Final Project Report (3/30/12)

"A comparative analysis of sedimentation and water quality in mangrove, shore, bay and reef environments below a developed vs. an undeveloped watershed, St. John, US Virgin Islands"

Submitted by:

Sarah C. Gray, Principle Investigator

Marine Science and Environmental Studies Department
University of San Diego (sgray@sandiego.edu)

Award Number: **NA10NMF4630065**
Recipient Name: **University of San Diego**
Award Period: **07/01/2010-12/31/2011**
Program Office: **Fisheries Habitat Conservation Program Office**
Program Officer: **Liz Fairey, 301.713.4300, liz.fairey@noaa.gov**

Introduction & Objectives:

In the US Virgin Islands, sediment constitutes the largest pollutant of coastal waters by volume and is thought to be the primary cause of coral reef degradation. The NOAA Coral Reef Conservation Program (CRCP) has supported our ongoing studies in St. John, US Virgin Islands to evaluate whether/how watershed development has impacted the quantity, quality (type), and spatial variability of sedimentation and water quality in bays with reefs. In 2010-11 sediment erosion control and sedimentation mitigation structures were constructed in one of our study bays with funding from the 2009 American Recovery and Reinvestment Act (ARRA). This project, the "*USVI Coastal Habitat Restoration through Watershed Stabilization,* aimed to reduce sediment-loading rates into the coastal waters. As part of the ARRA monitoring plan, my research team has been conducting sediment monitoring in locations in Coral Bay below where the planned erosion reduction projects will be constructed. This CRC research grant was awarded as a supplement to ARRA funding to conduct sediment monitoring of non-ARRA "control" sites from Aug. 2010-Feb. 2011 that are 1) below undeveloped watersheds (Lameshur Bay and a sub-watershed within Coral Bay), and 2) below developed watersheds for which no sediment control mitigation work is being undertaken. We also expanded our monitoring efforts to include the pristine mangrove areas in Hurricane Hole, where healthy and diverse coral communities have colonized the prop roots of mangroves, in spite of apparently low light levels. The locations of our 2010-2011 regular sampling stations on St. John, USVI are shown in Figs. 1, 2, and 3 and described in Table 1.

Our study examined sediments in three reservoirs in the bays: suspended sediments (water samples), settling sediments (sediment traps) and accumulated sediments (bay-floor benthic surface samples). In addition we have measured marine water quality and our regular sampling sites and at strategic locations above our shore sediment traps. Our project aimed to address the following questions:

1) *What are the composition (grain size distribution, organic matter type and quantity, mineralogy, and relative carbonate/siliceous ratio, chemical composition) and quantity (flux rate or concentration) of suspended, settling, and accumulated sediments collected between 7/1/10-6/30/11?*
2) *How do these characteristics vary temporally during the study period (and with previous seasons), with environmental parameters (storms, runoff, wind and currents) and with watershed changes (such as new development or sediment mitigation)?*
3) *For the reef sites, is there a relationship between parameters of sediment flux and the condition of the reefs?*
4) *How do parameters of water quality (TSS, turbidity, elemental chemistry) vary between different areas with different types and degrees of development?*

Our specific educational and public outreach objectives were to: a) establish scientific and educational collaborative partnerships with scientists working in the USVI and interested citizens; b) inform students and the public about the impacts of watershed development on corals reefs, and c) provide tangible data for territorial and local environmental managers to inform policy decisions.

RESEARCH ACTIVITIES & RESULTS:

A. FIELDWORK: Sediment & water quality sampling and in-field laboratory analyses (August, 2010-June 2011):

From July 18th-August 13th, 2010, Gray and a team of student researchers from USD and CICESE in Ensenada, Mexico set up 25 sediment traps at 14 stations in 4 bays (Great Lameshur, Little Lameshur, Coral Bay, and Hurricane Hole) for ongoing sediment monitoring in St. John (Figs. 1, 2 & 3; Table 1). During our 25 day field season in St. John, we collected and processed sediment trap samples that had been collecting over the summer, repaired and replaced sediment traps, conducted storm water sampling, met with collaborators and research partners at UVI and in the Coral Bay Community, trained new VIERS research volunteer (Whitney Sears) and part-time field assistants (Roy Proctor, Katie Day and Matt Knoblock) and conducted outreach activities. Sediment traps used for previous field seasons had to be replaced and or repaired and the current meters were repaired and redeployed. At 6 shore & mangrove locations, "storm" sediment traps were set up to monitor sedimentation during discrete storm events. At 7 locations, paired traps of differing trap heights above the substrate (30 and 60 cm) were deployed to examine the effect of trap height on sediment trap accumulation (Table 1). During previous field seasons (08-09) the shore traps were deployed in a few locations at only 30 cm above the bay-floor (to maximize their proximity to the ghut outfall), rather than 60 cm above the bay floor as in deeper locations (bay and reef sites). By deploying paired short (30 cm) and tall (60 cm) traps at these locations this year, we hope to evaluate the relative impact of re-suspension over new sediment delivery. In both bays, traps were deployed in mangrove, shore, bay and reef environments (Table 1).

Within Coral Bay, sites were chosen to sample below watersheds with different degrees of development. For example the Plantation Hill sites (TC-10 & TC-13; Fig. 1, 2, Table 1) drains a sub-watershed with no upslope development and only minimal development at the base of the slope. The Calibash Boom site (TC-1) is below an active construction site with sediment ponds to reduce sediment delivery to the shore. The Shipwreck Landing site (TC-3) is below a developed (un-mitigated) steep watershed (Fig. 1, 2, Table 1). We sited two sampling stations in the mangrove areas of Coral Bay Harbor (TC-5 & TC-8), which drain the largest watershed (Fig. 2). This year we expanded our monitoring to include two additional sites in the pristine mangrove areas in Hurricane Hole, where healthy and diverse coral communities inhabit the mangrove in spite of limited light penetration. Great Lameshur Bay is below a watershed that is totally within the VI National Park, and is thus largely undeveloped (except for a few roads and the VIERS camp) (Fig. 3). In Great Lameshur Bay, sediment traps were deployed in the mangroves, near the ghut (drainage) outfall and at three reef sites (Fig. 3; Table 1). This year we added two traps in the shore area of Little Lameshur Bay, which drains an adjacent, undeveloped watershed within the Virgin Islands National Park. Our reef sampling sites in Lameshur Bay include two traps at Yawzi Point and one trap at Tectite Reef.

In addition to sediment trap and marine water sampling stations, we deployed two acoustic current meters (Falmouth 2D ACM) on the south side of Coral Bay to monitor circulation within the bay and to determine the effect of currents on sediment resuspension (Fig. 2). A rain gage was deployed above the VIERS station in Lameshur Bay.

From August 2010-June, 2011 Whitney Sears, our research assistant in residence at the Virgin Islands Environmental Resource Station (VIERS) collected water and sediment samples at regular intervals every 26 days with the help of five local field assistants. Between July, 2010-June 2011 there were nine sampling periods of approximately 26 days each (except in April-May because Sears went off island). Although we proposed only to sample through the end of February, 2011, additional funds from the University of San Diego to support the summer, 2010 field work made it possible for us to extend our NOAA CRC-funded sampling through June, 2011. Beginning July of 2011, the regular marine sediment and water quality sampling was funded by a subsequent NOAA CRC grant.

During the summer to fall of 2010, there were a high number of storms in St. John, some of which brought significant sediment runoff into the bays. May through July was unusually rainy, so the ground was soaked when additional rain fell in late July. According to the *St. John Tradewinds* of 7/26/10, "Total rainfall for May reached 10.6 inches and total rainfall for June was 7.48 inches according to measurements by Boulon. This was the wettest June and the second wettest May that Boulon has recorded". The following major storm events occurred during our field season: a) low pressure system: 7/20/10-7/23/10; b) Hurricane Earl: 8/30/10-8/31/10; c) Tropical Storm Otto: 10/5/10-10/7/10; and d) a rain event associated with a cold front: 11/6-11/9/10. Except for Hurricane Earl, which brought mostly wind and little rain to the island, all of these events resulted in unprecedented sediment runoff into the bays and turned the color of the bays brown. Some of our sediment traps were buried or destroyed as a result of this storm activity. New sediment traps had to be constructed and deployed to replace the damaged and buried traps and some data was lost due to the storms.

B. LABORATORY METHODS

For each of the collection periods from July 2010-June 2011, sediments (suspended, trapped, and bottom) and water samples were processed at the VIERS (Virgin Islands Environmental Resource Station) laboratory. Dried and frozen sediments and water samples were sent to the University of San Diego for further chemical and geological analyses. The % organic matter and % carbonate sediment in each sample was measured by Loss on Ignition (LOI) (combusting 3 hours at 550°C for % organic and 950° C for 3 hours for % carbonate) (Heiri et al., 2001). The proportion (%) of terrigenous sediment was then determined by subtraction from the % organic and % carbonate and multiplied by the sediment accumulation rate to get the rate of terrigenous sediment accumulation in the trap tubes. Grain size distributions were determined using a Beckman-Coulter LS200 Laser Particle Sorter. Representative samples from the terrestrial and marine environment were powdered and scanned on an X-Ray diffractometer (XRD) to determine bulk and thin sections of rocks and sediments were examined under a petrographic microscope.

C. RESULTS & DISCUSSION

a) Sediment composition.

The sediment composition (% terrigenous) varied between environments and between watersheds/bays (Fig. 4). The mean terrigenous proportion (%) was highest nearest the shoreline (terrigenous > 56%) and decreased with distance from shore to the reef where it made up between 14-28% of the sediment. For all environments, the mean proportion of terrigenous sediment was higher below the developed watershed (Coral Bay).

b) Total and terrigenous sediment accumulation.

Terrigenous sediment accumulation was highly variable between sites (Fig. 5). Mean terrigenous accumulation rates were higher at shore sites than at reef sites in both the developed and reference locations. The highest mean terrigenous accumulation rates were recorded at two sites below areas of extensive watershed development: Coral Harbor (TC-5 & TC-8), and Shipwreck (TC-3) (Fig. 2). The watershed above Coral Harbor is the largest watershed on St. John and contains many dirt roads (Fig. 1). Mangroves lining the shoreline at the Coral Harbor may effectively be reducing terrigenous sediment delivery. Though Calabash (TC-3) is a steep and developed watershed adjacent to and geographically similar to the Shipwreck watershed, terrigenous sedimentation rates at the Calabash site were lower than at Shipwreck (TC-1) (Fig. 5). Construction of a leaky sediment retention pond in 2008 at Calabash may have reduced terrigenous sediment runoff during all but the major storm events (when it overflows). Similar in size, steepness, and geographic orientation to Shipwreck and Calabash along the south shore of Coral Bay, Plantation Hill (TC-10, TC-13) consists of two sub-watersheds with minimal or no development (Figs. 1 & 2). Mean terrigenous sediment accumulation rates below the reference sub-watershed of Plantation Hill (TC-10, TC-13) were less than below developed & unmitigated Shipwreck and Coral Harbor watersheds (Fig. 5).

Total and terrigenous sediment accumulation results for the 2010-11 season is plotted with data collected during previous field seasons and presented by environment (mangrove, shore & reef) in Figures 6-8. Total and terrigenous sediment accumulation was higher below the developed watersheds compared to the undeveloped watersheds. The total and terrigenous sediment trap accumulation rates were lowest at two locations in Coral Bay below less-developed or undeveloped watersheds (Plantation Hill TC-10 & TC-13) and Hurricane Hole (THH-1) (Figs. 6-8). For most of the 2.5-year time series, total and terrigenous sediment accumulation was higher at the Coral Bay reefs than at the Lameshur Bay Reefs (Yawzi & Tektite) (Figs. 6-8). However, during the fall months (Sept.-Nov.) of 2010, higher total and terrigenous sediment accumulation was recorded at the Lameshur Bay reefs. For all environments, the highest total and terrigenous sediment accumulation and proportion were recorded during the fall months (Sept.-Nov.) of 2010 when there were record rains and sediment runoff into both Coral and Lameshur Bays (Figs. 6-8).

c) The impact of the 2010 rainy season on sedimentation.

