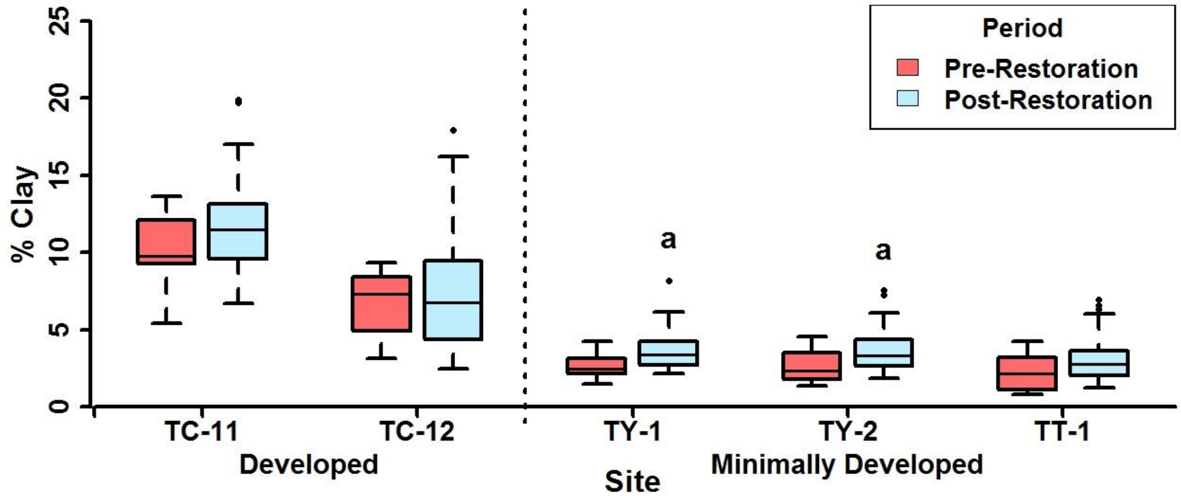

Figure 12A. % Clay in sediment traps pre- vs. post-restoration at reef sites during fall sampling periods. "a" indicates significant difference between pre- and post-restoration.

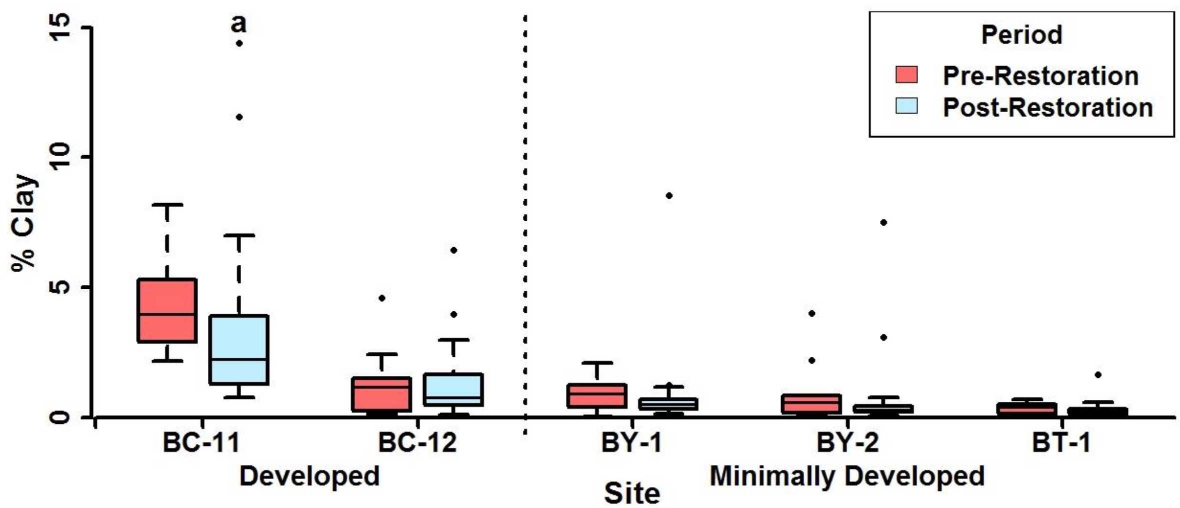

Figure 12B. % Clay in benthic samples pre- vs. post-restoration at reef sites during fall sampling periods. "a" indicates significant difference between pre- and post-restoration.

