Final Project Report (3/31/10)

"A comparative study of Fringing Reefs below Developed v. Undeveloped Watersheds, U.S. Virgin Islands"

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INTRODUCTION

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 factors governing the quantity, duration and type of sedimentat that may potentially affect a particular coral reef are complex and variable. Developing the most effective watershed sediment management strategies requires a thorough site-specific knowledge of the unique terrestrial, oceanographic and biological processes that impact the quantity, quality (type), and temporal variability of sedimentation on an individual reef. Therefore, detailed and comprehensive monitoring of both sedimentologic & physical processes affecting individual reefs is a critical compliment to ecological monitoring of coral reef health.

The research objective of our study was to establish a baseline of data from which to evaluate how development in watersheds on St. John has impacted the quantity, quality (type), and spatial variability of sedimentation in bays with reefs. Empirical and modeling studies in these St. John watersheds have demonstrated that development (construction, area of impervious surfaces, dirt roads, etc.) has increased the sediment yields from the watersheds above background levels (Ramos-Scharrón and Macdonald, 2005, 2007). Local environmental managers on St. John have been funded to implement sediment mitigation structures and need data to help locate and test their effectiveness and provide pre-mitigation baseline values. Approximately 56% of the area of the island of St. John, USVI is contained within the Virgin Islands National Park. Outside the boundaries of the park, the conversion of rural forests into home sites has enhanced sediment delivery into coastal waters by increasing erosion from roadbeds and cut slopes. Our approach was to collect and compare sediments within and among three bays with reefs—two drained by developed watersheds (Fish and Coral Bay) and one drained by a relatively pristine undeveloped watershed (Great Lameshur) within the VI National Park. We have focused our sampling to target a) locations with biologically monitored reefs,

c) locations where watershed erosion processes have been well studied, and d) locations where future construction and/or sediment mitigation is planned or underway.

This project was the first phase of an ongoing multi-year program of near-shore sediment monitoring that will compliment ongoing efforts by other researchers to monitor terrestrial watersheds and the marine biologic and physical environment. The data from the 2008-9 field season that was collected on this grant will comprise an important part of what will become a continuous 3+ year time series of sedimentation data for our sampling sites. We were funded by grants from NOAA General Coral Reef Conservation Program and NOAA ARRA to continue our sediment monitoring during the fall-winter seasons of 2009-2010. In partnership with educational and community groups we have been funded by the NOAA Coastal & Marine Habitat Restoration for funding under the American Recovery and Reinvestment Act (ARRA) to participate in a program of sediment erosion mitigation and monitoring in two of our study watersheds (Fish Bay and Coral Bay) called the "USVI Coastal Habitat Restoration through Watershed Stabilization" (http://www.usvircd.org/NOAA-ARRA_Grant.htm). The goal of this 2-year project is to reduce sediment loading to coral reef habitats by implementing erosion & sediment control BMPs. We will monitor sedimentation in Coral Bay at select locations through February of 2011. So by February of 2011, we will have monitored sedimentation/water quality for four field seasons in Fish and Lameshur Bays and two field seasons in Coral Bay (Aug.-Nov. 2007; Aug. 08-Mar. '09; Aug. 09-Mar.10; and Aug. 10-Feb. 11). The findings from this grant will provide critical baseline data for interpretation of future monitoring efforts.

Our outreach goal was to establish ongoing research & educational partnerships between the University of San Diego, local environmental managers and community groups and researchers in the USVI.

OBJECTIVES

Research

Our study was guided by the following research questions:

1. What is the composition (organic, carbonate, terrigenous and grain size distribution) and quantity (flux rate or concentration) of sediments (suspended, trapped, and benthic surface)?
2. How do these characteristics vary spatially within each bay along pathways of sediment dispersal (mangrove to shore to bay to reef) and among the bays?
3. How do these characteristics vary temporally during the study (short term) and with storms and runoff events and other environmental parameters (wind, currents, waves, etc.)?
4. How might coral reefs in each bay be affected by sedimentation?
5. How can this information be used to evaluate the effectiveness of sediment mitigation approaches for St. John and other islands?