The summer and fall rainy season of 2010 was very unusual with historically high rainfall and runoff. This was accompanied by total and terrigenous sedimentation rates that were 100's to 1000's of times higher than the mean for the 4.5 to 5.5 years that we've been monitoring sedimentation (Fig. 9). For example, terrigenous sedimentation rates were between 1000 to 2500 times higher at the Lameshur reefs between Sept. and October of 2010 than the 5.5- year mean (Fig. 9). In Coral Bay, terrigenous sedimentation rates 100-200 times higher than the 4.5-year mean were recorded. Comparison of mean monthly and maximum daily rainfall at our VIERS rain gauge for 2008-2011 shows that 2010 was a year with significantly higher rainfall and a longer rainy season (June-Nov.) than 2008, 2009 or 2011 (Fig. 10).

Examination of temporal variability in sedimentation since 2007 or 2008 at the shore sites (Fig. 20) shows that for most sampling periods, the highest rates of terrigenous accumulation were recorded below the developed watersheds (dashed lines in Fig. 11) compared to the undeveloped reference sites (solid lines in Fig. 11). The highest rates of terrigenous sediment accumulation occurred when there were periods of significant terrigenous runoff (indicated by the red storm symbol in the figure). The highest terrigenous sediment accumulation during the 4-5 year time series was recorded following Hurricane Otto (which passed St. John on 10/9/10-10/11/10) (Fig. 11).

d) Sedimentation impacts on coral reefs.

At the reef sites the highest total (dashed lines) and terrigenous (solid lines) sediment accumulation was recorded during storm events (Fig. 12). In addition, both total and terrigenous accumulation were higher at the reefs below the developed watershed (Coral Bay) than below the undeveloped watershed (Lameshur Bay) for most sampling periods. An exception was observed during the sampling period when Hurricane Earl (8/30/10-8/31/10) passed over St. John (Fig. 12). Total sediment accumulation at the Lameshur Bay reefs was the highest measured at reefs during the time series (Fig. 12). This storm did not bring much terrigenous runoff but brought high swells and waves from the south, which re-suspended carbonate bottom sediment in Lameshur Bay, turning the bay a whitish color. By comparison, H. Earl had less impact on sedimentation at the CB reefs, which were somewhat protected from the southerly swell. The variable impact of this storm event at different reefs illustrates the necessity of site-specific monitoring to accurately quantify the specific sedimentary response to storms.

Pastorak and Bilyard (1985) suggested that sediment accumulation rates of 10-50 $mg/cm^2/day$ and > 50 $mg/cm^2/day$ cause "moderate to severe" and "severe to catastrophic" sediment stress, respectively. High sedimentation rates (>100 $mg/cm^2/day$) have also been shown to kill exposed coral tissue (Riegl and Branch 1995) or reduce photosynthetic yields (Philipp and Fabricius 2003). Though relatively low sediment accumulation rates (< 10 $mg/cm^2/day$) persisted at both the Lameshur Bay and Coral Bay reefs for most of the time series, three major storm events resulted in total sediment accumulation rates greater than 50 $mg/cm^2/day$ and one event produced rates greater than 100 $mg/cm^2/day$ (Fig. 12). Our data therefore suggest that these reefs are not under persistent chronic sedimentation stress, in contrast to other reefs in the USVI, such as those at Fish Bay (Gray et al., 2009). However, these integrated (26-day) mean accumulation rates may underestimate the acute sedimentation that occurs during the few days that a storm passes over.

Total sediment accumulation rates on the Lameshur reefs from Aug-Oct. of 2010 were over two times higher than sedimentation rates (50mg/cm2/day) that have been shown to be harmful to coral reefs (Fig. 12). In addition, both the total and terrigenous sedimentation rates during 2010 were much higher than any of the other years we monitored sedimentation (2007-11) (Fig. 13). These reefs have been ecologically monitored for over 25 years by Dr. Peter Edmonds at CSU Northridge. Dr. Edmonds and I are working on a paper to document how the unusual 2010 conditions on these reefs may have impacted the ecosystem. Though there does not appear to be a negative impact on coral health in the Lameshur reefs following the 2010 season, Dr. Edmonds' team has recorded an increase in the recruitment of suspension feeders, which may be linked to the unusually high total and terrigenous sedimentation at the Lameshur reefs (Fig. 13) (P. Edmonds, pers. Comm.).

e) Sedimentation at "impacted" vs. "reference" sites.

One of the reasons to expand our field sampling sites to include more "control" or reference sites was to establish a baseline in order to determine if the ratio of terrigenous accumulation between developed "impacted" and "control" or references sites will decrease after the ARRA mitigation structures and BMP's are completed (pre- vs. post-mitigation). Mean terrigenous accumulation measurements were on average 10-160 times higher below developed vs. undeveloped watersheds (Fig. 14).

f) Effect of trap height.

Comparison of mean terrigenous sediment trap accumulation rates measured at the same locations in 30 cm and 60 cm traps (Fig. 15) revealed that the shorter 30 cm traps always collected more sediment than then 60 cm traps. This difference between 30 and 60 cm accumulation was less at the undeveloped sites such as Plantation Hill (TC-10) and Hurricane Hole (THH-1) (Fig. 15). This higher accumulation is due to enhanced re-suspension in shallow water. Therefore we will use data from the 60 cm traps to address the objectives.

g) Sediment texture.

Textural (grain size) characteristics of the sediments are presented in Figure 16. Sediments at most sites were comprised of less than 10% clay, between 20-50% silt and between 30-80% sand (Fig. 16).

***h) Turbidity/TSS*.**

In reports for pervious NOAA DCRC final grant reports (NOAA Grant *#NA09NMF4630116),* we presented data comparing marine TSS (total suspended sediment) (turbidity) in Coral and Lameshur Bays between 2010 storm events and background conditions. In addition to this focused sampling during storms, we also sampled for TSS at all of our sediment trap sampling sites on regular monitoring days (approximately every 26 days from Aug. 2010-June 2011). Most of these samples were collected during "fair weather" conditions because monitoring was cancelled if the weather was not good. Generally, median TSS was typically less than 10 mg/L at reef and shore sites and less than 15 mg/L at mangrove sites (Fig. 17), suggesting generally clear conditions at the St. John reefs. During fair weather conditions, there does not appear to be a difference in TSS/turbidity between developed and undeveloped watersheds in equivalent environments (Fig. 17). However, these data were highly variable and the maximum TSS (max outlier red cross in Figure 17) was always highest below the developed watersheds. This difference in the TSS of outliers was greatest at the shore locations. For all but one environment, the highest TSS was recorded in October, 2010, a few weeks following hurricane Otto. These data suggest relatively clear water at the Coral Bay and Lameshur Reef during most of the year except following large storms.

i) Geological analyses of watershed and marine rocks and sediments.

The focus of the mineralogical and thin section analysis was to identify potential mineralogic sources of geogenic metals in bedrock, examine the extent of weathering in rock and sediments on a microscopic scale, and observing differences and similarities in mineralogy between sample locations (ridge, soil, stream sediment, and shallow bay and reef areas). The geologic unit, which makes up the watersheds above Lameshur and Coral Bays, The Water Island Formation, is composed of two major rock types, plagiorhyolite and basalt (spilite). Plagiorhyolite is a silicic albite-rich extrusive with varying percentages (up to 20%) of small phenocrysts of quartz and plagioclase encompassed in an aphanitic ground mass (Fig. 18A). The basalts of the Water Island Formation are mostly spilitic in composition and consist of pillow basalt, pillow breccia, and hyaloclastite. Examination of the basalt thin sections revealed very fine-grained matrix composed of plagioclase, clinopyroxene, epidote, chlorite, and opaque minerals and phenocrysts of elongated plagioclase grains (1 mm in length) (Fig. 18B). Terrestrial sediment thin sections had varying fractions of lithic fragments that were easily identifiable as either plagiorhyolite, basalt (spilite), or hydrothermally altered bedrock units (Fig. 18C) with additional organic matter, and individual grains of quartz, plagioclase, biotite and fine-grained Illite clay. Several samples had grains of sediment that showed weathering rinds. These orange weathering rinds may be an iron oxide coating which weathered from iron from minerals such as biotite, pyroxene, and clinochlore. All of these minerals were with XRD. Marine sediments showed variable amounts of carbonates (Fig. 18D). Terrestrial grains in the marine environment were mostly plagiorhyolite or individual quartz grains with minor amounts of spilite and feldspars were also observed. Marine sediment also contained variable concentrations of illite clay and organic matter.

SUMMARY OF RESEARCH RESULTS AND RESEARCH OUTCOMES

Our research has produced the following results:

a) Nine 26-day sediment and water quality monitoring periods were conducted in 2010-11 at multiple sites in mangrove, shore and reef enviornments in Coral, Lameshur and Hurricane Hole Bays. Some of these sites were new undeveloped "control" sites that had not previously been the target of monitoring.
b) Data from the 2010-11 field season confirmed previous results that there were higher total and terrigenous sediment accumulation rates in all environments below developed watersheds and during periods of high rainfall. Mean terrigenous accumulation measurements were on average 10-160 times higher at developed sites compared to equivalent undeveloped reference sites. As in previous years, the highest total and terrigenous sediment accumulation rates during 2010-11 were recorded below the Shipwreck watershed (TC-3) in Coral Bay.
c) For all environments, the highest total and terrigenous sediment accumulation and proportion were recorded during the fall months (Sept.-Nov.) of 2010 when there were record rains and sediment runoff on St. John. The highest terrigenous sediment accumulation during the 4-5 year time series was recorded following Hurricane Otto (which passed St. John on 10/9/10-10/11/10).
d) Though relatively low sediment accumulation rates (< 10 $mg/cm^2/day$) persisted at both the Lameshur Bay and Coral Bay reefs for most of the time series, three major storm events resulted in total sediment accumulation rates greater than 50 $mg/cm^2/day$ and one event produced rates greater than 100 $mg/cm^2/day$. Our data therefore suggest that these reefs are not under persistent chronic sedimentation stress. However, total and terrigenous sedimentation rates during 2010 were much higher than any of the other years we monitored sedimentation.
e) Generally, median TSS was typically less than 10 mg/L at reef and shore sites and less than 15 mg/L at mangrove sites, suggesting generally clear conditions at the St. John reefs. However, the maximum TSS was always highest below the developed watersheds during storm events.
f) This study characterized the lithology and mineralogy and major element composition of the terrigenous rocks and sediments that comprise the terrigenous component of the marine sediments and the watershed rocks and sediments.
g) These data will provide a valuable baseline to evaluate whether NOAA/ARRA erosion mitigation BMP's implemented in late 2011 will measurably reduce sedimentation in Coral Bay.

Research outcomes (Table 2):

a) One scientific manuscript has been submitted (Gray et al., 12th International Coral Reef Symposium Proceedings) and several are in preparation (Table 2, Appendix I).

b) Data from this study have contributed to four presentations or posters at scientific meetings (Table 2).
c) Data from this study have contributed to two invited presentations by S. Gray (Table 2).
d) Two NOAA Coral Reef Conservation proposals for ongoing studies to build on this work have been submitted and one has been funded (Table 2).
e) Data from this study are contributing to three ongoing MS theses.
f) Data from this study have contributed to undergraduate senior thesis for four USD Marine Science students (Table 2).

OUTREACH

A. NOAA/ARRA partnership. Funding from this NOAA GCRC grant has provided an opportunity for our research group to continue to partner with other USVI groups to examine the impact of watershed erosion mitigation and continued sediment monitoring. During this reporting period, we've kept in contact through meetings, emails, and regular bimonthly conference calls with our ARRA research partners at the Virgin Islands Resources Conservation & Development Council (V.I. RC&D), the Coral Bay Community Council, and researchers at the Center for Marine and Environmental Studies (CMES) at the University of the Virgin Islands (Tyler Smith and Marcia Taylor) and the University of Texas at Austin (Carlos Ramos Sharron). Dr. Ramos Sharron has provided us sediment samples from his terrestrial sediment sampling activities. Data from this NOAA GCRC study is providing critically important control and baseline data that will be used as a benchmark for pre- mitigation and treatment and control comparisons following completion of the ARRA mitigation.

B. Coral Bay Community Council (CBCC), EPA CARE & Coral Bay community. We have worked closely with the Coral Bay Community Council (CBCC) to ensure that the data we collected for this project would be of maximum use to their community efforts for watershed management. The CBCC has strongly supported our efforts to obtain continued funding for this research by providing letters of support. On 7/30/10, Coral Bay Community Council sponsored a public presentation by Gray at the Maho Bay resort on St. John entitled "Why is the water brown? Sedimentation studies in St. John bays and coral reefs". The presentation was well attended and covered by the local media (Table 3). CBCC has also featured our research on their website. In December 2010, Gray met in San Diego with Sharon Coldren, the President of the Coral Bay Community Council to share our research results (Table 3). Data from our current meters have been of great interest to Dr. Barry Divine and members of the Coral Bay community who want to evaluate the impact of a desalination plant planned for Coral Bay. We continue to work with members of the Coral Bay Community who volunteer as field assistants and provide discounted use of their boats.