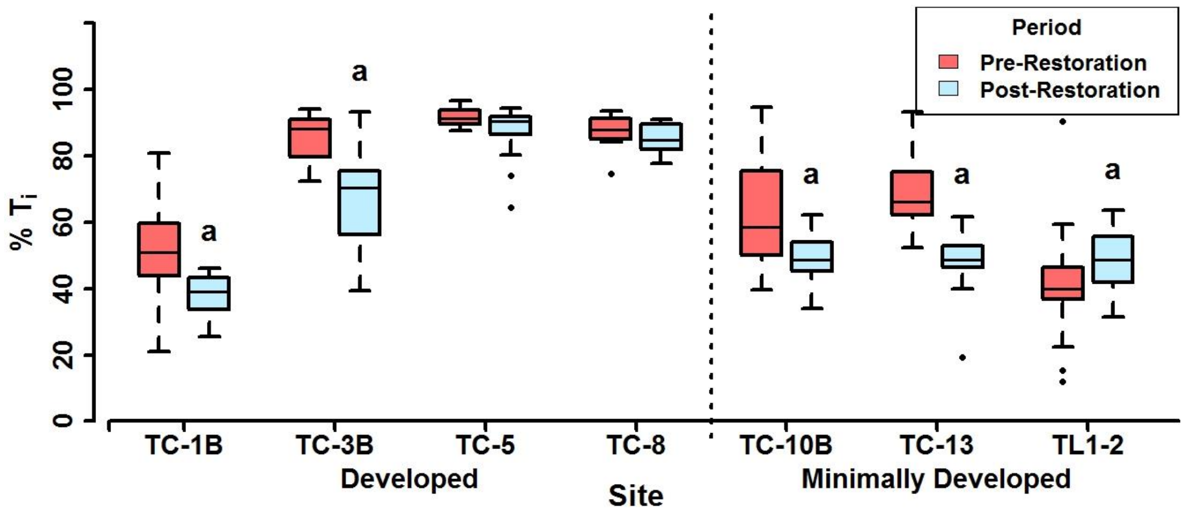

Figure 13A. % Terrigenous$_{inorganic}$ in sediment traps pre- vs. post-restoration at shore sites during fall sampling periods. "a" indicates significant difference between pre- and post- restoration.