Education and outreach

Our outreach goals were to establish research & educational partnerships between the University of San Diego and local educational, environmental, and citizens groups and to facilitate a deeper understanding about the impact of watershed processes on the health of coral reefs in the US Virgin Islands.

Our specific educational outreach objectives were to:

1. Establish scientific and educational collaborative partnerships with scientists working in the USVI,

2. Conduct public and educational workshops about the impacts of watershed development on corals reefs,
3. Provide tangible data for environmental managers, government officials, and local citizens that could be used to more effectively site, plan and design appropriate runoff/sediment mitigation strategies (such as sediment fences and ponds, road paving, etc.).
4. Teach graduate, undergraduate, and high school students about the process of scientific enquiry through full participation in the field and laboratory portion of this research program.

METHODS

Description of sampling sites (Figures 1 & 2)

We studied sedimentation in three bays in St. John, each of which drains from a distinct watershed (Figure 1). Lameshur bay drains an undeveloped watershed within the VI National Park and thus was considered a "control bay". Fish Bay and Coral Bay drain developed watersheds and thus were considered "developed" or "impacted bays" (Figure 2). Great Lameshur Bay is located on the southeast windward portion of the island below a 3.7 km^2 watershed. The only developed areas within the watershed are the Virgin Islands Environmental Resource Station (VIERS), a ranger station, and a few unpaved roads and hiking trails (Figure 2). The southeastern side of Great Lameshur Bay is most exposed to wind and wave action. Yawzii Point, one reef site for this study, is found on the tip of this eastern portion of the bay. However, the rest of the bay is protected by a peninsula, which protects the inner bay from swell and waves (Figures 1 & 2).

Located on the southwest part of the island, Fish Bay drains a large (5.9 km^2) developed watershed, most of which is outside of the VI National Park. Within the watershed, there are both paved and unpaved road networks. As in Great Lameshur Bay, the greatest wave action from the northeast trade winds occurs near the mouth of Fish Bay along the cliffs on the western shoreline. We expected Fish and Great Lameshur bays to be exposed to similar wave and wind action due to their southward geographic orientation (Figures 1 & 2).

Coral Bay, the largest bay on St. John, drains several sub-watersheds and is considered one of two NOAA "priority watersheds" on St. John because of its intensive development and the abundance of sensitive habitats such as salt ponds, coral cover, mangrove wetlands, and sea-grass cover. Three of these sub-watersheds were the target of this study: the main Coral Bay watershed, which is large and extensively developed, and two smaller steep watersheds on the south east side of Coral Bay: Calabash Boom and Shipwreck Watershed. The shore drainage (ghut outfalls) from the main Coral Bay watershed are lined by mangroves, which may naturally filter sediment input from this large and extensively developed watershed. The steep watersheds above Calabash Boom and Shipwreck contain minimal sediment/water retention ponds and there are no shoreline mangroves. During the field season, Reliance Housing Foundation built a 72-unit affordable housing development across Route 107 from Johnson's Bay in Calabash Boom. Reliance installed some erosion- and sediment-control measures to deal with the large amount of sediment-laden water that flows onto the site from the uphill neighbors. These sediment mitigation structures were designed to capture the sediment in runoff behind runoff fences and in sediment ponds. One of the aims of our study was to evaluate whether or not these sediment mitigation measures were affecting bay sedimentation.