C. Other community and educational outreach activities. Funding from this grant has provided the opportunity for us to share information about our research findings and the impact of land-based sources of pollution to other researchers, university and K-12 students, and members of the community (Table 3). The fact that our field research is sited at VIERS (Virgin Islands Environmental Resource Station) provides an opportunity to speak to visiting K-12, university and community groups who visit VIERS from around the country/world (Table 3). Two notable outreach activities we conducted from July 27-29, 2010 were a presentation and workshop at the VIERS "Eco" Camp, which was attended by Caribbean middle-high school students (Fig. 19, Table 3).

D. Scientific collaborations. Data collected and activities associated with this grant have provided the opportunity to collaborate with other scientists. Dr. Pete Edmonds, a coral reef ecologist at CSU Northridge and I are currently collaborating on a journal article that will link changes in sedimentation and other physical environmental parameters during the fall of 2010 with ecological changes his team has documented on the Lameshur Reefs. Dr. Tyler Smith, a coral reef ecologist at the University of the Virgin Islands (UVI), are comparing sedimentation on the Coral Bay reefs to parameters of reef health. Dr. Carlos Ramos Sharron, of UT Austin has worked with us to synthesize rain data from various locations and has provided samples from terrestrial sediment traps, which we will analyze geologically. Data from our current meters have been of use to Drs. Nasseer Idrisi and Barry Devine of the UVI and well as Dr. Caroline Rogers of the USGS who are interested in evaluating the physical oceanography and circulation patterns in Coral Bay.

E. USD student research projects. Two USD Master of Science students (Robert Harrington and Whitney Sears) and 4 USD undergraduate students (Casey Chapman, Maverick Carey, Ryan Quilley, and Joyce Hseih) in the Marine Science and Environmental Studies Department at USD conducted undergraduate using data collected partially as a result of this grant. Four former and current undergraduate and graduate students presented talks and posters about their research at the 91st Annual Western Society of Naturalists meeting held from 11/11/10-11/14/10 in San Diego (Table 2) an are co-authors on a journal article and abstract that has been submitted for presentation at the 12th International Coral Reef Symposium, which will be held in July of 2012 (Appendix I). In addition to formal graduate and undergraduate research projects, some examples and photos from this project are used as a case study to illustrate concepts in several of the USD courses I teach including: Geological Oceanography, Environmental Geology, and Introduction to Earth Science.

REFERENCES

Gray SC, Gobbi KL, Narwold PV (2009) Comparison of Sedimentation in Bays and Reefs below Developed versus Undeveloped Watershed on St. John, US Virgin Islands. Proc of the 11th Int Coral Reef Sym 1:351-356

Heiri OF, Lotter F, Lemke EG (2001) Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Jour of Paleolimnol 25:101-110

Pastorok RA, Bilyard GR (1985) Effects of sewage pollution on coral-reef communities. Mar Ecol Prog Ser 21:175–189

Philipp E, Fabricius, K (2003) Photophysiological stress in scleractinian corals in response to short term sedimentation. Jour Exp Mar Bio Ecol 287: 57-78

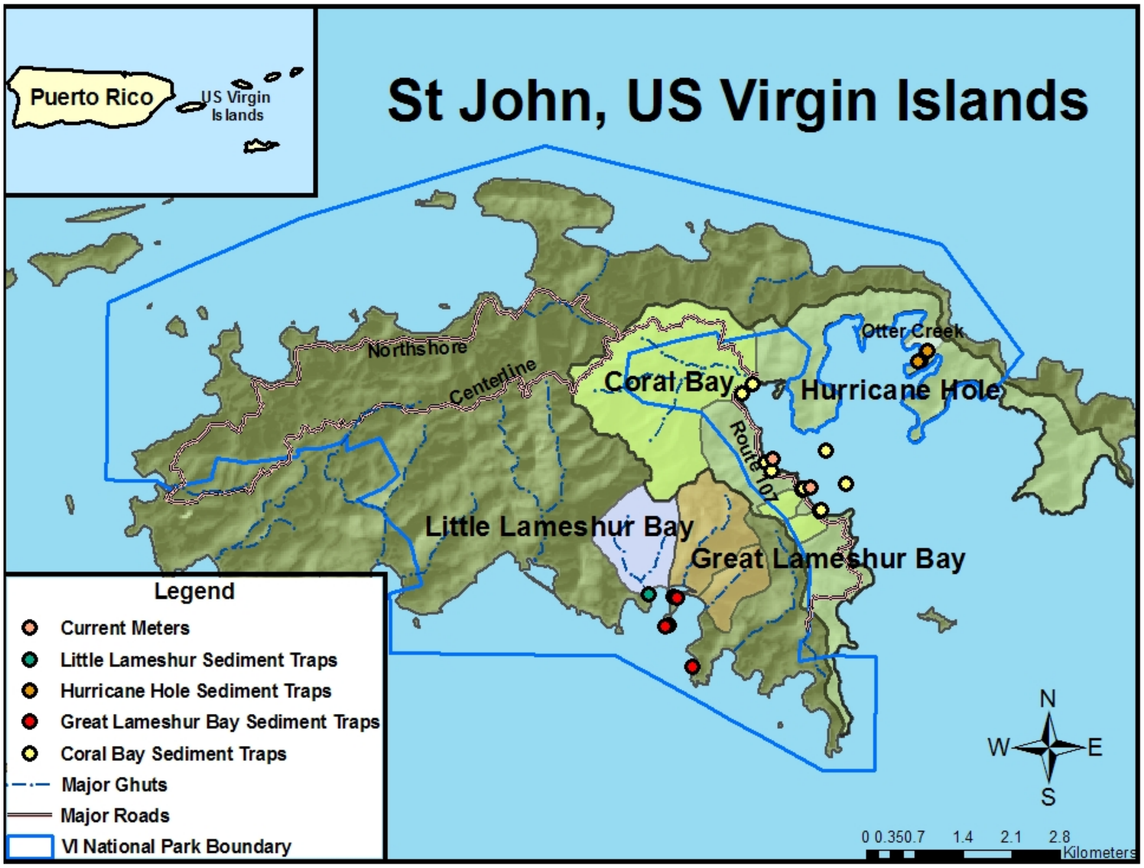

Figure 1. *Map of St. John showing the boundary of the VI National Park (blue line) and the watersheds and sediment trap/sampling locations. Some of the watersheds above Coral Bay are developed. Great Lameshur Bay watershed is mostly undeveloped within the VI National Park.*

Table 1. Sampling locations, sediment trap height and sampling interval for sediment traps.

Bay	Station	Environment	Trap	Trap Height (cm)	Collection interval	Lat. 18' N. (min.)	Long. 64' W. (min.)
Coral	Calabash Shore	Shore	TC-1	30	26-day	19.810	42.278
			TC-1B	60	26-day	19.815	42.272
			TC-1S	30	storm	19.815	42.271
	Shipwreck Shore	Shore	TC-3	30	26-day	19.976	42.429
			TC-3S	30	storm	19.980	42.424
			TC-3B	60	26-day	19.977	42.423
	Plantation Hill Shore	Shore	TC-10B	60	26-day	20.187	42.733
		Shore	TC-13	60	26-day	20.122	42.687
	South Mangrove	Mangrove/bay	TC-8	60	26-day	20.720	42.931
	North Mangrove	Mangrove/bay	TC-5	60	26-day	20.795	42.849
			TC-5S	60	storm	20.793	42.849
	North Reef	Reef	TC-11	60	26-day	20.278	42.241
	South Reef	Reef	TC-12	60	26-day	20.018	42.072
Hurricane Hole	Hurricane Hole Shore	Mangrove	THH-1B	60	26-day	20.988	41.471
			THH-2	60	26-day	21.065	41.414
			THH-3M	30	26-day	20.982	41.485
G. Lameshur	G. Lameshur Mangrove	Mangrove	TL1-M	60	26-day	19.125	43.477
			TL1-MS	60	storm	19.125	43.477
	G. Lameshur Shore	Shore	TL1-2	30	26-day	19.123	43.448
			TL1-2S	30	storm	19.123	43.448
	Tectite Reef	Reef	TT-1	60	26-day	18.585	43.315
	Yawzi Reef	Reef	TY-1	60	26-day	18.910	43.512
			TY-2	60	26-day	18.901	43.540
L. Lameshur	Little Lameshur Shore	Shore	TL2-6	60	26-day	19.146	43.681
			TL2-6S	60	storm	19.145	43.682

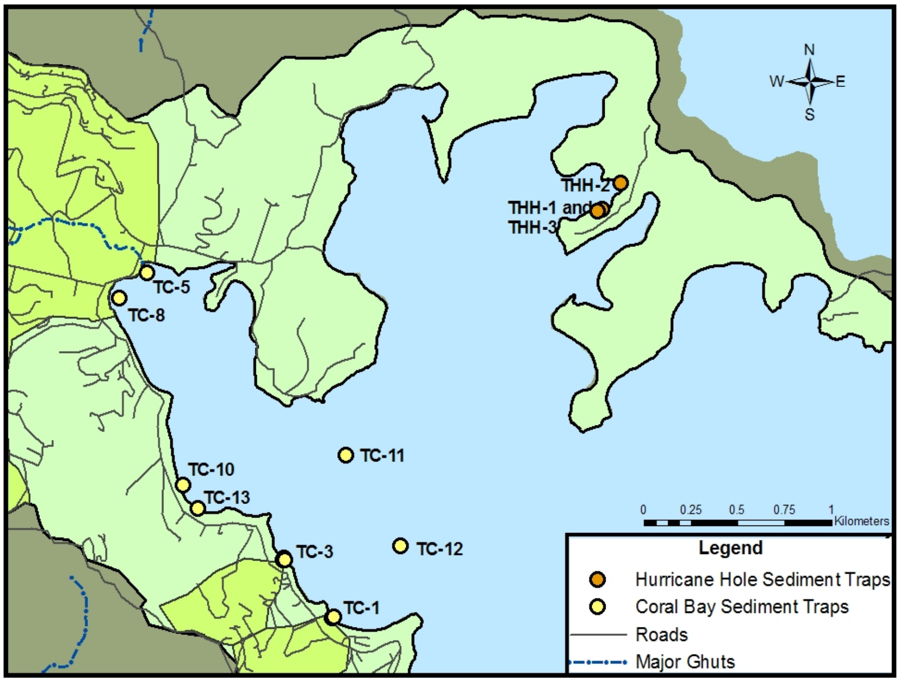

Figure 2. *Map of Coral Bay and Hurricane Hole showing the sediment trap/sampling locations. The watersheds above TC-5, TC-8, TC-1 and TC-3 are developed. TC-10 and TC-13 are below Plantation Hill, a watershed with minimal development. Three environments are represented: a) mangroves: HH-1, HH-2, HH-3, TC-5 & TC-8; b) shore: TC-1, TC-3, TC-10, TC-13, and c) reefs: TC-11 & TC-12.*

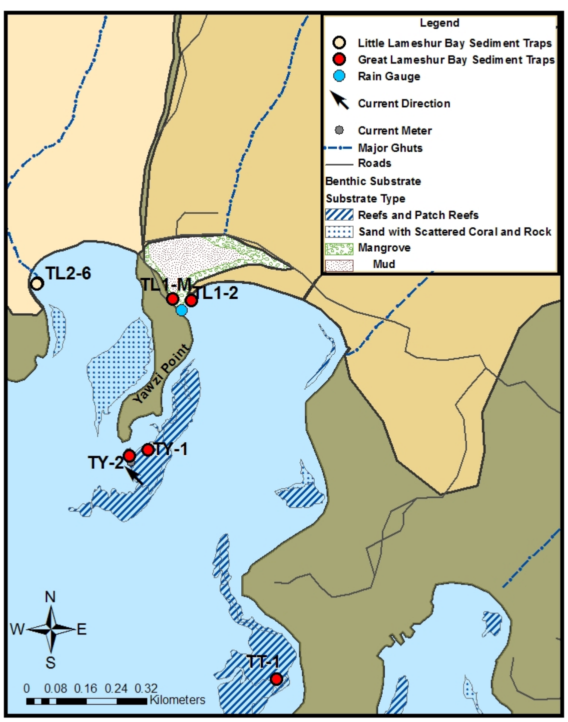

Figure 3. *Map of Great and Little Lameshur Bay below undeveloped watersheds in the Virgin Islands National Park. Three environments are represented: a) mangroves: TL1-M, b) shore: TC-1, TC-3, TL1-2, TL2-6, and c) reefs: Yawzi Point: TY-1, TY2, Tectite: TT-1.*