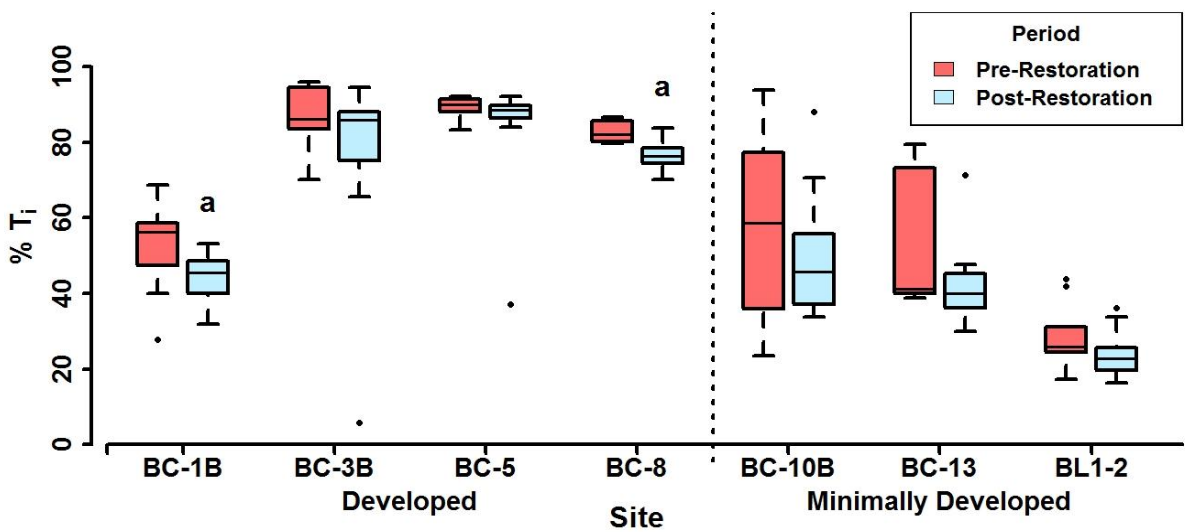

Figure 13B. % Terrigenous$_{inorganic}$ in benthic samples pre- vs. post-restoration at shore sites during fall sampling periods. "a" indicates significant difference between pre- and post- restoration.

Pre-vs. Post-Restoration during Periods with Equivalent Storms

Sampling periods with mean rainfall per day >4 mm were defined as "storm periods" and pooled to perform a comparative storm analysis. Pre- and post-restoration sampling periods with similar mean daily rainfall were identified and compared (Table 4) by calculating the percent change in % clay, % T_i, and TAR pre- vs. post-restoration.

There was a decrease in trap and benthic % clay post-restoration for approximately 80% & 78%, respectively of large storm comparisons at developed shore sites (2-129% decrease) compared to a smaller decrease (5-52%) during only ~25% and 50% of the large storm period comparisons for trap and benthic sediments, respectively at the minimally developed sites. For small storm periods (<6 mm of average mean daily rainfall), there was a decrease in trap and benthic % clay post-restoration for approximately 55% and 72% of small storm comparisons at developed shore sites compared to only ~21% and 56% of the small storm period comparisons for trap and benthic samples, respectively at the minimally developed shore sites. The pattern of post-restoration decreases in % clay at the shore sites was not observed at the reef sites.

In general, % T_i decreased in the trap sediment post-restoration for most equivalent storm comparisons across sites with the exceptions of Coral Harbor sites and TY-1 and TY-2. No consistent trends were observed in TAR when comparing pre- and post-restoration equivalent storm periods.

Table 4. *List of sampling periods with "equivalent storms".*

Pre-Storm Recovery Date	Post-Storm Recovery Date	Rainfall per Period (mm) Pre	Rainfall per Period (mm) Post	Mean Rainfall per Day (mm) Pre	Mean Rainfall per Day (mm) Post
12/2/2009	12/7/2013	259.1	251.7	10.4	8.1
12/2/2010	10/11/2011	157.2	171.5	6.6	6.6
12/2/2010	9/17/2011	157.2	152.9	6.6	5.9
12/2/2010	9/16/2014	157.2	150.4	6.6	5.8
12/2/2010	11/6/2014	157.2	147.3	6.6	5.7
12/2/2010	12/3/2012	157.2	147.8	6.6	5.5
6/29/2011	10/11/2011	163.6	171.5	6.3	6.6
6/29/2011	9/17/2011	163.6	152.9	6.3	5.9
6/29/2011	9/16/2014	163.6	150.4	6.3	5.8
6/29/2011	11/6/2014	163.6	147.3	6.3	5.7
6/29/2011	12/3/2012	163.6	147.8	6.3	5.5
7/25/2011	10/11/2011	149.6	171.5	5.8	6.6
7/25/2011	9/17/2011	149.6	152.9	5.8	5.9
7/25/2011	9/16/2014	149.6	150.4	5.8	5.8
7/25/2011	11/6/2014	149.6	147.3	5.8	5.7
7/25/2011	12/3/2012	149.6	147.8	5.8	5.5
9/15/2010	11/5/2011	130.0	116.3	5.0	4.7
11/7/2009	11/5/2011	120.9	116.3	4.7	4.7
1/24/2010	8/21/2014	112.5	121.7	4.3	4.1

PART V: OUTREACH ACTIVITIES AND PRODUCTS

Our outreach activities during the reporting period are summarized in Table 5. Outreach activities and products included a) five scientific abstracts and presentations at professional meetings, b) awarding of funding from the University of Puerto Rico Sea Grant College to support a project, which builds off of this work, c) two expert witness reports, d) an MS theses, and e) 3 manuscripts in preparation.