Field and laboratory methodologies (Figures 1, 2 & 3)

In August of 2008, twenty-four sediment traps were placed in mangrove, shore, bay and reef environments in three bays: Great Lameshur Bay (undeveloped), Fish Bay (developed), and Coral Bay (developed with sediment mitigation structures) (Figures 1 & 2). Sediment sampling was initiated during the fall of 2007 in the sampling locations in Fish and Lameshur Bays (Gray et al., 2009; Gobbi et al., 2009). During the 2008-9 field season for this grant, we continued sampling in Fish and Lameshur Bays and added 7 additional sediment traps in three locations in Coral Bay: 1) Calabash Boom, below an active construction site with sediment ponds to reduce sediment delivery to the shore; 2) Shipwreck Landing, below a developed (un-mitigated) steep watershed and 3) the mangrove areas of Coral Bay Harbor (Figure 2). In addition, we deployed acoustic current meters (Falmouth 2D ACM) at reef sites in Fish and Yawzi reefs to evaluate the relative contribution of current energy to sediment re-suspension and deployed a rain gauge in Lameshur Bay (Figure 2).

Sediment traps consisting of 4 exchangeable PVC tubes attached to a metal stake were deployed along transects from the gut (drainage) outfall to the reefs. These traps were sampled every three weeks from August 2008 through March 2009 (Figure 3). Following each sampling, sediments and water samples were processed in the VIERS laboratory before being sent to USD for further analysis. At VIERS, three of the four sediment trap tubes on each trap were filtered, rinsed to remove salt, dried and weighed. The dry mass of each sediment trap tube therefore provided a replicate measurement of the mass of sediment flux over the time deployed. Water samples with suspended sediments were collected near the bay-floor and at the surface next to each sediment trap (Figure 3) and at other locations of interest in order characterize the TSS (Total Suspended Solids) and TOM (Total Organic Matter). Water samples were filtered through a glass fiber filter (GF/F Whatman) combusted beforehand at 550° C for 1 hour and then frozen until analysis in the USD laboratory.

At USD, sediment and water samples and environmental data were analyzed in the laboratory by graduate and undergraduate student researchers under the P.I.'s supervision. The grain size distribution was assessed using a Beckman-Coulter LS200 Laser Particle Sorter. The % organic matter was determined by Loss on Ignition (LOI) following methods of Heiri et al. 2001 (combusting three replicate samples in the muffle furnace for three hours at 550°C). To determine the % carbonate, samples were combusted at 950° C for three hours (Heiri et al. 2001).

RESEARCH RESULTS

Sediment flux (Figures 4, 5 & 6)

Sedimentation rates and patterns for G. Lameshur and Fish Bays were generally similar between the 2008-9, and the previous 2007 field season. Sediment flux rates ranged from 0.6-705 mg $cm^{-2}d^{-1}$ for all trap locations in every bay (Figures 4 and 5). Sediment flux rates were 3-162 times higher on the reefs below the developed watersheds compared to the undeveloped watershed for all sampling periods. Mean field-season flux rates were highest at the shore stations at Coral Bay, the reef site at Fish Bay and the mangrove site in Lameshur Bay (Figure 6).

When sediment flux rates were compared between equivalent environments (mangrove, shore, bay, and reefs) in the three bays, the mean sediment flux rates recorded in the mangroves were higher below the developed (Coral Harbor Mangroves: 24 $mgcm^{-2}d^{-1}$) compared to the undeveloped watershed (Great Lameshur Bay mangroves: 17 $mgcm^{-2}d^{-1}$). Similarly, the shore mean sediment flux rates were much higher below the developed (Coral Bay shore; 705 $mgcm^{-2}d^{-1}$; Fish Bay: 231 $mgcm^{-2}d^{-1}$)

compared the undeveloped bay (Great Lameshur Bay:16 $mgcm^{-2}d^{-1}$). For the reef environments, flux rates (2-548$mgcm^{-2}d^{-1}$) on the fringing reefs in Fish Bay were high enough (above 50$mgcm^{-2}d^{-1}$) in 11 out of the 12 sampling periods to cause "severe to catastrophic stress" to the corals (Pastorok and Bilyard 1985) (Figure 6). In Coral Bay, flux rates (3-18$mgcm^{-2}d^{-1}$) on the patch reefs were comparably lower and would mainly qualify as "normal to moderate stress" to the corals. In Great Lameshur Bay, flux rates (0.7-107$mgcm^{-2}d^{-1}$) on the fringing reefs were also lower than Fish Bay reefs (Figure 6).