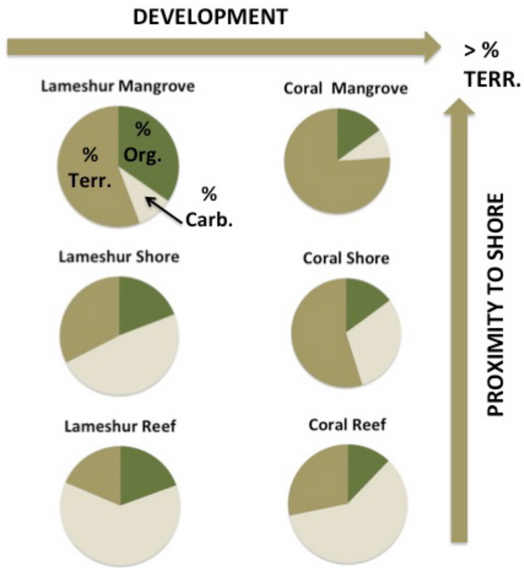

Figure 4. *Comparison of mean sediment composition (% terrigenous, % organic, and % carbonate) at mangrove, shore and Reef environments in bays below a developed (Coral) and undeveloped (Lameshur*) watershed within the Virgin Islands National Park for the period 8/09-12/11. The proportion of terrigenous sediment increases with proximity to shore and degree of development. (N=28, 28, and 84 for Lameshur Bay mangrove, shore and reef, respectively; N=56, 84, and 56 for Coral Bay mangrove, shore and reef, respectively).*

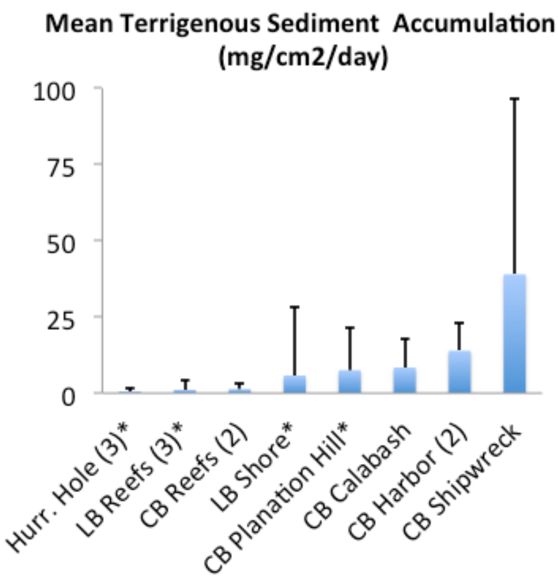

Figure 5. *Variation in mean (+/- SD) terrigenous sediment accumulation in (mg/cm^2/day) for shore and reef sites (60 cm above the substrate) in Coral Bay (CB), Lameshur Bay (LB) and Hurricane Hole (Fig. 1) over the time period when we've been collecting data. These data represent over 1000 individual measurements over 2.5 to 5 years. The sites below undeveloped watersheds are marked by asterisks. The highest mean terrigenous sedimentation occurred at the Shipwreck site, below an undeveloped/unmitigated watershed along the south shore of Coral Bay.*

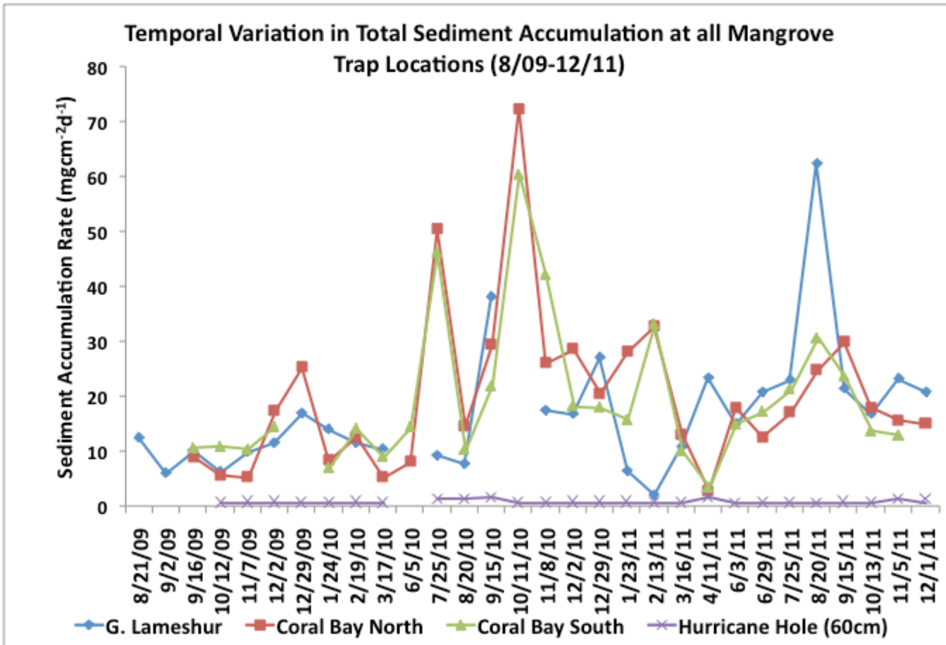

Figure 6A. *Total sediment accumulation in mg/cm^2/day at mangrove sites for every sampling period from 8/21/09-12/1/11. Highest sediment accumulation was recorded in the Coral Bay Harbor for all but one sampling period and during October of 2010 when there were record rains and sediment runoff.*

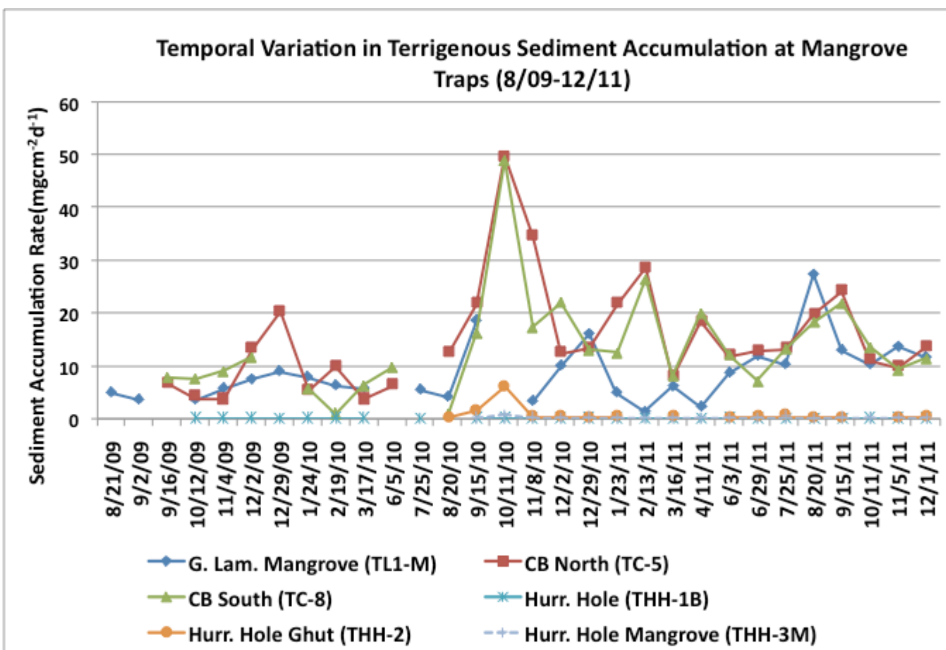

Figure 6B. *Terrigenous sediment accumulation in mg/cm^2/day at the mangrove sites for every sampling period from 8/21/09-12/1/11. Highest terrigenous sediment accumulation was at the CB Harbor for all but one sampling period and during October of 2010 when there were record rains and sediment runoff associated with Hurricane Omar.*

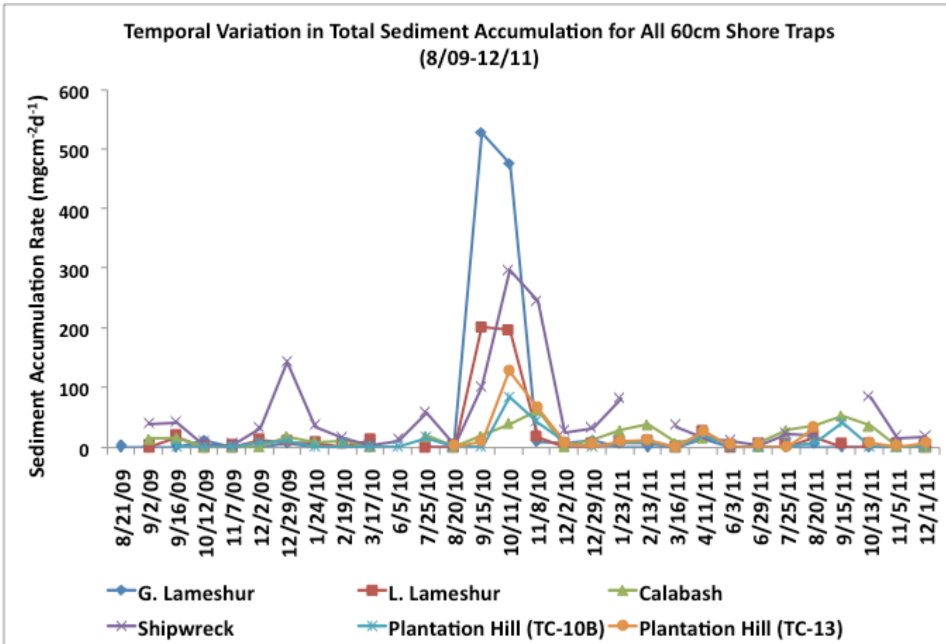

Figure 7A. *Total sediment accumulation in mg/cm²/day at shore sites for every sampling period from 8/21/09-12/1/11. Highest total sediment accumulation was recorded at the Shipwreck site (TC-3B) for most sampling periods and during October of 2010 when there were record rains and sediment runoff. Total accumulation at Plantation Hill sites (TC-10B and TC-13), which are undeveloped "control site" are almost always lower than at the Shipwreck site.*

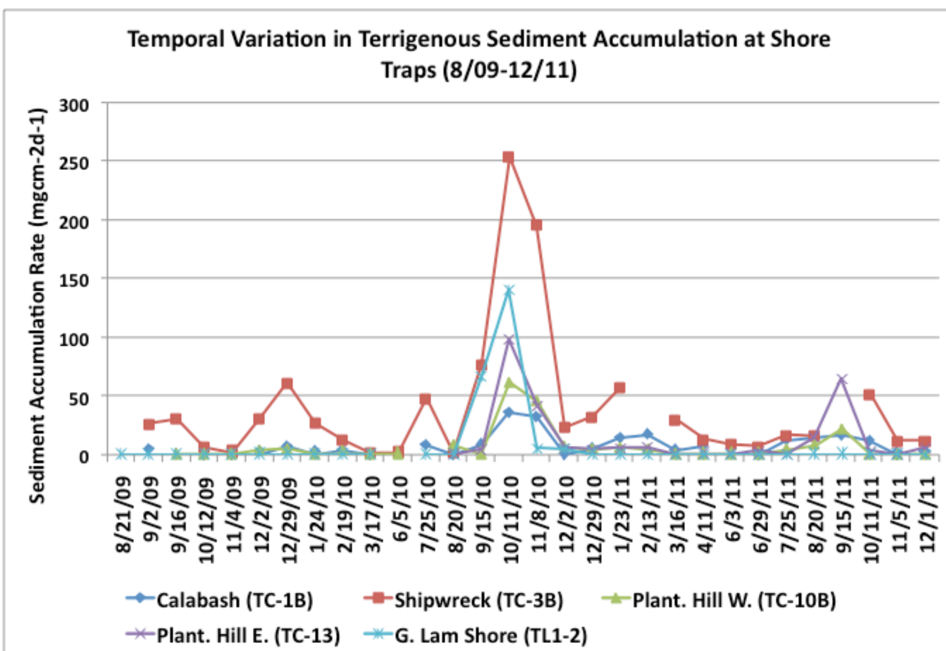

Figure 7B. *Terrigenous sediment accumulation in mg/cm²/day at shore sites (60 cm traps only) for every sampling period from 8/21/09-12/1/11. Terrigenous sediment accumulation was highest at the Shipwreck site (TC- 3B) for most sampling periods. Highest terrigenous sediment accumulation was recorded during the fall months (Sept.-Nov.) of 2010 when there were record rains and runoff at all locations.*