The P.I. supervised student research for one graduate student, Stephen Campbell, and undergraduate student Tyler Barnes. Members of our team (field assistants Heidi Hirsh and Jennifer Kisabeth, and graduate student Whitney Sears) presented a summary of our research and conducted a workshop for USVI high school students attending the VIERS science camp. Sarah Gray and her research team met with community management partners in the USVI (Coral Bay Community Council) and communicated with scientific collaborators Carlos Ramos-Scharrón (UT, Austin), Gregg Brooks (Eckerd College), and James Whinney (James Cook University, Australia) and in March of 2017 presented their results to NOAA managers. Overall, we estimate that these outreach activities reached over 220 people. Copies of abstracts, reports, and presentations were submitted with previous interim reports.

i. *Professional meeting abstracts & presentations*

1. Gray, S.C., Ramos-Scharrón, C.E., Sears, W.*, Brooks, G., Larson, R.A., LaFevor, M.C., and Roy, J. (2016). Ridge to reef integrated terrestrial-marine monitoring to assess the impact of watershed restoration on coral reef sedimentation, St. John, US Virgin Islands. *13th International Coral Reef Symposium, June 19th-24th, 2016, Honolulu, HI.*

2. Campbell, S.E., Gray, S.C., Whinney, J., Ramos-Scharrón, C.E., Campbell, S. and LaFevor, M.C., (2016). Watershed runoff and sediment resuspension: factors affecting turbidity and sedimentation in bays with Coral Reefs, St. John, USVI. *13th International Coral Reef Symposium, June 19th-24th, 2016, Honolulu, HI.*

3. Carilli, J., McNally, S., and Gray, S.C. (2016). Assessing Mitigation Efforts To Reduce Sediment Runoff On Coral Reefs In St. John, USVI using coral geochemical proxies. *13th International Coral Reef Symposium, June 19th-24th, 2016, Honolulu, HI.*

4. Larson, R.A., Brooks, G., Gray, S.C., Ramos-Scharron C.E., Campbell, S., and Clark, N. (2016). Assessment of the Historical Impact of Land Use and Restoration Activities on Sediment Delivery and Accumulation in Coral Bay, St. John, USVI. *NOAA in the Caribbean Meeting, May 9th-11th, 2016, San Juan, Puerto Rico.*

5. Campbell, S.E., Gray, S.C., Whinney, J., Ramos-Scharrón, C.E., Campbell, S. and LaFevor, M.C., (2015). Watershed-Marine Linkages: Monitoring how Terrigenous Runoff and Wave-Induced Resuspension Affect Marine Sediment Dynamics in Bays with Coral Reefs, St. John, USVI. *NOAA in the Caribbean Meeting, May 9th-11th, 2016, San Juan, Puerto Rico.*

6. Gray, S.C. and Ramos-Scharron, C.E., "Ridge to reef integrated terrestrial-marine monitoring to assess the impact of watershed restoration on coral reef sedimentation in St. John, US Virgin Islands. *Presentation to NOAA's Coral Reef Conservation Program, Silver Spring, Maryland, 3 March 2017.*

ii. Reports

1. Gray, S.C. (2016). "Expert Witness Report Regarding Water Quality Impacts of the Sirius Marina Proposal". Submitted to the Coral Bay Community Council, US Virgin Islands.