Examination of variation in flux over the August-March field season revealed that the highest sediment flux rates were recorded during the sampling period during which Hurricane Omar passed near St. John (10/15/08-10/16/08) at most locations (except Shipwreck and Calabash Boom) (Figures 4 & 5). The highest sediment flux rates repeatedly occurred at the shore in Coral Bay, and ranged from 8-705 mg $cm^{-2}d^{-1}$. For the southern sites in Coral Bay, we were surprised to find that the highest bulk sediment flux rates occurred during the winter/spring of 2009, rather than the fall rainy season 2008 as we expected. In this location, swells and wave energy are highest in the dry months of the winter/spring, suggesting that at these locations, re-suspension of sediment from the bay floor, rather than new sediment delivery from the ghuts (ephemeral streams) during rainfall events, contributed to the total sediment flux. Examination of current and wind data also supported that there was an increase in exposure to waves and currents in the Shipwreck and Calabash shore sites during the winter/spring months of 2009. The shore traps were also deployed 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 were the traps deployed in deeper locations (bay and reef sites). Our field experiments measuring sediment flux into sediment traps at differing trap heights at the same location indicated that this short (30 cm) trap would have been vulnerable to resuspension induced sediment flux (see below).

<u>Sediment Composition (Figures 7, 8 & 9)</u>

In addition to the total bulk sediment flux, the composition of fluxing sediment (carbonate, terrigenous, organic matter) was also examined (Figure 7). There were marked differences in the relative sediment composition between bays. Coral Bay sites collected the greatest proportion and flux of terrigenous sediment. Compositional flux rates ranged from (0.1-41, 0.2-270, 0.1-387) mg $cm^{-2}d^{-1}$ for organic, carbonate, and terrigenous components, respectively for all trap locations in all bays. Distinct compositional sediment flux ratios characterized sediments collected in each of the four environments: mangrove, shore, bay, and reef (Kolupski et al., 2010). The terrigenous flux was highest at the Shipwreck site for every sampling period (Figure 7).

Shore terrigenous flux rates were 2-1954 times higher in bays below the developed compared to the undeveloped watershed, and reef terrigenous flux rates were 1.4-107 times higher (Figure 8). Organic flux rates were also higher (1.4-55 times) on the reefs below developed watersheds compared to the undeveloped watershed. Within Coral Bay, mean terrigenous and total sediment flux rates were higher at the Shipwreck site (where there are no sedimentation ponds or other sediment mitigation measures in place) than at the Calabash Boom site (where sedimentation ponds and fences have been constructed to block sediment input into the near shore waters) (Figure 8). However, terrigenous sediment flux was higher at both the Shipwreck and Calabash Boom sites than at the Coral Bay mangrove sites, above which the greatest development and polluted storm-water likely ran off (Figure 7 and 8).

The highest terrigenous sediment flux rates corresponded to the period of highest rainfall when Hurricane Omar passed near St. John (10/15/09-10/16/09) for 15 out 17 trap locations in Great Lameshur and Fish Bays, and all trap locations in the Coral Harbor Mangroves (Figure 8). However, at Calabash Boom and Shipwreck, the highest terrigenous flux occurred during the spring. The high winter-spring terrigenous flux observed in the shore sites of Fish and Coral bay may be related to a) resuspension due to the short (30 cm) trap height, and/or b) a fall-winter shift in wave height and in the prevailing current directions and speed that was recorded by our current meters (see below) (Kolupski et al., 2010).

There was a clear pattern of spatial variability in total and compositional flux along the pathway of sediment dispersal from the ghut outfall to the reefs (Figure 9). Total sediment flux decreased beyond the shore and then increased near the reef areas, while, as expected, terrigneous flux decreased with distance from the ghut outfall. The ratio of carbonate to terrigenous flux (Ci/Ti) increased with distance from the shore to the reef (Figure 9).