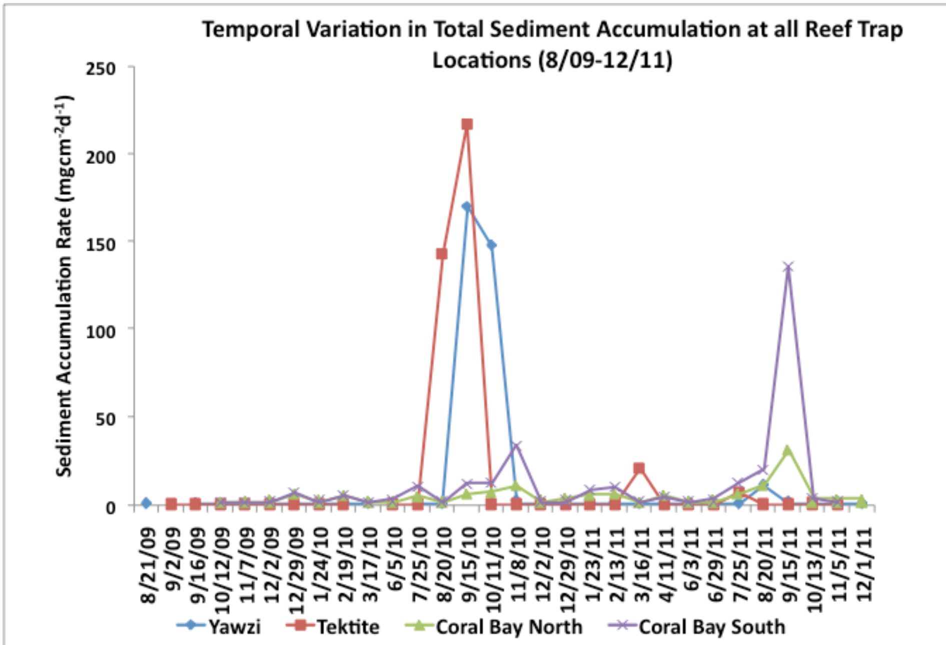

Figure 8A. *Total sediment accumulation in mg/cm²/day at the Coral Bay and Lameshur Bay reef sites for every sampling period from 8/21/09-12/1/11. Highest sediment accumulation occurred during the fall months (Sept.-Nov.) of 2010 and Aug. of 2011. The high sediment accumulation in August of 2011 was likely due to re-suspension of carbonate sediment rather than input of excess terrrigenous sedument from watershed runoff. There was not a large peak in terrigenous accumulation (Fig. 9B) during that time.*

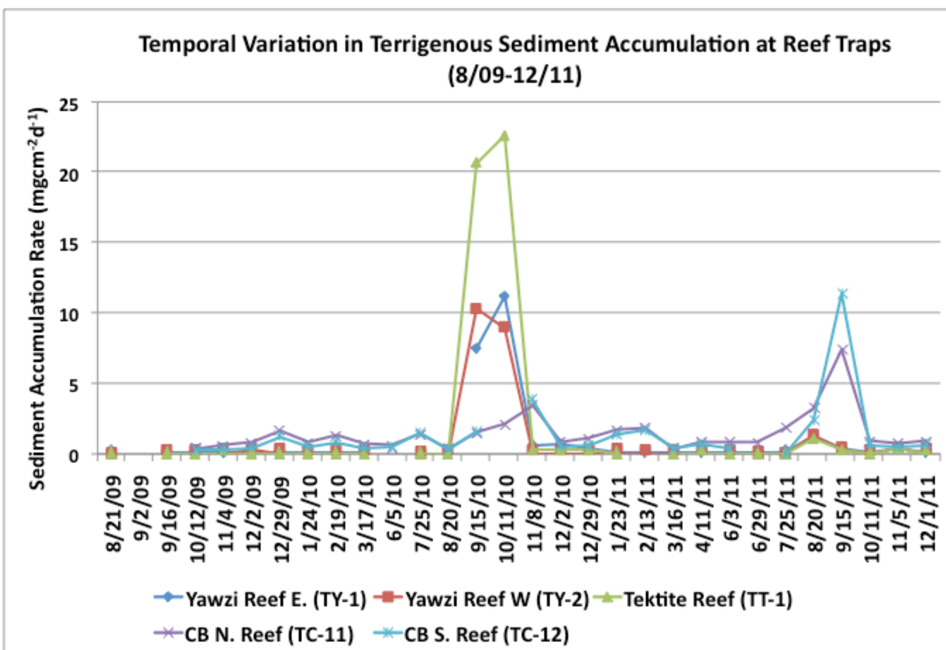

Figure 8B. *Terrigenous sediment accumulation in mg/cm²/day at reef sites for every sampling period from 8/21/09-12/1/11. For most of the time series, sediment accumulation was higher at the Coral Bay reefs than at the Lameshur Bay Reefs (Yawzi & Tektite). Highest sediment accumulation was recorded at the Coral Bay reefs during the fall month (Sept.-Nov.) of 2010 when there were record rains and runoff.*

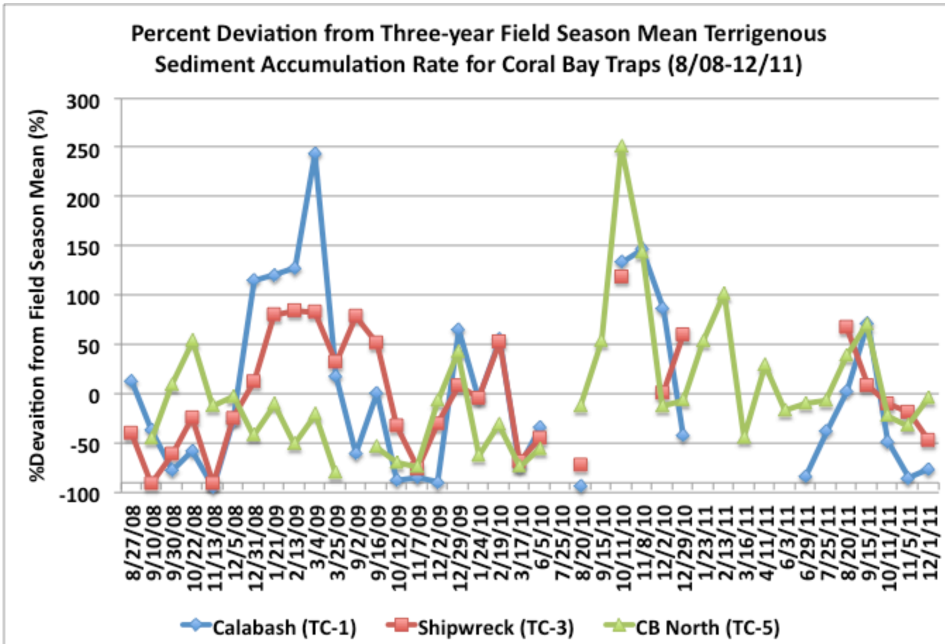

Figure 9A. *Percent deviation from 4.5- year (8/08-12/11) field-season mean terrigenous sediment accumulation at three shore/mangrove sites in Coral Bay. Data illustrate that the highest anomalies in terrigenous accumulation occur during the fall season for CB-North. High accumulation in during the winter months of 2009 along the South Shore of Coral Bay may be related to winter waves.*

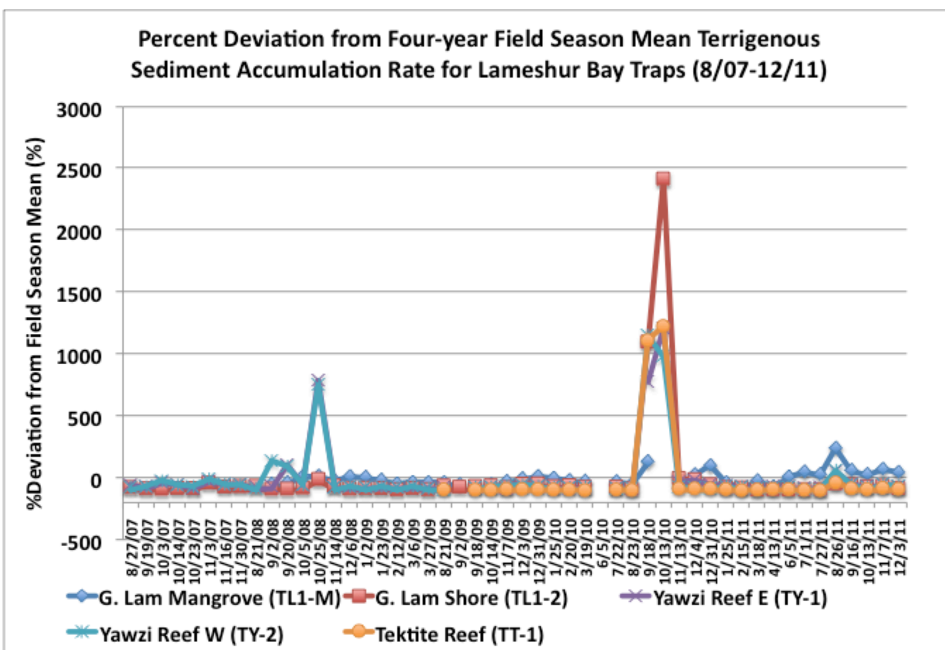

Figure 9B. *Percent deviation from 5.5-year (8/07-12/11) field-season mean terrigenous sediment accumulation at three shore, mangrove and reef sites in Lameshur Bay. Data illustrate that the highest anomalies in terrigenous accumulation occur during two periods, Hurricane Omar in 2008 and during multiple storm events in September and October of 2010.*

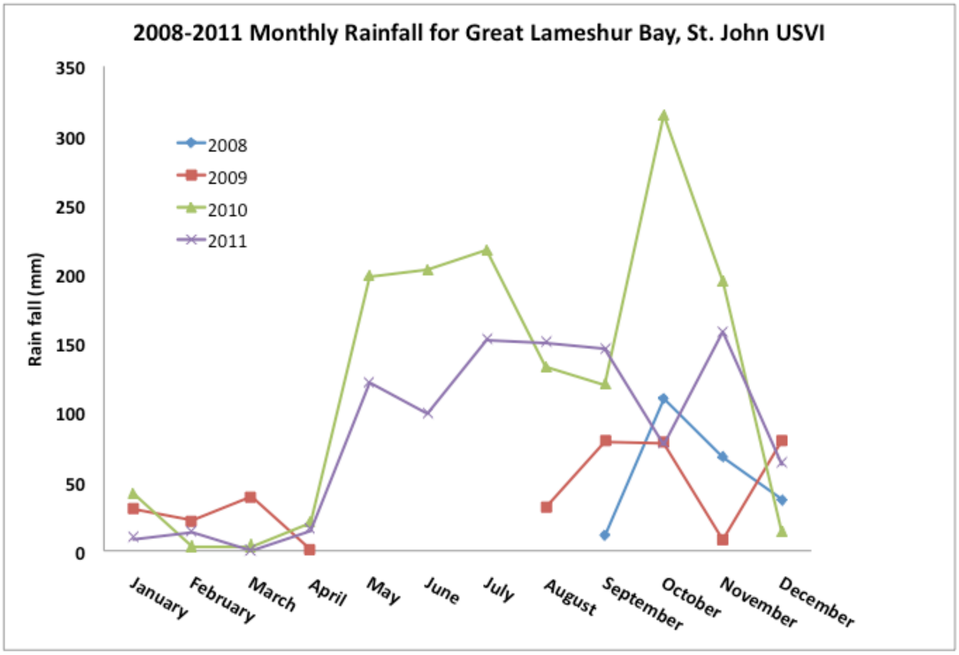

Figure 10A. *Comparison of monthly rainfall between years (2008-2011) at VIERS in Great Lameshur Bay. The rainy season (June-November) of 2010 stands out as a year with an unusually high rainfall.*