2. Gray, S.C. (2015). "Expert Witness Report Regarding Water Quality Impacts of the Summers End Marina Proposal". Submitted to the Coral Bay Community Council, US Virgin Islands.

iii. Grants awarded

3. University of Puerto Rico Sea Grant College. Gray, S.C. & Ramos-Scharrón, C.E. and Brooks, G. "Assessment of the Impact of Watershed Development and Restoration on Marine Sediment Dynamics, St. John, USVI" (2016-18).

iv. MS Thesis

4. Campbell, S.E. The Effect of Watershed Runoff and Sediment Resuspension on Turbidity and Sediment Deposition in St. John, US Virgin Islands: Implications for Watershed and Marine Development and Restoration in Bays with Coral Reefs

v. Journal Articles (in preparation)

5. Gray, S.C., Ramos-Scharrón, C.E., Sears, W., Swiderski, M., Brooks, G., Larson, R.A., LaFevor, M.C., and Roy, J. (2017). Ridge to reef integrated terrestrial-marine monitoring to assess the impact of watershed restoration on coral reef sedimentation, St. John, US Virgin Islands.

6. Campbell, S.E., Gray, S.C., Whinney, J., Ramos-Scharrón, C.E., Campbell, S. and LaFevor, M.C., (2017). Watershed runoff and sediment resuspension: factors affecting turbidity and sedimentation in bays with Coral Reefs, St. John, USVI.

7. Gray, S.C., Campbell, S.E., Whinney, J., Ramos-Scharrón, C.E., Campbell, S., and Swiderski, M. (2017). Monitoring sediment dynamics using Nephelometers and Sediment Traps: Challenges and Considerations

Table 4. *Log of outreach activities*

Date	Location	Person involved	Type of Event	Audience /meeting type & (Number)
7/23/14	VIERS, St. John, USVI	H. Hirsh, W. Sears, J. Kisabeth	Hands-on workshop for USVI students attending "Science Camp" at VIERS	High school students (17)
1/19/15	St. John USVI	Gray & Campbell	Met with Coral Bay Community Council President Sharon Coldren	Local environmental manager
2/27/15	San Diego, CA	Gray	Submitted expert witness report on behalf of the Coral Bay Community	http://savecoralbay.com/expert-report-on-water-

			Council regarding Coral Bay marina development proposal	quality-sarah-gray-ph-d/
4/30/15	San Diego, CA	Barnes & Gray	*Inside USD* web article	General public
5/12/15-5/16/15	San Diego, CA	Ramos-Scharron & Gray	Multi-day meeting to discuss linking terrestrial and marine data & publication plans	2
10/1/15	San Diego	Gray	Submitted Expert Witness report to the Coral Bay Community Council for Marina development	General public/website (50)
12/11/15	San Francisco, CA	Campbell, Gray, Ramos-Scharrón, Hirsh	Presentation to the American Geophysical Union Fall Meeting	International Scientists (20)
1/15/16	San Diego	Gray, Campbell, Ramos-Scharrón, Carilli	Three abstracts submitted (and accepted) for the 13th Coral Reef Symposium to be held in Honolulu, HI, 6/19/16	
2/21/16	New Orleans, LA	Larson, Brooks, Gray, Campbell	Presentation at the 2016 Ocean Sciences Meeting	International Scientists (30)
3/6/16	Sydney, Australia	Carilli, Gray	Presentation at the International Coastal Symposium	International Scientists (30)
5/10/16	San Juan, Puerto Rico	Campbell, Gray, Larson & Brooks	2 presentations at the NOAA in the Caribbean 2016	International Scientists & environmental managers (20)
6/21/16	Honolulu Hawaii	Campbell, Carilli	2 presentations at the 13th International Coral Reef Symposium	International Scientists (30)
7/8/16	St. John, USVI	Gray, S., Campbell, S., Carrano, E.	Meeting with USVI local environmental management entity Coral Bay Community Council	Local environmental managers (4)
3/3/17	Greenbelt, Md	Gray & Ramos-Scharron	Presentation and meeting with NOAA Coral Reef Managers	Scientists and managers (10)

REFERENCES

Bak, R.P.M. 1978. Lethal and sublethal effects of dredging on reef corals. Marine Pollution Bulletin 9, 14–16.

Brooks, G.R., B. Devine, R.A. Larson, and B.P. Rood. 2007. Sedimentary development of Coral Bay, St. John, USVI: A shift from natural to anthropogenic influences. Caribbean Journal of Science 43:226-243.