<u>Sediment Texture (Figures 10 & 11)</u>

Textural (grain size) parameters (mean, median, mode, sorting, % clay, % sand, etc.) of the bulk sediment were analyzed at shore and reef sites in all three bays (Figure 10). The mean grain size at the shore and reef stations over the field season ranged from 124-410 microns (fine-medium sand) (Figs. 8, 9). Though there was little difference in the mean grain size of sedimentation on the reefs in the three bays (125-190 microns: fine sand), the sediment was coarser at Lameshur shore than in the shore locations of the two developed bays (Figure 10). Dust from unpaved roads, the greatest contributor to anthropogenic sediment pollution (Ramos-Sharron et al., 2005, 2007), is typically very fine grained. These textural results are therefore consistent with an unpaved road source of sediment for the developed bays. For all bays there were significant ($p<0.001$) positive correlations between mean grain size, total flux, carbonate flux, and currents. In the developed bays, mean grain size significantly ($p<0.001$) decreased with terrigenous % and flux. There was also a significant increase in mean grain size with %sand ($p=0.04$) and a significant decrease ($p<0.001$) in mean grain size with %clay. In Great Lameshur and Fish Bays, the coarsest mean grain size occurred after Hurricane Omar (Lameshur Bay: 323μm; Fish Bay: 308μm) (Figure 11). For sediments in Great Lameshur and Fish Bays: mean grain size coarsened with current magnitude ($p<0.001$) but fined with wind speed and wave height ($p<0.001$). Analyses of the composition of sieved sediments (< 75 microns) revealed that fine grains contained sediments of variable composition and that fine silts and sands were not predominately terrigneous in composition (Gray et al., 2009).

From the % clay and silt (< 63 micron), the fine (<63 micron) flux was calculated and was always below 6-8 $mgcm^{-2}d^{-1}$ at all the coral reef sites.

<u>Total Suspended Solids (TSS)/Total Organic Matter (TOM)</u>

TSS (total suspended solids) and TOM (total organic matter) measured from replicate water samples collected at each site during 6 sampling periods ranged from <1 to 175 mg/l for TSS and < 0.2 to 46 mg/l for TOM over the field season, with the highest TSS measured at the Shipwreck shore site and the lowest values measured at the bay and reef sites. The highest mean field season TSS and TOM values were at the Lameshur Bay mangroves (23 and 6 mg/l) and the Coral Bay shore sites (13 and 3 mg/l). Generally, TSS decreased with distance from the ghut (ephemeral stream) outfall. The highest TSS and TOM were measured during the field season following Hurricane Omar. At their shore sites, the mean TSS was higher during the spring compared to the fall sampling periods at Coral Bay and Fish Bay shore sites, which was consistent with patters of sediment flux.

TSS values were consistent with previous published results in St. John.

<u>Environmental parameters (rain, currents, wind and waves)</u>

The higher mean flux rates in Coral and Fish bay shore zones during the spring months (when rain was minimal) compared to the fall rainy season (Figure 5) may be explained by the greater current, wind, and wave heights during the spring and with a wind/current direction that hit the S.E.

shore of Coral Bay more directly during the spring. Falmouth 2D ACM current meters deployed at Lameshur and Fish Bay reefs measured stronger mean currents at the Fish Bay (4.43 cms^{-1}) compared to the Great Lameshur Bay (3.06 cms^{-1}) reefs with stronger currents in spring (Dec. 7. 2008 – Mar. 27, 2009) compared to fall (Aug. 13, 2008 – Dec. 6) for both bays. For both Great Lameshur and Fish Bays, there was a significant negative relationship ($p<0.001$ for both bays) between current direction and current magnitude. There were also significantly higher mean wind speeds (2.16ms^{-1}) and mean maximum wind gusts (4.7ms^{-1}) in the spring compared to the fall (mean wind speeds: 1.79ms^{-1}; mean maximum wind gusts: 3.9ms^{-1}). Wind directions changed during the field season from southeasterly (102°) in the fall to easterly (87°) in the spring. During 2009-10, we have deployed our current meters in Coral Bay so we expect to have better knowledge of the spatial and temporal variation in circulation patters within Coral Bay once these data are analyzed.