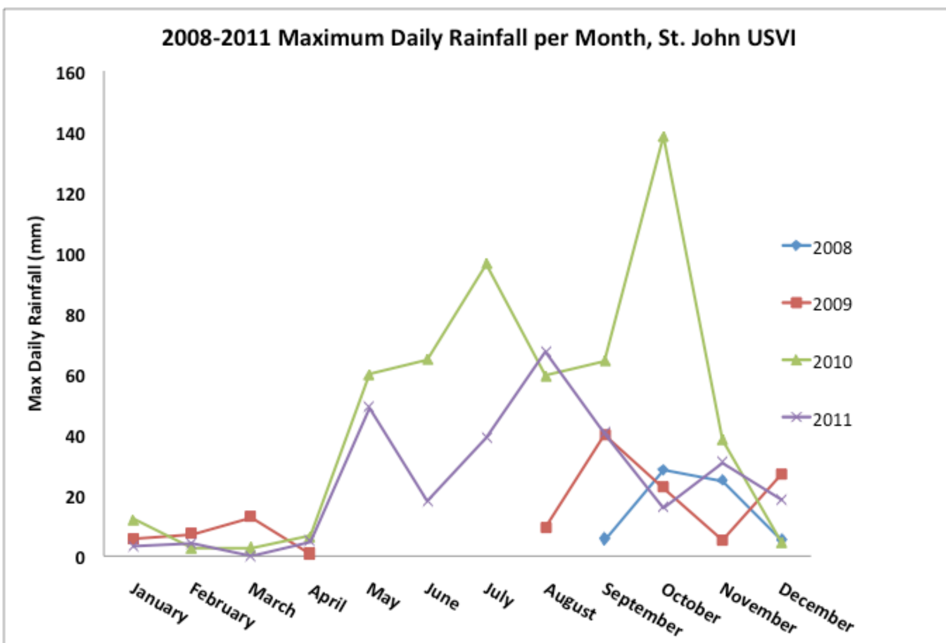

Figure 10B. *Comparison of maximum daily rainfall per month between years (2008-2011) at VIERS in Great Lameshur Bay. The rainy season (June-November) of 2010 stands out as a year with unusually high maximum daily rainfall.*

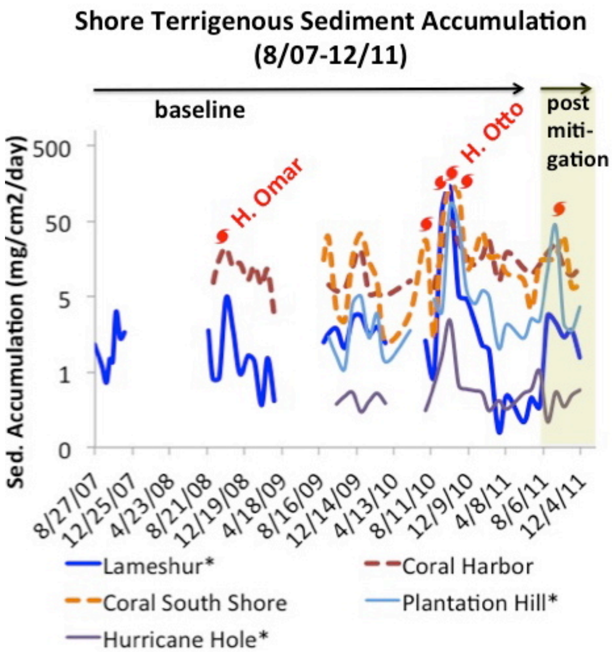

Figure 11. *Temporal variability (8/07-12/11) in mean terrigenous sediment accumulation in shore and mangrove environments below developed (dashed) and undeveloped (solid, asterisk) locations. Highest terrigenous accumulation occurs during periods when there are major runoff events brought on by low-pressure systems or tropical storms/hurricanes. Major runoff events are indicated by the storm symbols. Watershed erosion mitigation structures were completed in Coral Bay in July of 2011, which marks the beginning of our post-mitigation period.*

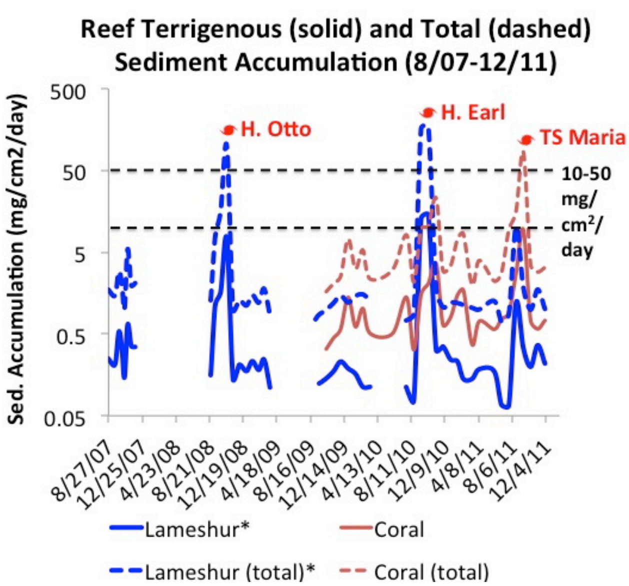

Figure 12. *Temporal variability (8/07-12/11) in mean total (dashed) and terrigenous sediment accumulation (solid) at reef sites in Coral Bay (developed watershed) and Lameshur Bay (reference watershed). Highest total and terrigenous accumulation occurred during major storms. Sediment accumulation rates during these storm periods surpass 10 and reach up to 100 mg/cm²/day, a sedimentation rate which has been suggested to cause coral stress.*

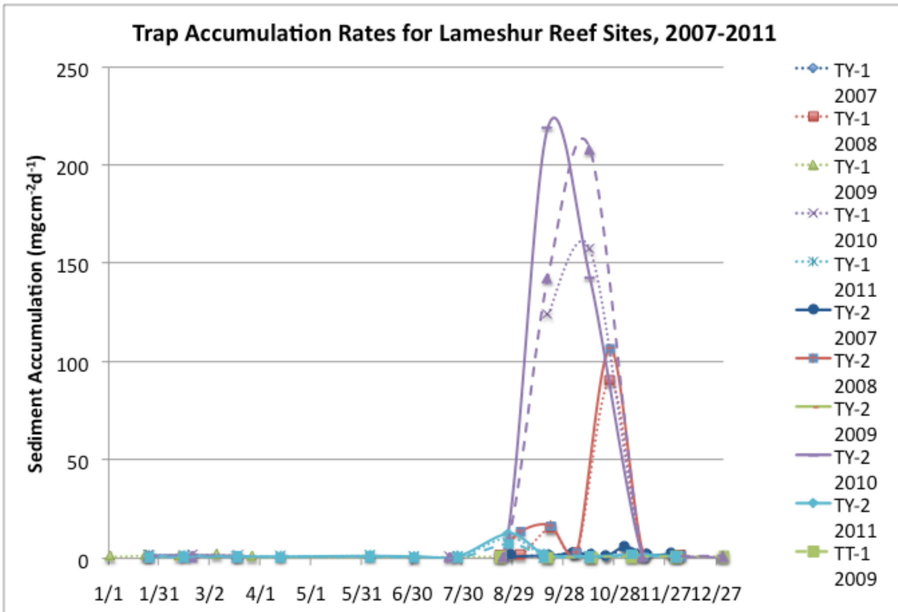

***Figure 13A**. Comparison of total trap accumulation rates at the Lameshur Bay reef sites for 5 years (2007-2011) shows unusually high rates of sedimentation on the reef during the fall of 2010 (Aug-Oct.) (marked by purple lines) compared to the other years. Total sedimentation rates were also high during Hurricane Omar in October of 2008. Sedimentation rates on the Lameshure reefs from Aug-Oct. of 2010 were over two times higher than sedimentation rates (50mg/cm2/day) shown to be harmful to coral reefs.*

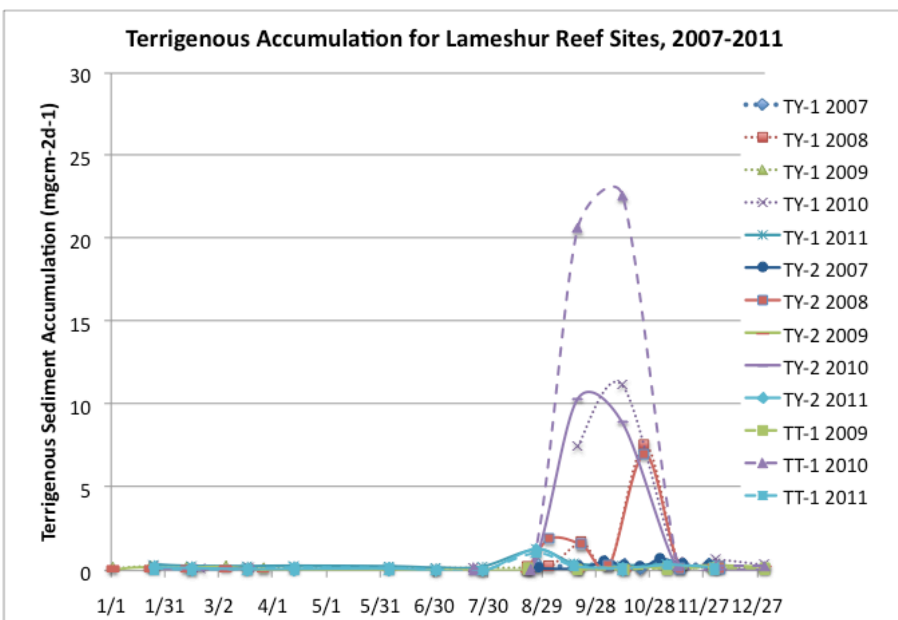

***Figure 13B**. Comparison of terrigenous trap accumulation rates at the Lameshur Bay reef sites for 5 years (2007-2011) shows unusually high rates of terrigenous sedimentation on the reef during the fall of 2010 (Aug-Oct.) (marked by purple lines) compared to the other years. Though most of the sedimentation at these sites is carbonate, these data show a pulse of terrigenous sediment input during the Fall of 2010.*

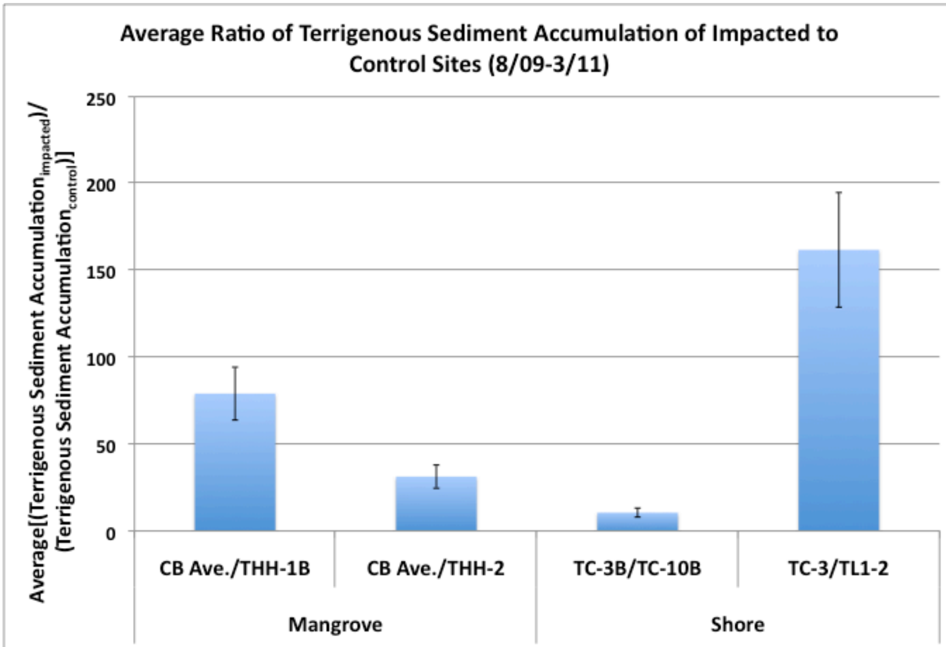

Figure 14. *Ratio of mean terrigenous sediment accumulation in the "impacted" vs. the "control sites" for 8/08-3/11 in mangrove and shore environments shows mean terrigenous accumulation 10-160 times higher below developed vs. undeveloped watersheds.*