Brown, B.E., Le Tissier, M.D.A., Scoffin, T.P., and A.W. Tudhope. 1990. Evaluation of the environmental impact of dredging on intertidal coral reefs at Ko Phuket, Thailand, using ecological and physiological parameters. Marine Ecology Progress Series 65:273–281.

Butman, C.A., Grant W.D., and K.D. Stolzenbach. 1986. Prediction of sediment trap biases in turbulent flows: A theoretical analysis based on observations from the literature. Journal of Marine Research 44:601-644.

Erftemeijer PLA, Riegl B, Hoeksema BW, Todd PA (2012) Environmental impacts of dredging and other sediment disturbances on corals: A review. Mar Pollut Bull 64: 1737-1765.

Gray, S.C., C. Ramos-Scharrón, W. Sears, G. Brooks, R. Larson, M. LaFevor, and J. Roy. 2016. Ridge to reef integrated terrestrial-marine monitoring to assess the impact of watershed restoration on coral reef sedimentation in St. John, US Virgin Islands. 13th International Coral Reef Symposium; 19-24 June 2016; Honolulu, Hawaii.

Gray, S.C., K.L. Gobbi, and P.V. Narwold. 2008. Comparison of Sedimentation in Bays and Reefs below Developed versus Undeveloped Watersheds on St. John, US Virgin Islands. Proceedings of the 11th International Coral Reef Symposium, 1-5.

Gray, S.C., W. Sears, M.L. Kolupski, Z.C. Hastings, N.W. Przyuski, M.D. Fox, and A. DeGrood. 2012. Factors affecting land-based sedimentation in coastal bays, US Virgin Islands. Proceedings of the 12th International Coral Reef Symposium, 9-13.

Jones, R.J. 2011. Environmental Effects of the cruise tourism boom: sediment resuspension from cruise ships and the possible effects of increased turbidity and sediment deposition on corals (Bermuda). Bulletin of Marine Science 87(3):659-679.

MacDonald, L.H., D.M. Anderson, and W.E. Dietrich. 1997. Paradise threatened: Land use and erosion on St. John, US Virgin Islands. Environmental Management 21:851-863.

Ramos-Scharrón, C.E., and L.H. MacDonald, 2007a. Measurement and prediction of natural and anthropogenic sediment sources, St. John, U.S. Virgin Islands. Catena 71:250-266.

Ramos-Scharrón, C.E., and L.H. MacDonald, 2007b. Runoff and suspended sediment yields from an unpaved road segment, St John, US Virgin Islands. Hydrological Processes 21:35-50.

Ramos-Scharrón, C.E., S. Atkinson, K. Day, B. Devine, K.R. Munroe, and B. Swanson. 2012. USVI Coastal Habitat Restoration through Watershed Stabilization Project, NOAA-ARRA: 2009-2012 Terrestrial Monitoring Component Final Report.

Ridd, P., and P. Larcombe. 1994. Biofouling control for optical backscatter suspended sediment sensors. Marine Geology 116:225-258.

Ridd, P., G. Day, S. Thomas, J. Harradence, D. Fox, J. Bunt, O. Renagi, and C. Jago. 2001. Measurement of sediment deposition rates using an optical backscatter sensor. Estuarine, Coastal and Shelf Science 52:155-163.

Rogers, C.S. 1983. Sublethal and lethal effects of sediments applied to common Caribbean Reef corals in the field. Marine Pollution Bulletin 14:378-382.

Storlazzi, C.D., M.E. Field, and M.H. Bothner. 2011. The use (and misuse) of sediment traps in coral reef environments: theory, observations, and suggested protocols. Coral Reefs 30:23-38.

Thomas, S., and P.V. Ridd. 2004. Review of methods to measure short time scale sediment accumulation. Marine Geology 207:95-114.

Thomas, S., and P.V. Ridd. 2005. Field assessment of innovative sensor for monitoring of sediment accumulation on inshore coral reefs. Marine Pollution Bulleting 51:470-480.

Thomas, S., Ridd, P.V., and P.J. Smith. 2002. New instrumentation for sediment dynamics studies. Marine Technology Society 36(1):55-58.