In addition to stronger winds and currents, there were significantly higher mean wave heights ($p<0.001$) in the spring (1.19m) compared to the fall (0.90m). The higher sediment flux in the spring in Coral Bay shore and Fish bay reef locations may therefore be related to resuspension induced by higher wave and current action during the spring, rather than by terrigenous sediment delivery from watershed runoff.

Resuspension

In order to evaluate the effects of sediment resuspension (eroded from the bottom substrate) on our total and sediment flux rates we a) quantified sediment "erodability" around each site; b) developed a "re-suspension index" for each site and sampling period based on a compositional comparison between bottom (benthic) and trapped sediment; c) examined trap height effects on total flux; and d) examined the relationship between total flux and currents and texture. Measurements of the available sediment around each trap location showed that there is plenty of erodible sediment available for resuspension at all sampling locations. The calculated resuspension Index showed that the highest contribution of bottom sediment resuspension to the total sediment flux occurred at 3 locations: Calabash Boom shore, Shipwreck shore and the Fish Bay reef (west side).

Comparison of sediment flux between traps set at differing heights (30, 60, 90 cm above seafloor) demonstrated that trap height affects total sediment flux due to resuspension of bottom sediment for the short (30 cm) traps. Traps of this height were placed at the shore sites for each of the bays due to the shallow water depth. During the 2009-10 field season, we have deployed paired short (30 cm) and tall (60 cm) traps at these locations to further evaluate the relative impact of re-suspension over new sediment delivery. These 2009-10 data will provide information to help us separate the terrigenous sediment flux due to resuspension from the sediment flux due to sediment delivery. These data, in combination with the measurement of higher sediment flux during sampling periods with higher current/wind/waves and lower rainfall (runoff) at a few key sites (Calabash shore, Shipwreck shore and Fish Bay west reef) indicated that sediment flux at these stations may be recording sediment resuspension as well as new sediment delivery. Therefore, the data from these locations needed to be interpreted with resuspension in mind.

Sediment stress to the coral reefs

Flux rates measured during this study indicated that the corals in Fish Bay were likely under chronic sediment stress that, according to previous studies could have induced "severe to catastrophic stress" to the corals (Pastorok and Bilyard 1985) (Figure 6). In Coral Bay, flux rates (3-18 $mgcm^{-2}d^{-1}$) on the near-shore patch reefs were comparably lower and would mainly qualify as "normal to moderate stress" to the corals. In Great Lameshur Bay, flux rates (0.7-107 $mgcm^{-2}d^{-1}$) on the reefs were below the sediment stress threshold for all but one sampling period (during which Hurricane

Omar passed over St. John). Although our data show the highest rates of sediment flux recorded on reefs below developed watersheds, our data cannot unequivocally link reef sediment stress to watershed development activities without further study. Compositional analyses of the sediment reveals that carbonate (or marine sediment) makes up the greatest proportion sediment flux and that wave and current induced resuspension of mixed carbonate and terrigenous sediment from the sea-floor contributes to the total sediment flux (especially at the west Fish Bay reef site). However our data also show that higher terrigenous flux at reefs below the developed bays contribute significantly to the total sediment flux onto the reef.