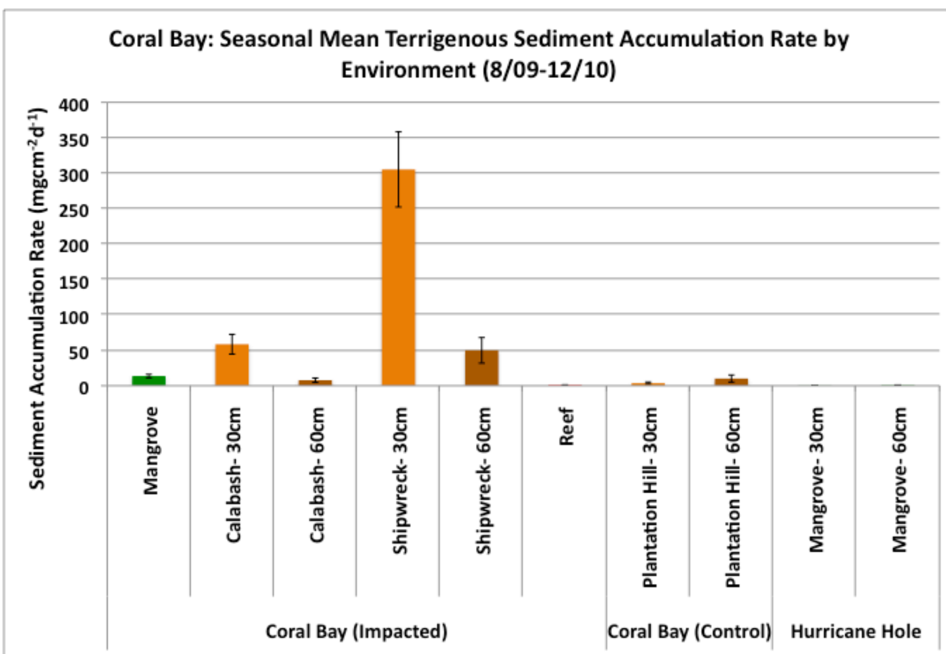

Figure 15. *Mean terrigenous sediment accumulation for the period 8/21/09-12/2/10 showing higher accumulation inshore sites that were 30 cm above the seafloor than those that were 60 cm above the seafloor. This higher accumulation is due to enhanced resuspension in shallow water.*

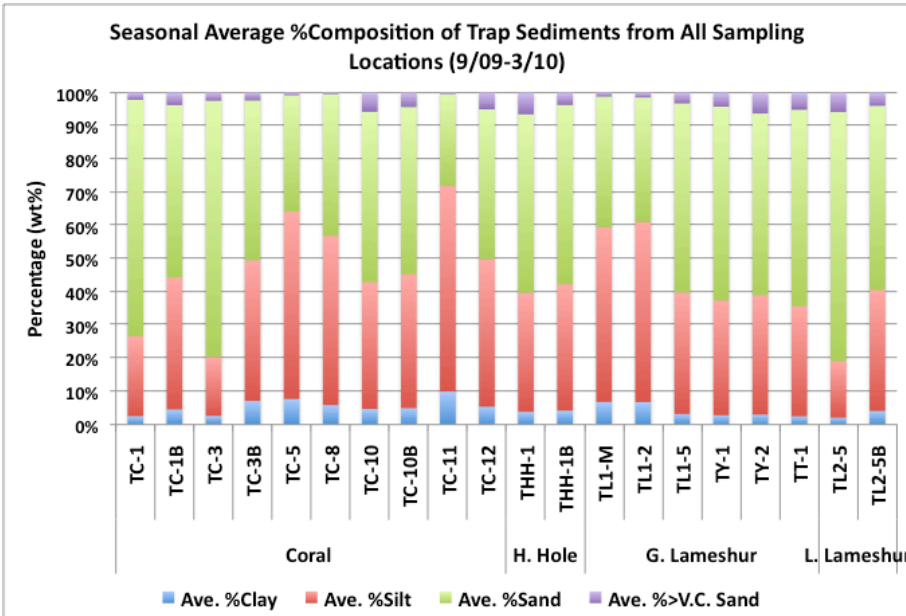

Figure 16. *Mean texture (grain size) distributions of the sediments at each site for the 18- month field season. Sediment at most sites was comprised of less than 10% clay, between 20-50% silt and between 30-80% sand.*

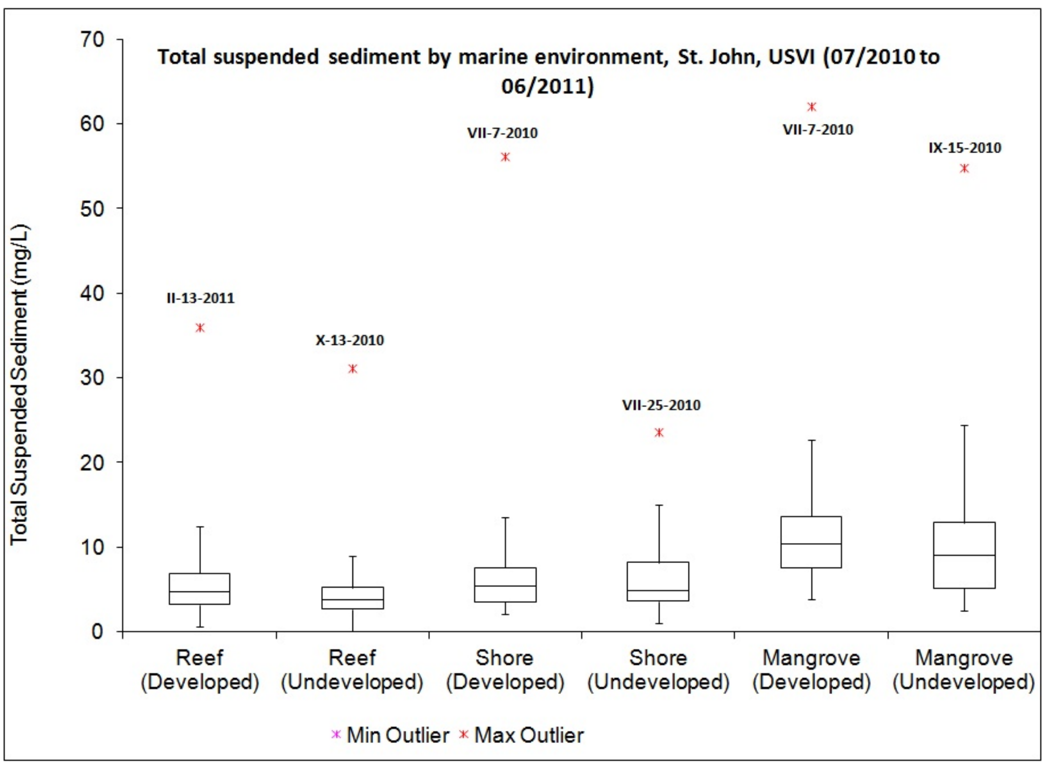

Figure 17. *Box and whisker plots of median TSS Total Suspended Sediment/turbidity) at reef, shore and mangrove sites below developed and undeveloped watersheds. Samples were collected approximately every 26 days (during mostly fair weather conditions) from 7/2010 to 6/2011. Red crosses mark the maximum outliers with the date that the outlier value was measured. Most (all but one) maxima outlier TSS were measured following storm events in the fall of 2010.*

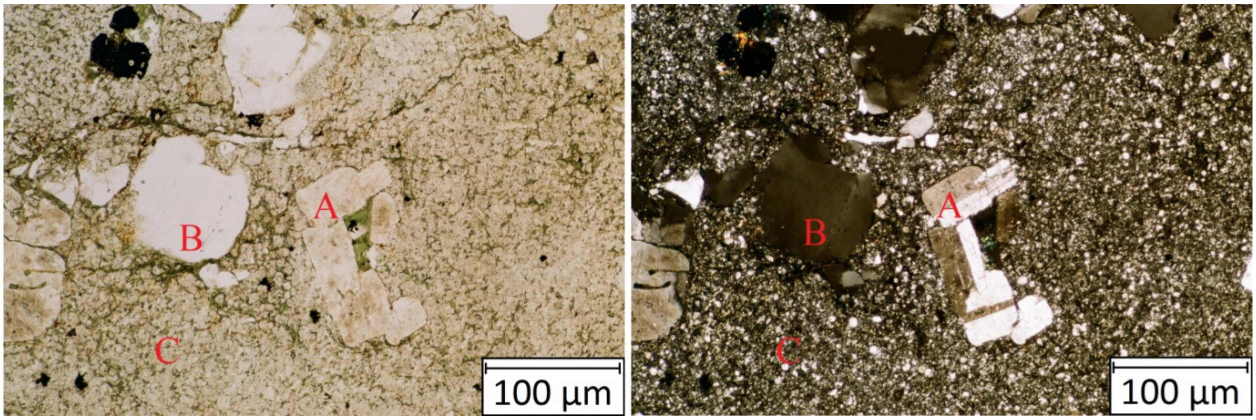

Figure 18A. *Thin section of Water Island Plagiorhyolite (sample WR-L2-21) from the Little Lameshur Watershed. Both images taken at 20x magnification. The left picture is in plane polarized light while the right picture is in cross polarized light. Albite phenocrysts are marked by "A", quartz phenocrysts are marked by "B", and a "C" marks the fine grained ground mass composed mostly of primary minerals quartz and albite and a secondary mineral chlorite.*

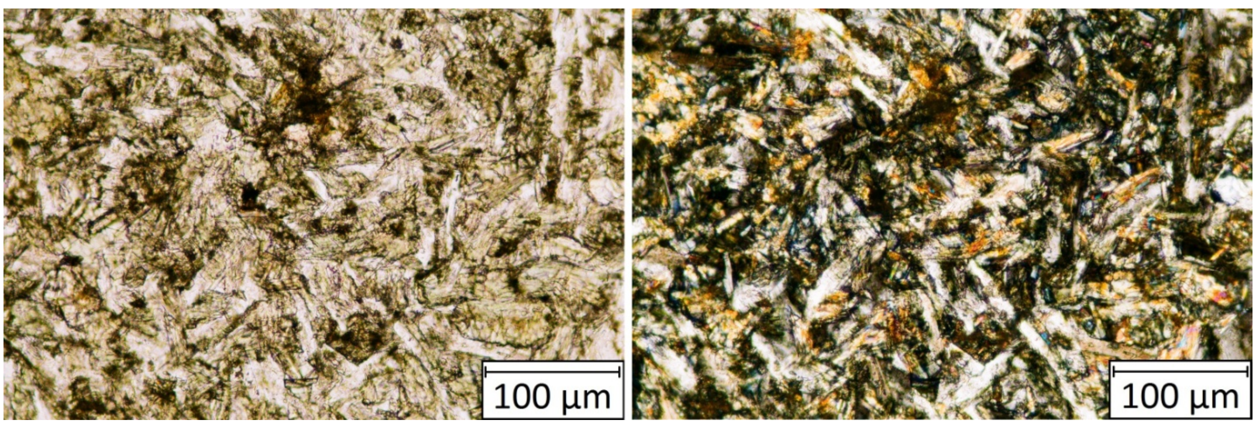

Figure 18B. *Thin section of Water Island Basalt (sample WR-CB-66) from the Shipwreck Watershed. Image taken at 20x magnification. The left picture is in plane polarized light while the right picture is in cross polarized light. Elongated white minerals are plagioclase*

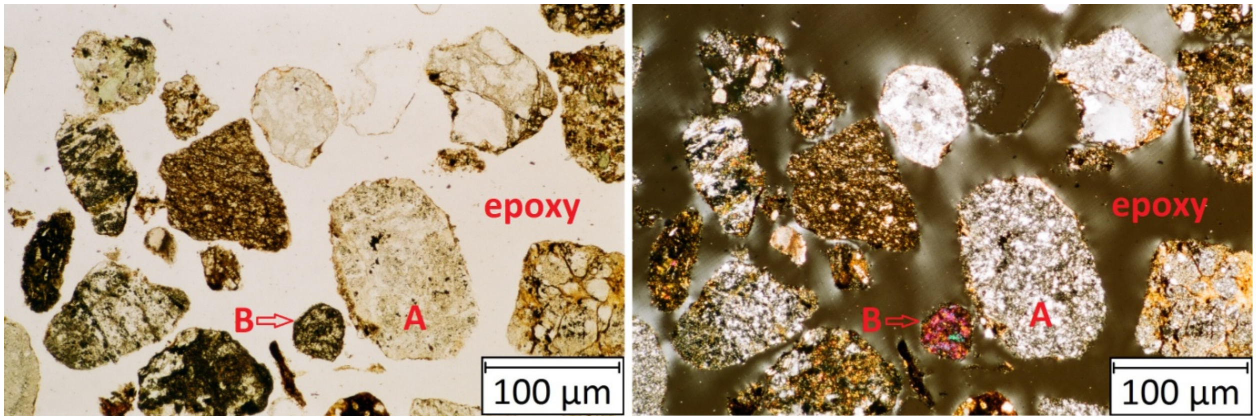

Figure 18C. *A thin section of sediment from Shipwreck watershed (WWS-CB-31) set into epoxy. Image taken at 20x magnification. The left image is in plane polarized light while the right image is in cross polarized light. Plagiorhyolite grains are identified by an "A" and a "B" indentifies basalt grains.*