Thomas et al. (2003) defined a scale of turbidity impact zones (from "background to severe") for TSS values ranging from <5 to 30 mg/l. The highest TSS measured at the reef sites (6 mg/L) was on just over what Thomas et al. (2003) considered to be background levels. Therefore, we did not measure turbidity levels high enough to induce stress to the corals. However, we only sampled during fair weather conditions and not following storm periods, which should induce higher TSS/turbidity. Future studies should examine turbidity at the reef sites during and immediately following storm events. Field season mean fine (<63 micron) flux rates measured in all reef sites in St. John will well below the 33 $mgcm^{-2}d^{-1}$ threshold of induced sediment stress shown by Weber et al. (2006) to cause physiological stress in corals (Figure 11C). However, Weber et al. (2006) did not directly test the stress response to fine flux rates below 33 $mgcm^{-2}d^{-1}$. It is therefore unclear whether the level of fine grained sediment flux onto the reefs (< 6 $mgcm^{-2}d^{-1}$) would induce physiological stress to the corals because the impact of fine grained flux rate below 33 $mgcm^{-2}d^{-1}$ have not been tested.

<u>Implications for management</u>

Our data revealed that the greatest terrigenous sediment flux and TSS is found on the southeastern shore Coral Bay near the Calabash and Shipwreck ghut outfalls. Terrigenous flux below the developed watershed in Fish Bay was also many times higher than in Lameshur Bay, below the undeveloped watershed. Combined with the textural and compositional data these data suggests that watershed development likely increased terrigneous fine-grained sediment flux into the bays. For Coral Bay, the mangroves that line the shoreline of the Coral Bay harbor appear to be effectively filtering or reducing the terrigenous sediment flux rates in the bay. The lower terrigenous flux at the mangrove sites (below the watershed with the greatest development) may indicate that the mangroves are acting as an effective natural filter for terrigenous runoff from the watershed.

If the factors controlling rates of sediment erosion and runoff from the Shipwreck and the Calabash watersheds are roughly similar, than the fact that we measured reduced terrigenous flux below the Calibash ghut (ephemeral stream outfall) may indicate that the man-made sedimentation ponds and fences that were built there may be reducing the input of land-based sediment at Calabash Boom compared to Shipwreck. However, despite sediment mitigation, terrigenous sediment flux at Calabash Boom was the second highest of the study and many times higher than at the shore location of the undeveloped bay. A large component of the total flux appears to be due to resuspension of sea-floor sediment. During 2009-10, we deployed taller sediment traps (60 cm above the bay floor) further from shore at those locations. Once we analyze the 2009-10 data, we will be able to more accurately determine the component of sediment flux that was due to resuspension.

Data from this study point to the Shipwreck and Calabash locations as priority locations for future sediment erosion mitigation. Based on these data, these watersheds have been targeted for construction of sediment erosion/mitigation projects in 2010 through the NOAA/ARRA "USVI Coastal Habitat Restoration through Watershed Stabilization" (see below).

OUTREACH ACTIVITIES

Our outreach goal was to establish ongoing research & educational partnerships with the Coral Bay Community Council, the University of the Virgin Islands, the Virgin Islands Environmental Resource Center (VIERS), the Virgin Islands Resources Conservation & Development Council (V.I. RC&D), researchers at the Center for Marine and Environmental Studies (CMES) at the University of the Virgin Islands and other local citizen's groups and to increase public awareness about the link between watershed activities, land-based pollution and coral reefs. In addition, our goal was to make these data available to governmental and community environmental managers who will use them as baseline data to site or evaluate the effectiveness of future watershed erosion mitigation BMPs.

ARRA Partnership

Funding from this NOAA GCRC grant has provided an opportunity for our research group to partner with other USVI groups to fund watershed erosion mitigation and continued sediment monitoring. In partnership with 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), in the Spring of 2009, we submitted a proposal to the NOAA Coastal & Marine Habitat Restoration for funding under the American Recovery and Reinvestment Act (ARRA). The proposal was to fund sediment erosion mitigation and monitoring in two of our study watersheds (Fish Bay and Coral Bay). In July of 2009 V.I. RC&D and partners were awarded over $2.7 million from ARRA NOAA Coastal & Marine Habitat Restoration for the project "USVI Coastal Habitat Restoration through Watershed Stabilization" (http://www.usvircd.org/NOAA-ARRA_Grant.htm). The goal of this 2-year project is to reduce sediment loading to coral reef habitats in three USVI bays by over 100 tons by implementing erosion & sediment control BMPs. For Coral Bay, data from this NOAA GCRC research project was used to evaluate the most important locations to site proposed erosion mitigation. Our sediment flux data from the 2008/9 season demonstrated a need to locate BMP's/mitigation in the watershed above our Shipwreck and Calabash sites. Although most of the funding from ARRA will be used to build erosion & sediment control structures, terrestrial and a limited amount of marine monitoring have also been funded. As a partner in the ARRA program, our USD research team will conduct sediment monitoring in 6 locations in CB below the planned erosion reduction projects. The sample collection methodologies, trap design, and laboratory protocols we designed and tested for this NOAA GCRC project have been adopted for the ARRA marine monitoring program, which will be implemented by three groups (our USD research team in Coral Bay, Tyler Smith of UVI in Fish Bay and Marcia Taylor of UVI in St. Croix). In addition, marine monitoring sampling sites in Fish and Coral Bay for ARRA have been sited so as to sample in the same locations we used for this NOAA GCRC study.

Therefore, data from this NOAA GCRC study have provided critically important baseline data are already in use as benchmark values to quantify pre- and post-mitigation comparisons. Almost all of the watershed areas that have been chosen for ARRA erosion & sediment control BMPs in Coral Bay and Fish Bayare sited directly above where our USD research team has been conducting shoreline and reef sediment monitoring. Therefore, there will be 2-3 years of baseline data at the monitoring sites for comparison.

Funding on this grant has paved the way for my research team to establish ongoing partnerships with the ARRA partners. VI RC & D has supported our efforts to obtain funding to continue our sedimentation studies at sites outside those being funded for marine monitoring by ARRA through letters of support for our research proposals.

Coral Bay Community Council (CBCC), EPA CARE & the 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. We have joined their EPA watershed management CARE grant team (http://www.coralbaycommunitycouncil.org/) and conducted meetings with their EPA/CARE storm-water engineer, Joe Mina to share our data. On November 16th of 2009, we presented our results at a workshop in St. Thomas entitled "EPA CARE Land & Sea Research Seminar and Leadership Conference", which brought together researchers studying the impact of watershed erosion in the USVI with environmental managers and public officials (Table 1). We continue to work with members of the Coral Bay Community who volunteer as field assistants and provide discounted use of their boats.

Other community, educational, and scientific 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 faculty, and members of the community (Figure 12, Table 1). Our outreach has targeted the local (USVI) community as well San Diego, around the country and even Mexico. 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 1 summarizes several community and educational outreach activities and media interview my research team has conducted. Two notable outreach activities we conducted in August of 2009 were the VIERS Eco Camp and the St. John Youth Rally (Figure 12; Table 1). We conducted a two-day workshop for Caribbean middle-high school students attending science "Eco Camp" at VIERS. We presented lectures about our research and involved the students in laboratory and field demonstrations of our research techniques (Figure 12). My research team set up a booth at the St. John Youth Rally, where we discussed our research and talked about the impact of non-point source pollution on coral reefs (Figure 12).

Scientific community

We have presented four invited scientific presentation to various scientific and educational organizations and have presented a poster for the American Geophysical Union Ocean Sciences Meeting (Kolupski et al., 2010) (Table 1). We are working on journal articles based on this work, which we hope to submit in the next year.

USD student research projects

One USD Master of Science student (Meg Kolupski) and 3 USD undergraduate students (Amalia Degrood, Desere Rawling and Joyce Hsieh) in the Marine Science and Environmental Studies Department are conducting theses based on this research. Examples and photos from this project are used as a case study to illustrate concepts in several of the classes I teach including: Geological Oceanography, Environmental Geology, and Introduction to Earth Science.

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