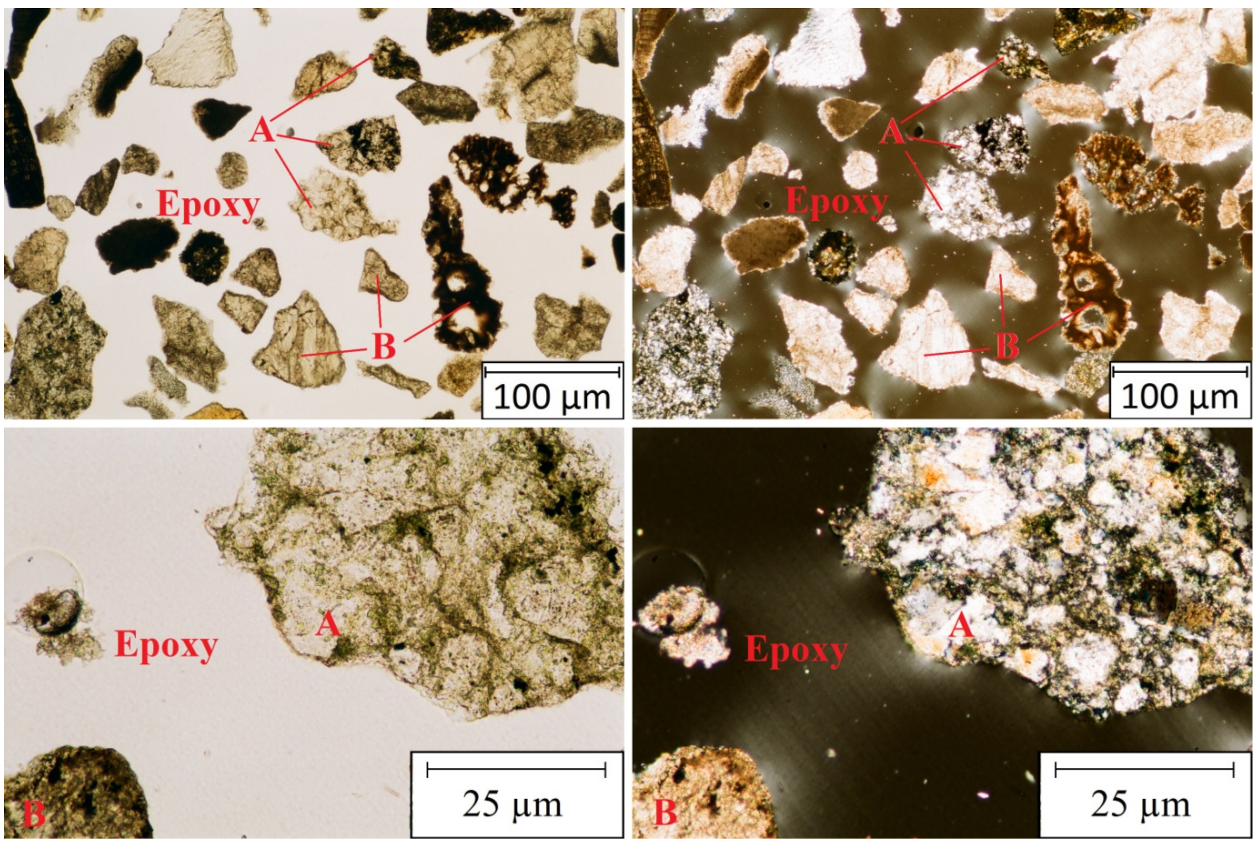

Figure 18D. *A thin section of sediment set into epoxy from BT-1, a marine sediment trap located on a fringing coral reef in Great Lameshur Bay. Both top images are at 20x magnification and both bottom images are at 100x magnification. The pictures on the left are taken with plane polarized light while the pictures on the right are taken in cross polarized light. Terrestrial mineral grains are identified by an "A" and a "B" indentifies carbonate grains.*

Table 2. *Research outcomes.*

Scientific Journal Articles (resulting partially from this work) (Apendix I):

1. Gray, S.C., Sears, W.T., Kolupski, M.L., DeGrood, A.M., and Fox, M.D. (2012, in review). Factors affecting land-based sedimentation in coastal bays, US Virgin Islands. *12th International Coral Reef Symposium, Proceedings, Cairns, Australia. (see appendix)*

Scientific Abstracts & Presentations (resulting partially from this work):

1. Gray, S.C., Sears, W.T., Kolupski, M.L., DeGrood, A.M., and Fox, M.D. (2012). Factors affecting land-based sedimentation in coastal bays, US Virgin Islands. *12th International Coral Reef Symposium, July 9th-13th, 2012, Cairns, Australia.*
2. DeGrood, A.M.*, Kolupski, M.L.*, Fox, M.D.**, and Gray, S.C. (2010). Temporal and spatial variation in sediment texture on coral reefs, US Virgin Islands. *91st Annual Western Society of Naturalists Meeting, San Diego, CA 11/11-11/14/10.*
3. Quilley, R.G.*, Przyuski, N.W.**, and Gray, S.C. (2010). A comparison of sedimentation and turbidity in mnagrove environments among areas of variable human impact, St. John, US Virgin Islands. *91st Annual Western Society of Naturalists Meeting, San Diego, CA 11/11-11/14/10.*
4. Rawling, D.W.*, Fox, M.D.**, and Gray, S.C. (2010). Can sediment texture be used as a proxy to measure terrigenous (land-derived) sediment flux on coral reefs? *91st Annual Western Society of Naturalists Meeting, San Diego, CA 11/11-11/14/10.*

Invited Presentations:

1. Smith, T., and Gray, S. C. "Water quality and sedimentation research in the US Virgin Islands" US Coral Reef Task Force Meeting, Silver Spring, MD (2/24/12).
2. Coral Bay Community Council, Public Presentation, St. John, USVI (7/30/10): "Why is the water brown? Sedimentation studies in St. John, USVI".

Proposals Submitted:

1. NOAA Coral Reef Conservation Program Domestic Coral Reef Conservation Grants (Recommended for funding): "Post-mitigation monitoring to determine the impact of watershed erosion control on LBSP to coral reefs, USVI" $75,000 with $75,000 in cost share (2012-2013).
2. NOAA Coral Reef Conservation Program Domestic Coral Reef Conservation Grants: "Effects of Watershed Erosion Control on Land Based Sources of Pollution to Coral Reefs in RCP Priority Sites" $94,844 with $94,933 in cost share (2011-2012).

MS theses (in progress)

Harrington, R. (USD), Sears, W. (USD), Guidino Elizondo, N. (Centro de Investigacion Cientifica de Educacion Superior de Ensenada, Baja California: CICESE).

Undergraduate senior theses (completed)

Chapman, C., Quilley, R., Casey, M., and Hseih, Y.

Figure 19. *Sarah Gray and the USD student research team conducted a presentation and hands-on laboratory workshop for 16 students (aged 12-16) from the Virgin Islands attending VIERS Eco Science Camp (7/27/10-7/29/10).*

Table 3. *Log of outreach activities (7/1/10-12/31/11).*

Date	***Location***	***Person involved***	***Type of Event***	***Audience Type & (Number)***
Bi-monthly	*Conference Call*	*ARRA partners*	*Conference Calls*	*ARRA Partners*
7/27/10	*VIERS, St John, USVI*	*Gray*	*Presentation: VIERS Eco Camp*	*Middle & high school students (16)*
7/29/10	*VIERS, St. John, USVI*	*Gray & research team*	*Laboratory workshop: VIERS Eco Camp*	*Middle & high school students (16)*
7/30/10	*Maho Bay Resort, St. John, USVI*	*Gray*	*Public presentation: "Why is the water brown? Sedimentation studies in St. John bays and coral reefs"*	*Community (30)*
7/30/10	*Maho Bay Resort, St. John, USVI*	*Gray*	*Media interview & article*	*St. John Source newspaper*
8/2/10	*Univ. of the Virgin Islands, St. Thomas USVI*	*Gray & Tyler Smith*	*Meeting with USVI research partner*	
8/5/10	*Coral Bay, St. John, USVI*	*Gray, research team & Sharon Coldren, President CBCC*	*Meeting and tour of ARRA watershed sediment mitigation projects in the Calibash Boom watershed*	
11/7/20	*VIERS, St. John, USVI*	*Sears*	*Project presentation and lab tour*	*Board of Clean Islands International & attendees at the Tektite conference (12)*
11/11/10-11/14/10	*San Diego, CA*	*Kolupski and others*	*Presentation: 91st Annual Western Society of Naturalists meeting*	*Scientists & students (25-100)*
11/11/10-11/14/10	*San Diego, CA*	*DeGrood and others*	*Poster: 91st Annual Western Society of Naturalists meeting*	*Scientists & students (25-100)*
11/11/10-11/14/10	*San Diego, CA*	*Quilley and others*	*Poster: 91st Annual Western Society of Naturalists meeting*	*Scientists & students (25-100)*
11/11/10-11/14/10	*San Diego, CA*	*Rawling and others*	*Poster: 91st Annual Western Society of Naturalists meeting*	*Scientists & students (25-100)*
11/19/10	*San Diego, CA*	*Casey Chapman*	*USD Marine Science Senior Seminar Presentation*	*USD Faculty & students, general public & students (30)*
12/8/10	*San Diego, CA*	*Gray & Sharon Coldren, President, CBCC*	*Meeting with USVI community partner*	
2/19/11	*VIERS, St. John, USVI*	*Whitney Sears*	*Project presentation and VIERS lab tour*	*High school students (20)*
3/08/11	*VIERS, St. John, USVI*	*Whitney Sears*	*Project presentation and VIERS lab tour*	*Professor and students, Michigan State University (3)*
3/21/11	*VIERS, St. John, USVI*	*Whitney Sears*	*Project presentation and VIERS lab tour*	*President, University of the Virgin Islands (1)*
3/25/11	*University of San Diego*	*Deserae Rawling*	*Senior Seminar Presentation: Can*	*University students and faculty (30)*

			sediment texture be used as a proxy to measure terrigenous (land-derived) sediment flux on coral reefs?	
4/1/11	*University of San Diego*	*Maverick Carey*	*Senior Seminar Presentation: Tropical bioindicators: using Foraminifera to assess water quality in a coral reef environment, St. John, USVI*	*University students and faculty (30)*
4/12/11	*VIERS, St. John, USVI*	*Whitney Sears*	*Project presentation and VIERS lab tour*	*VIERS visitors (4)*
4/14/11	*University of San Diego*	*Maverick Carey*	*Creative Collaborations Poster: Tropical bioindicators: using Foraminifera to assess water quality in a coral reef environment, St. John, USVI*	*University students and faculty (300)*
4/14/11	*University of San Diego*	*Thomas DeCarlo*	*Creative Collaborations Poster: Tropical bioindicators: using Foraminifera to assess water quality in a coral reef environment, St. John, USVI*	*University students and faculty (300)*
4/14/11	*University of San Diego*	*Deserae Rawling*	*Creative Collaborations Poster: Can sediment texture be used as a proxy to measure terrigenous (land-derived) sediment flux on coral reefs?*	*University students and faculty (300) http://www.sandiego.edu/creative/*
4/14/11	*University of San Diego*	*Yi-Chen Hseih*	*Creative Collaborations Presentation: "The impact of watershed development on turbidity in the bays with coral reefs in St. John, US Virgin Islands"*	*University students and faculty (300)*
4/26/11	*University of San Diego*	*Megan Kolupski*	*Masters Thesis Defence Presentation: "Sedimentation in coastal bays with coral reefs: Impacts of watershed development, St. John, USVI"*	*University students and faculty (80)*
4/29/11	*University of San Diego*	*Yi-Chen Hseih*	*Senior Seminar Presentation: "The impact of watershed development on turbidity in the bays with coral reefs in St. John, USVI"*	*University students and faculty (30)*